Why Does a Fly Ball Carry Better to Centerfield?

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I. INTRODUCTION

Have you ever noticed that baseballs hit to centerfield carry farther than those hit to left or right field? I'll show some direct evidence for the phenomenon shortly. For now, simply take my word for it so I can pose the question in the title: Why is this so? My gut feeling has always been that it has something to do with spin on the ball, particularly the spin axis. Because of the dynamics of the ball-bat collision, balls hit to hit to left or right field have considerably more sidespin than balls hit to center. The primary effect of the sidespin is a phenomenon easily observed when watching a game: It causes the ball to follow a curved path, breaking toward the foul line.

But aside from this instinct, I have to admit that I never gave the matter much thought until recently. What stimulated my recent interest was a journal article[1] that claimed the reason for the reduced carry is the curved path followed by balls hit with sidespin as opposed to the straight path followed by balls hit with no sidespin. The horizontal distance of the landing point from home plate is reduced if the ball follows along a curved rather than a straight path, assuming otherwise identical launch conditions. The argument certainly makes sense qualitatively. But does it make sense quantitatively? And if not, then what are the primary reasons for the phenomenon? These are the questions I have asked myself and will address in this article.

II. THE EVIDENCE

The evidence for the ball carrying better to centerfield and the connection with sidespin is shown in Figs. 1-3. Each of these figures shows Statcast fly ball data for games played in Tropicana Field, which was chosen for this study since the atmospheric effects (temperature, etc.) are constant and wind is absent. The data include exit velocity, launch angle, spray angle, spin rate, spin axis, and distance. Only fly balls were chosen for which the batted ball was tracked to at least 80% of its eventual distance, assuring good accuracy in the distance measurement. The combination of spin rate and spin axis allows a separation of the total spin rate ω into backspin and sidespin rates, ω_b and ω_s, respectively.[2] Note that the sign of ω_s is positive for balls breaking toward the left field foul line and negative toward the right field foul line. All the data shown have an exit velocity in a range bracketing 100 mph, launch angles in the range 25°-30°, and ω_b in the range 2000-3000 rpm.

Fig. 1 shows the relationship between distance and ω_s. Fig. 2 shows the relationship between ω_s and spray angle for left-handed and right-handed batters separately. Fig. 3 shows the relationship between distance and spray angle, color coded by the magnitude of ω_s. In the latter two figures, the spray angle has been adjusted by batter handedness so that it is negative for the pull field and positive for the opposite field.

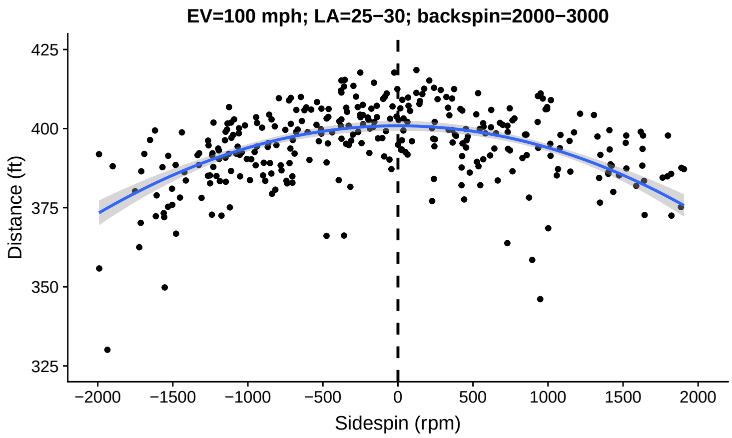

FIG. 1: Statcast data showing that fly ball distance decreases with sidespin ω_s, with all other launch variables (exit velocity, launch angle, and backspin) in narrow ranges. The curve is a parabolic fit to the data.

There is wealth of information contained in these three graphs, which is now summarized.

- Fly ball distance depends on ω_s (Fig. 1); ω_s depends on the spray angle (Fig. 2); therefore, fly ball distance depends on spray angle (Fig. 3). This phenomenon was the primary motivation for the study and will be discussed in Sec. III.

- Fly ball distance is largest when ω_s=0 and is roughly symmetric about ω_s=0. Indeed, as indicated in the caption to Fig. 1, the distance-ω_s data are well described by an

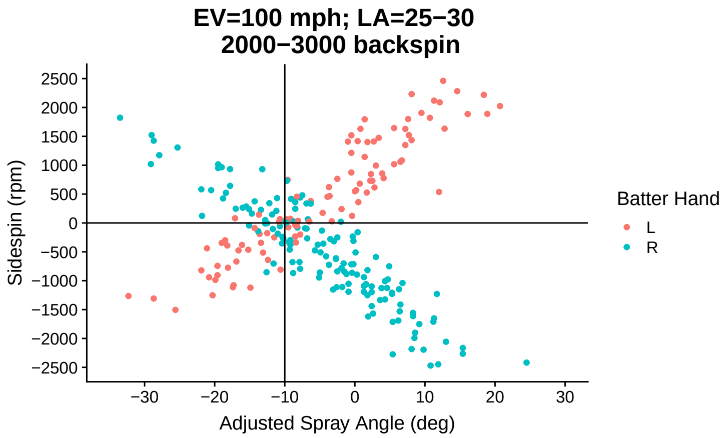

FIG. 2: Statcast data showing the dependence of sidespin on the spray angle for both left-handed and right-handed hitters. The spray angle has been adjusted for batter handedness so that negative and positive values correspond to balls hit to the pull and opposite fields, respectively. The sidespin is zero at a spray angle of approximately -10° (i.e., slightly to the pull side of straightaway centerfield).

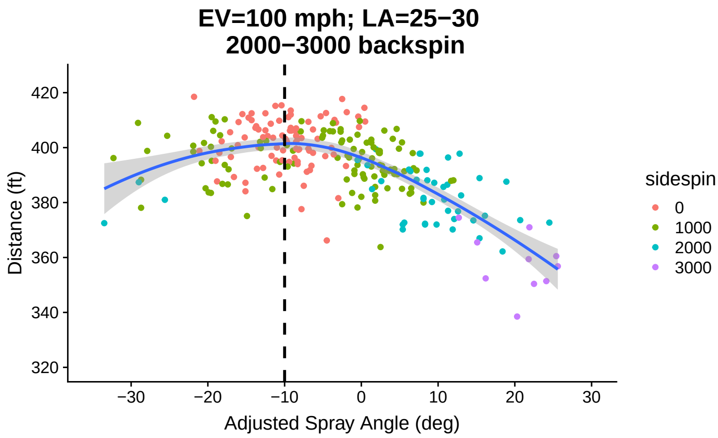

FIG. 3: Statcast data showing the dependence of distance on spray angle (adjusted as in Fig. 2), color coded by the magnitude of sidespin (rounded to the nearest 1000). These data show that the distance depends on spray angle, with a maximum at -10° (i.e., slightly to the pull side of straightaway centerfield). The data further show that sidespin reduces the carry of the ball (see also Fig. 1).

inverted parabola symmetric about 0.

- ω_s=0 (and therefore fly ball distance is maximum) at a spray angle slightly to the pull side of straightaway centerfield (≈10°). This is true for both left- and right-handed batters. This was a secondary motivation for the study and will be discussed in Sec. IV.

- As a consequence of the previous bullet point, balls hit at a given spray angle to the pull side (where the magnitude of ω_s is smaller) will carry farther than balls hit at the same spray angle on the opposite side (where the magnitude of ω_s is greater).

- As a further consequence, balls hit to the pull side of 10° break toward the right-field foul line (i.e. hook). Balls hit to the opposite side of 10° break toward the left-field foul line (i.e., slide). In particular, balls hit to straightaway centerfield (zero spray angle) slice toward the opposite field. For a given spray angle, the amount of slice for opposite field fly balls is greater than the amount of hook for the same spray angle on the pull side.

III. WHY DOES DISTANCE DEPEND ON SIDESPIN?

To attack this question, I utilized my Trajectory Calculator, a spreadsheet-based tool I created over the years to calculate the trajectories of batted balls. The tool uses a model for the aerodynamic forces on the ball, specifically the so-called drag and lift coefficients, and the parameters of the model were determined by fitting to actual trajectory data.[3] The advantage of using this tool is that certain features of the model can be switched on or off or parameters altered to investigate how these changes affect the trajectory, particularly the final distance.

While results for a variety of different initial conditions were investigated, those summarized below were for initial conditions similar to those of the data in the Figs. 1-3: exit velocity=100 mph, launch angle=27.5°, ω_b=2500 rpm, and ω_s either 0 or 1500 rpm. The latter resulted in a reduction of the fly ball distance by 12 ft. Here is what I have learned about the reasons for this reduction.

1. Approximately 40% of the reduction comes from the feature of the drag coefficient that it increases with the total spin $\omega = \sqrt{\omega_\mathrm{b}{}^2 + \omega_\mathrm{s}{}^2}$. Therefore when increasing ω_s from 0 to 1500 rpm, with ω_b fixed at 2500 rpm, ω increases from 2500 to 2915 rpm, resulting in a 3% increase in the drag coefficient, from 0.387 to 0.399, and a reduction in distance.

2. Approximately 15% of the reduction comes from the curved trajectory, the fact that the horizontal distance of the landing point from home plate is smaller when the

trajectory is curved than when it is straight. This small fraction of the total effect is at variance with the claim in the literature[1] that got me started on this project in the first place.

3. The remaining 45% of the reduction comes from three different factors–some of them subtle–associated with the Magnus force, the force responsible for the movement of a spinning baseball. These three factors all act to reduce the lift on the baseball, resulting in a reduction of the distance. It is not straightforward to quantify the individual contribution of these factors, since they are coupled together. However, it is easy to describe them.

   (a) When the ball leaves the bat, the backspin axis is horizontal and perpendicular to the horizontal direction of the baseball. As the baseball changes its horizontal direction due to the sidespin, that axis is no longer perpendicular to the direction; in effect, some of the backspin gets converted into gyrospin, thereby reducing the lift and decreasing the distance.

   (b) When the ball leaves the bat, the sidespin axis is primarily in the upward direction. However, since the ball starts out at a non-zero launch angle, a component of the sidespin points in the backward direction. As the ball changes direction in the horizontal plane, that backward component results in a downward force on the ball (i.e, "negative lift"), thereby reducing the total lift and the distance.

   (c) The relationship between the Magnus force and spin rate is nonlinear. For example, increasing ω by 16.6% (from 2500 to 2915 rpm) increases the Magnus force by only 8.3%. As a result, increasing the spin rate by adding sidespin while leaving the backspin unchanged actually reduces the lift due to the backspin.

IV. WHY IS SIDESPIN MINIMIZED ON PULL SIDE OF CENTERFIELD?

This topic has been previously discussed by Kagan[4] and Nathan,[5] so I won't repeat all the arguments in detail here. In a nutshell, here is their explanation. The primary reason for sidespin on a baseball is the horizontal angle of the bat with respect to the incoming pitch. When the batter is "out in front", the angle is such that the ball is hit predominately to the pull field, with hooking sidespin. When the batter is behind, the ball is hit predominantely to the opposite field, with slicing sidespin. If the bat is perpendicular to the incoming pitch, the ball is hit to centerfield, with essentially zero sidespin. With this mechanism, the dependence of $\omega_{\rm s}$ on the spray angle would look similar to that in Fig. 2, except shifted so that $\omega_{\rm s}$=0 at zero spray angle.

The reason for the shift of the zero point to the pull side is that the bat is not normally horizontal at impact but is usually tilted, with the barrel of the bat below the knob. Consider what happens when the bat is horizontal and perpendicular to the pitch. If the direction of the bat at contact is under the center of the ball, the result will be a fly ball to straightaway centerfield with pure backspin. However, when the bat is tilted downward but still perpendicular to the pitch, the spin axis gets rotated, reducing the backspin and resulting in a slicing sidespin.

So there are two different mechanisms for generating sidespin: the horizontal angle of the bat and the tilt angle of the bat. The combined effect of these two mechanisms is to shift the zero of $\omega_{\rm s}$ a little bit to the pull side, exactly as observed in the data. Detailed models of the ball-bat collision are in agreement with the data.[6] The precise amount of shift depends on the tilt angle, and the data in Fig. 2 represent an average over many fly balls.

V. WHY IS BACKSPIN MAXIMIZED FOR OPPOSITE FIELD?

Having satisfied myself that I understand the primary reasons why balls carry better to centerfield than to the pull or opposite field, I have to admit that there is something in the Statcast data that I initially did not understand, namely, the fact that $\omega_{\rm b}$ is largest for opposite-field hits and smallest for pull-field hits (see Fig. 4). This feature was something totally unexpected by me. Thanks to a suggestion from David Kagan and others, I think I now have at least a qualitative understanding of the phenomenon.

The suggestion is that the attack angle of the bat is not constant but changes throughout the swing, starting out negative during the downswing, passing through zero, and ending up positive. To model that behavior requires an assumption about the actual path of the bat during the swing. I assumed that the barrel of the bat follows a parabolic path, which implies an attack angle that varies linearly with the angle of the bat in the horizontal plane; it is negative (i.e., downward) when the bat axis is angled backward toward the catcher, zero when the axis is perpendicular to the incoming ball, and positive (i.e., upward) when the

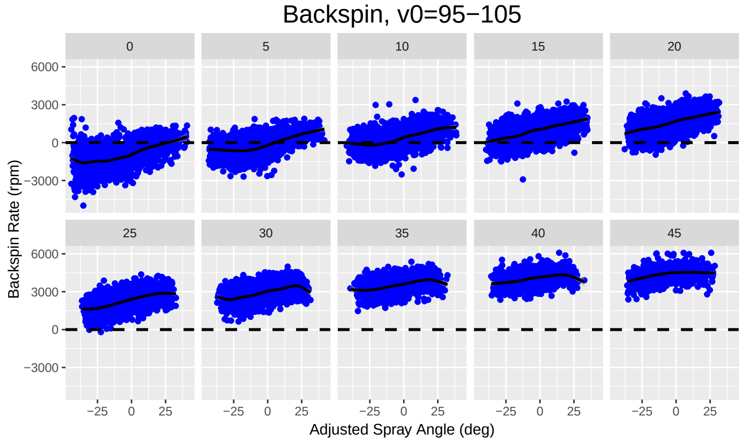

FIG. 4: Statcast data showing the dependence of backspin rate on spray angle (adjusted as in Fig. 2), for exit velocities in the range 95-105 mph and for different 5° buckets of launch angle. The solid curve is a smooth fit to the data while the dashed line indicates 0 rpm. These data show that the backspin rate is largest for opposite-field hits and smallest for pulled-field hits.

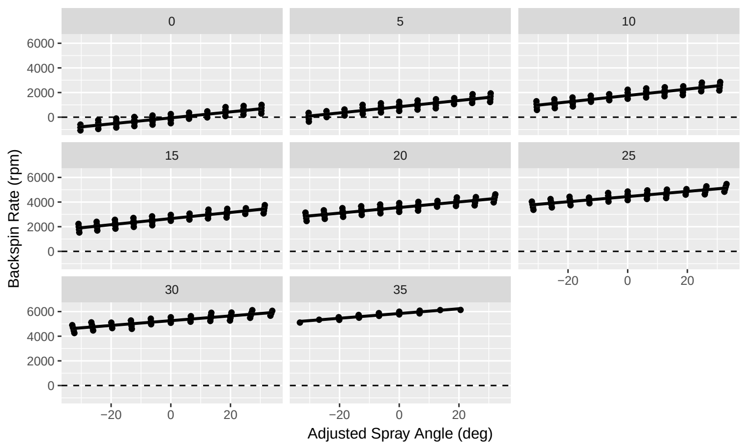

FIG. 5: Calculation of backspin vs. spray angle for different 5° buckets of launch angle, where the barrel of the bat was assumed to follow a parabolic path. These results are in qualitative agreement with the data of Fig. 4

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axis is angled forward toward the pitcher. With that assumption, it was a straightforward exercise to inject it into my ball-bat collision model[6] to calculate the parameters of the batted ball, particular the dependence of backspin on spray angle. The results, shown in Fig. 5, are in qualitative agreement with the Statcast data and give confidence that the essential physics is understood.

VI. SUMMARY

In this article, I have shown evidence from Statcast data that fly balls carry better to centerfield than to right or left field. I have also shown that the reason for reduced carry to left and right is sidespin. The reduced carry due to sidespin comes from two primary causes: the increased drag as the total spin increases and subtle changes to the Magnus force that reduce the lift. Finally I have shown that the curved path of a ball hit with sidespin contributes very little to the reduction of distance. The puzzle regarding the dependence of backspin on spray angle is now at least qualitatively understood.

Acknowledgments

Thanks to my friend and colleague Dr. David Kagan (@DrBaseballPhD) for some helpful comments on this article. Thanks also to David and several of my Twitter followers for the suggestion about the attack angle.

References

[1] H. Nakashima, G. Horiuchi, and S. Sakurai, "Three-dimensional batted ball in baseball: effect of ball spin on the flight distance," Sports Engineering **21**, 493-499 (2018).

[2] It should be noted that while the Trackman radar system, an integral part of Statcast, measures the total spin ω directly, it only infers the spin axis (and therefore ω_{b} and ω_{s}) from the trajectory, using a proprietary algorithm.

[3] A description of the model along with links for downloading the tool can be found at the author's web site: `http://baseball.physics.illinois.edu/trajectory-calculator-new3D.html`.

[4] David Kagan, "The Physics of a Foul Down the Line," David Kagan, The Hardball Times (May 22, 2014), `https://tht.fangraphs.com/tht-live/the-physics-of-a-foul-down-the-line/`.

[5] Alan Nathan, "Spinning Out Of Control," FanGraphs (October 26, 2016), `http://www.fangraphs.com/blogs/spinning-out-of-control/`.

[6] Alan Nathan, unpublished. The details of the 3D ball-bat collision model will be described in

a future publication. The 2D model is described here: `http://baseball.physics.illinois.edu/ppt/ModelingBallBatCollision.pptx`.