What Is The Hawkeye Spin Data Teaching Us?
III: Searching for the Seam-Shifted Wake

Alan M. Nathan*

Department of Physics, University of Illinois, Urbana, IL 61801

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I. INTRODUCTION

This article is long overdue. It builds upon two earlier articles I wrote approximately two years ago, when the Seam-Shifted Wake (SSW for short) first entered into the baseball vernacular. The first clear-cut evidence for SSW came from laboratory experiments by Prof. Barton Smith and his research group at Utah State [1], who showed that the orientation of the seams can play an important role in the movement of a pitch, over and above the expected movement due to the spin. The latter is referred to as the Magnus movement while the former is referred to as SSW. Fortuitously, that development occurred at around the same time that the Hawkeye pitch-tracking system was first utilized in MLB games. Both the Hawkeye system and its Trackman predecessor measure the trajectory and the spin rate (the "rpm")of a pitch . But there is one essential difference: Whereas Hawkeye measures the spin axis directly, Trackman can only infer the spin axis under the assumption that the observed direction of the movement is entirely due to Magnus. In the presence of SSW, that assumption is not necessarily correct. Therefore, any deviation between the spin axis directly measured by Hawkeye (the "optical" spin axis) and that based on the observed movement (the "inferred" spin axis) is direct evidence for SSW. The first such evidence in actual MLB games was reported by Smith, *et al.* in a ground-breaking article, It's Not Just About Magnus Anymore [2] based on Hawkeye data from the 2020 season. Many other articles about the subject have followed.

My own contribution to the subject came from the two earlier articles referred to above in

* a-nathan@illinois.edu

which I set up a formalism for doing the analysis. In the first article (I) [3], the formalism was developed for using the constant acceleration parametrization of the trajectory (9P) along with the Cartesian spin components, ω_x, ω_y, and ω_z, to separate the transverse acceleration (and therefore the movement) into Magnus and non-Magnus components. The separation requires knowledge of the magnitude of the Magnus component and its dependence on spin rate and spin efficiency; unfortunately those dependencies are known only approximately. In the second article (II) [4], the formalism was modified, following the suggestion of Healey [5], to separate the transverse acceleration into "lift" and "side" components, where the lift component is along the direction of the Magnus force and the side component is perpendicular to that direction. The advantage of the lift-side formalism is that the separation can be done exactly without any previous knowledge of the Magnus force other than its direction, where the latter is determined entirely by the velocity and spin vectors. However, it suffers from the disadvantage that, while the side component is necessarily SSW in origin, the lift component may include both Magnus and SSW components. Despite this disadvantage, this method will be pursued further in the present analysis.

The formalism developed in II will be used in this article to examine the differences between 4-seam (4S) and 2-seam (2S) pitches, including fastballs, sinkers, and changeups. The reader is referred to II for the formulas and notation, including a spreadsheet template for doing the analysis [6]. The data used in the analysis come from MLB games during the 2021 season. A preliminary version of this analysis based on data from the abbreviated 2020 season was presented by the author at the 2021 SABR Analytics Conference [7].

Before moving on, I want to emphasize an important point. Much of the literature about SSW refers to optical and inferred spin axes, as I did above. Since the optical spin axis is measured at release and the inferred spin axis is based on the movement at home plate, some people have the mistaken belief that the effect of the seams is to actually cause the spin axis to change between release and home plate. In reality, any shift of the spin axis between release and home plate is expected to be small. The correct way to think about what is going on is that the combined effect of the spin and the seams results in movement in a direction different from what would be expected based on the spin alone. In my discussion below, I prefer to talk about movement directions (lift, side, and total) rather than spin axis in the hope that it will avoid the confusion.

II. FASTBALLS AND SINKERS

A representative example that highlights the differences between fastballs (4S) and sinkers (2S) is that of Kyle Hendricks and is shown in Fig. 1 and summarized in Table I. Several interesting features are worth pointing out. First, relative to the lift (i.e., Magnus) direction (shown in blue), the actual movement shifts arm-side for sinkers by about 34°, whereas there is a much smaller glove-side shift of about 5° for fastballs. Hendricks is not unique in this respect, as shown in Fig. 2.

Second, the direction of the lift movement is within a few degrees for each type, despite the fact that the actual movement direction is very different. Once again, Hendricks is not unique here, as demonstrated in Fig. 3. This feature corrects a misunderstanding I have had since the start of the PITCHf/x tracking era. I (and many others) had incorrectly concluded that since the movement direction was very different for fastballs and sinkers, the spin axis must also be different. That conclusion was based on our previous misunderstanding that movement is the result of Magnus and nothing else. With the Hawkeye data and our new understanding of SSW, we are now finding that the spin axis is nearly identical for the two pitch types and is probably determined largely by arm slot; it is SSW that changes the actual movement direction.

Third, note that the spin rate and spin efficiency are slightly smaller for the sinker than the fastball, resulting in less movement in the lift direction. Nevertheless, sinkers have considerably more movement in the side direction due to SSW, so that the total movement is comparable for the two pitches. This particular phenomenon will be explored more generally in Section IV.

Finally, there is a curious feature in the data that deserves some explanation. It appears that the side contribution to the movement (red points) lies in a very narrow angular band compared to that of the lift and total movement. That is simply an illusion due to the fact that the magnitude of the side movement is small. In fact, one can see from the plot that the spread of red points gets larger as the magnitude of the side lift gets larger. Indeed, the data show that the standard deviation of the side movement angle is essentially identical to that of the lift movement angle.

TABLE I: Mean parameters of Kyle Hendricks's fastball and sinker, including the number of pitches N, release speed v_0, spin rate ω, spin efficiency ϵ, Total(T), Lift (L), and Side (S) movement directions (ϕ_T, etc.), and movement distance (M_T, etc.)

type	N	v_0 (mph)	ω (rpm)	ϵ	ϕ_T (deg)	ϕ_L (deg)	ϕ_S (deg)	M_T (inch)	M_L (inch)	M_S (inch)
Fastball	448	87.4	1936	0.93	116.3	121.5	68.5	16.7	16.5	2.2
Sinker	1140	87.4	1827	0.85	150.6	116.7	206.8	17.0	14.0	9.4

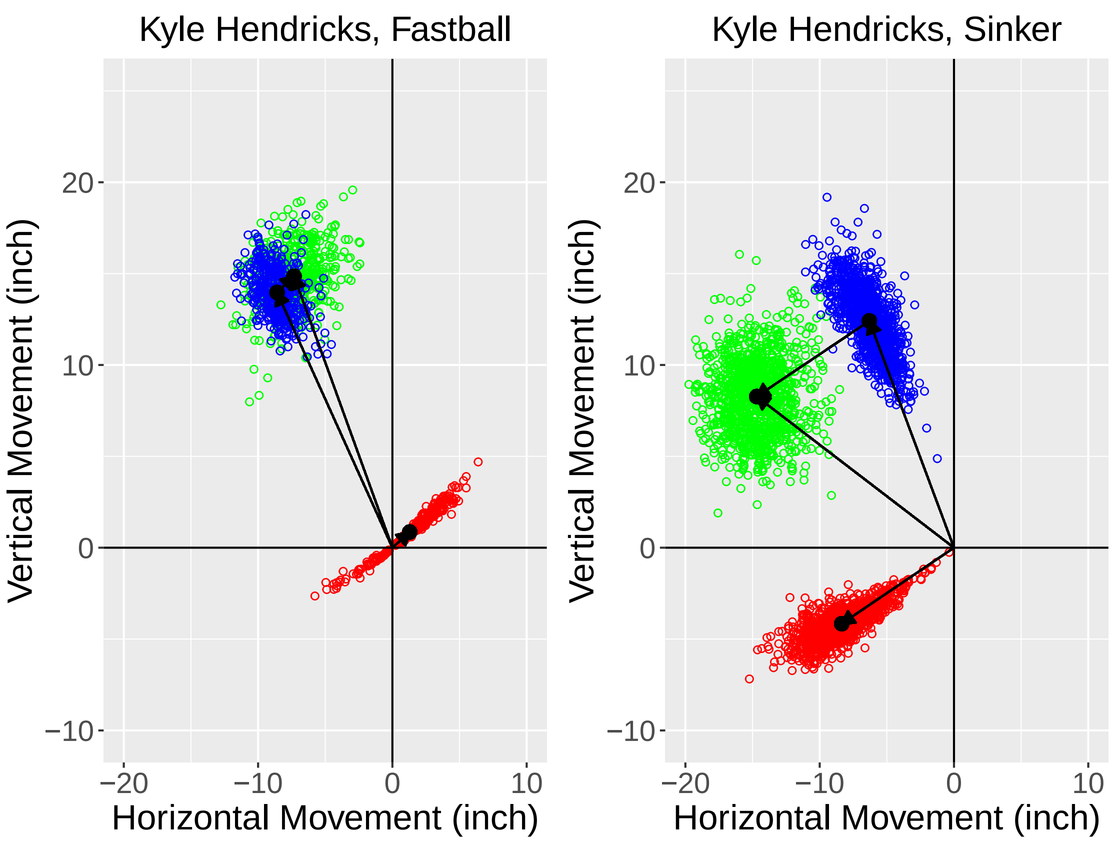

FIG. 1: Horizontal and vertcal movement from the catcher's perspective for Kyle Hendricks's fastball and sinker. Each pitch is represented by three points: green, blue, and red for the total, lift, and side movements, respectively. Total is the actual movement and is the vector sum of lift and side. The black dot is the mean value of each cluster, and the arrows are lines connecting the mean values and show the vector nature of their mutual relationship.

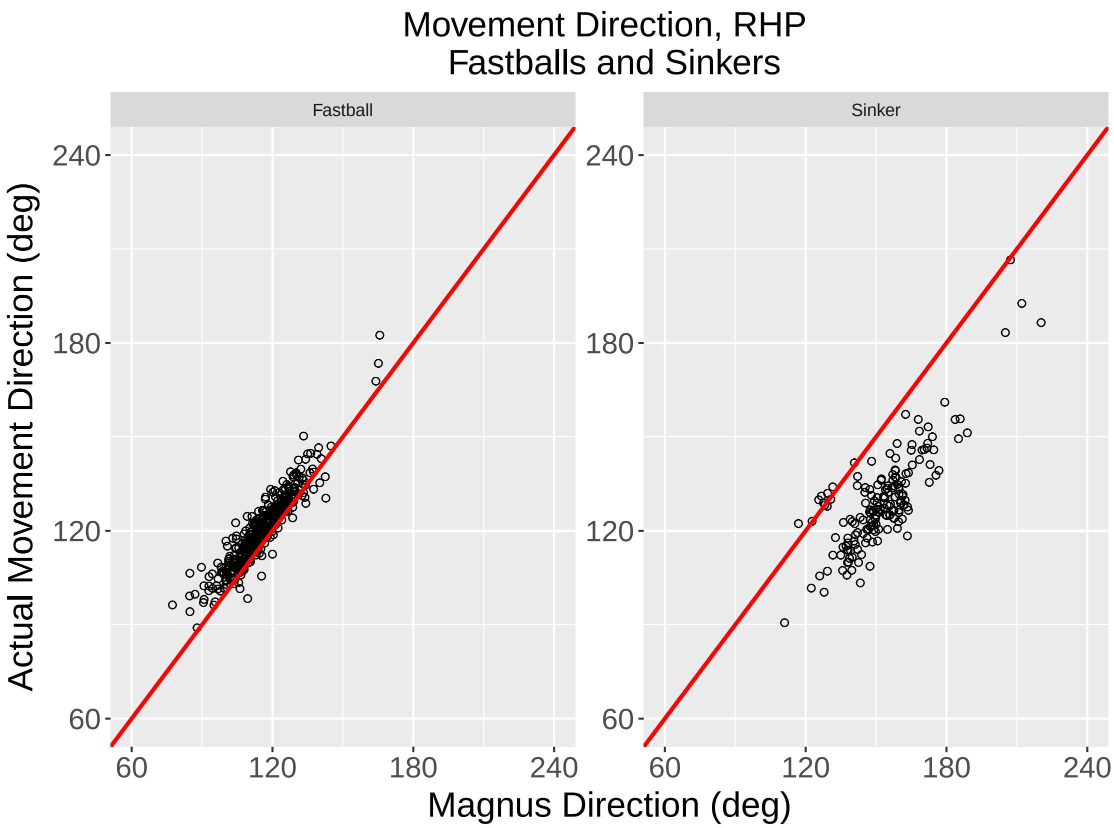

FIG. 2: Scatter plot of actual vs. Magnus movement directions for fastballs and sinkers, where each point is an average for a given right-handed pitcher throwing at least 200 pitches of a given type and the red line indicates equality. The angle is the direction of the movement relative to the x-axis (see Fig. 1), so that 0° is to the catcher's right, 90° is up, etc. The interesting feature is that, relative to the Magnus direction, there is a significant arm-side shift of the actual movement for sinkers compared to only a modest glove-side shift for fastballs.

III. KYLE HENDRICKS'S DUAL CHANGEUP

Eno Sarris noted in a FanGraphs article long ago [8] that Kyle Hendricks throws two different types of changeups, the evidence being two different clusters in his movement plots. This topic was further elucidated by Tom Tango in a Twitter thread from 2021 [9], using the formalism I developed in II to analyze the Hawkeye data. The analysis I present here pretty much follows Tango's.

As Sarris discussed, the evidence for the dual changeup comes from an examination of the movement plots, as shown in Fig. 4. Whether one views the plots as vertical-vs-horizontal or magnitude-vs-direction, there are two clearly identifiable clusters. In the figure, I used a

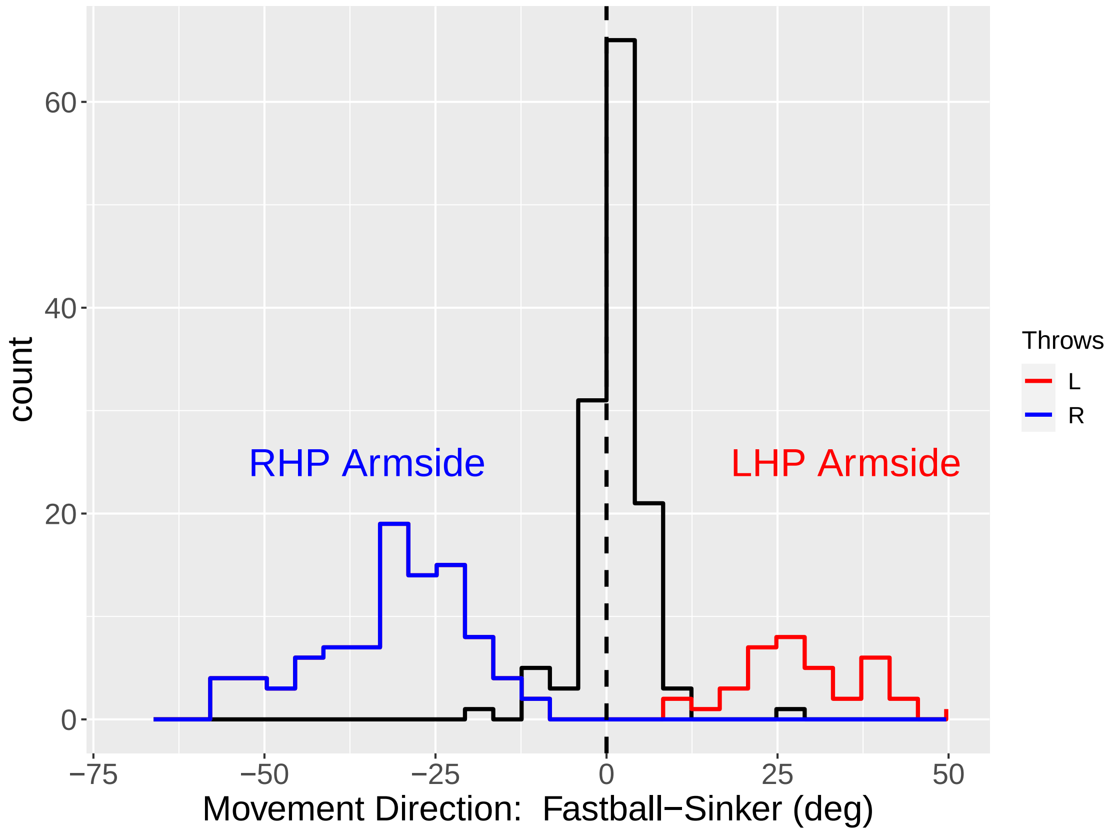

FIG. 3: Distribution of the differences between the actual and lift directions between fastballs and sinkers. Each count represents an average for pitchers with at least 100 of each pitch type, of which there are 131. The data show that despite there being a significant arm-side shift in movement for sinkers relative to fastballs, the spin axes coincide within a few degrees.

K-means technique to separate the two clusters, which are color-coded by seam orientation. Even without the color-coding, one can pretty easily separate the two clusters by eye. Having done that, I can next analyze the two groups in exactly the same way that I analyzed the Hendricks fastball and sinker in the preceding section. The results of doing such an analysis are given in Table II and Fig. 5. By direct comparison with fastballs and sinkers, one can tentatively identify the two changeups as 4S and 2S. Both are thrown at nearly the same release speed, spin rate, spin efficiency, and spin axis, but there is a significant arm-side movement for the 2S and a modest glove-side movement for the 4S.

To confirm the tentative assignments would require Hawkeye data showing the seam orientation. While those data are not publicly available, some results for the 2022 season have been reported in a Twitter post by Tango [10], and these results confirm the 2S and 4S

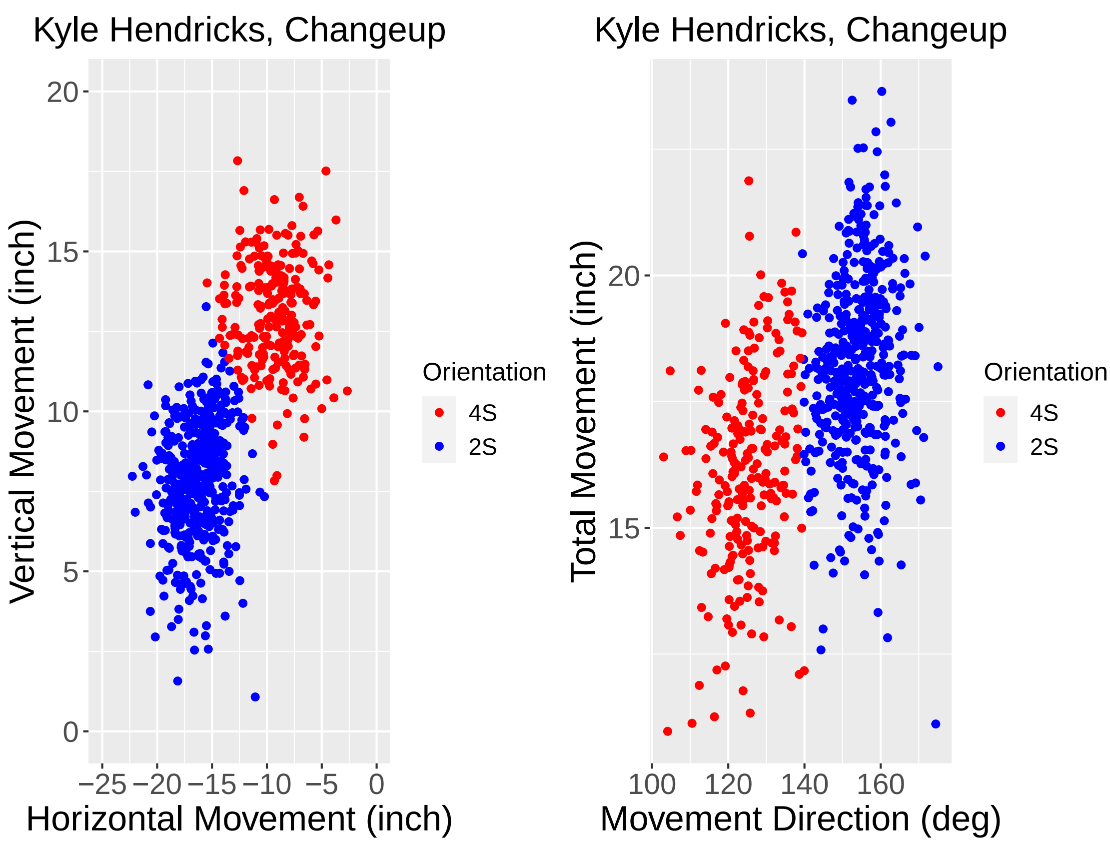

FIG. 4: Actual movement plots for Kyle Hendricks's changeup, where the left plot shows horizontal and vertical movement and the right plot shows magnitude and direction. The colors indicate 4S and 2S seam orientations, as determined from a K-means analysis.

TABLE II: Mean parameters of Kyle Hendricks's 4S and 2S changeups, including the number of pitches N, release speed v_0, spin rate ω, spin efficiency ϵ, Total(T), Lift (L), and Side (S) movement directions (ϕ_T, etc.), and movement distance (M_T, etc.)

type	N	v_0 (mph)	ω (rpm)	ϵ	ϕ_T (deg)	ϕ_L (deg)	ϕ_S (deg)	M_T (inch)	M_L (inch)	M_S (inch)
4S Changeup	235	79.7	1974	0.86	125.2	134.2	71.7	16.2	15.8	2.9
2S Changeup	472	80.4	2023	0.85	154.2	133.6	223.5	18.2	17.0	6.4

assignments for the Hendricks changeup. Additionally, Tango posted a list of other pitchers with confirmed 2S or 4S orientations for the changeup. The movement plots for Calib Smith (4S) and Eduardo Rodriguez (2S) are shown in Fig. 6. Comparison with the fastballs and sinkers show that the movement is that expected for the given seam orientation assignment.

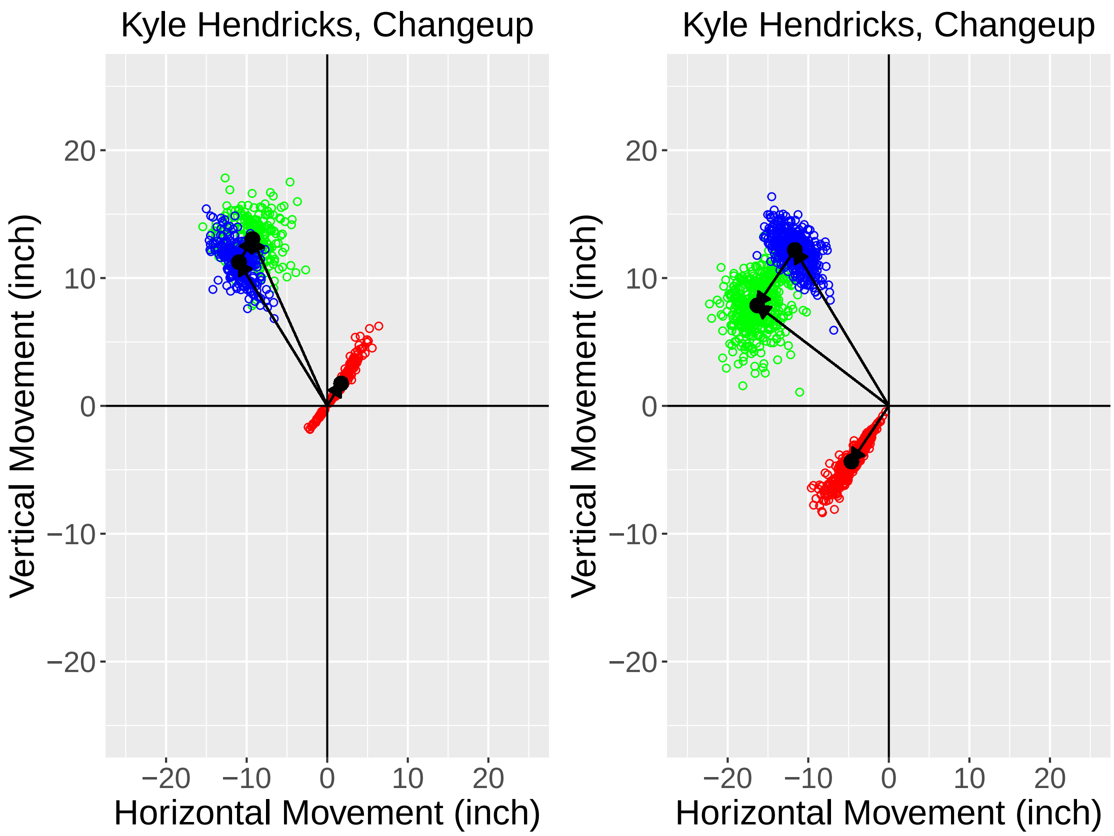

FIG. 5: Movement plots for Kyle Hendricks's changeups, separated into 4S (right) and 2S (left) components. The color coding and arrows have the same meaning as in Fig. 1.

IV. THE ROLE OF GYROSPIN

The final topic to discuss is that of the role of gyrospin in SSW. As discussed in some detail by Smith[1] on theoretical grounds, a small amount of gyrospin is essential for obtaining SSW movement, especially for 2S pitches. Briefly, to obtain a seam-shifted wake, it is necessary for there to be an asymmetry in the seam configuration relative to the direction of motion of the baseball and that asymmetry has to persist through a complete revolution of the ball. For a purely 2S pitch, that is not possible without tilting the axis of rotation to introduce some gyrospin, which necessarily reduces the spin efficiency.

This argument is borne out in the Statcast data, as shown in Fig. 7, which are averages for pitchers throwing at least 100 sinkers. The left plot shows how the deviation of the movement axis relative to the Magnus direction essentially vanishes at unit spin efficiency and increases rapidly as the spin efficiency deviations from one. The right plot shows how

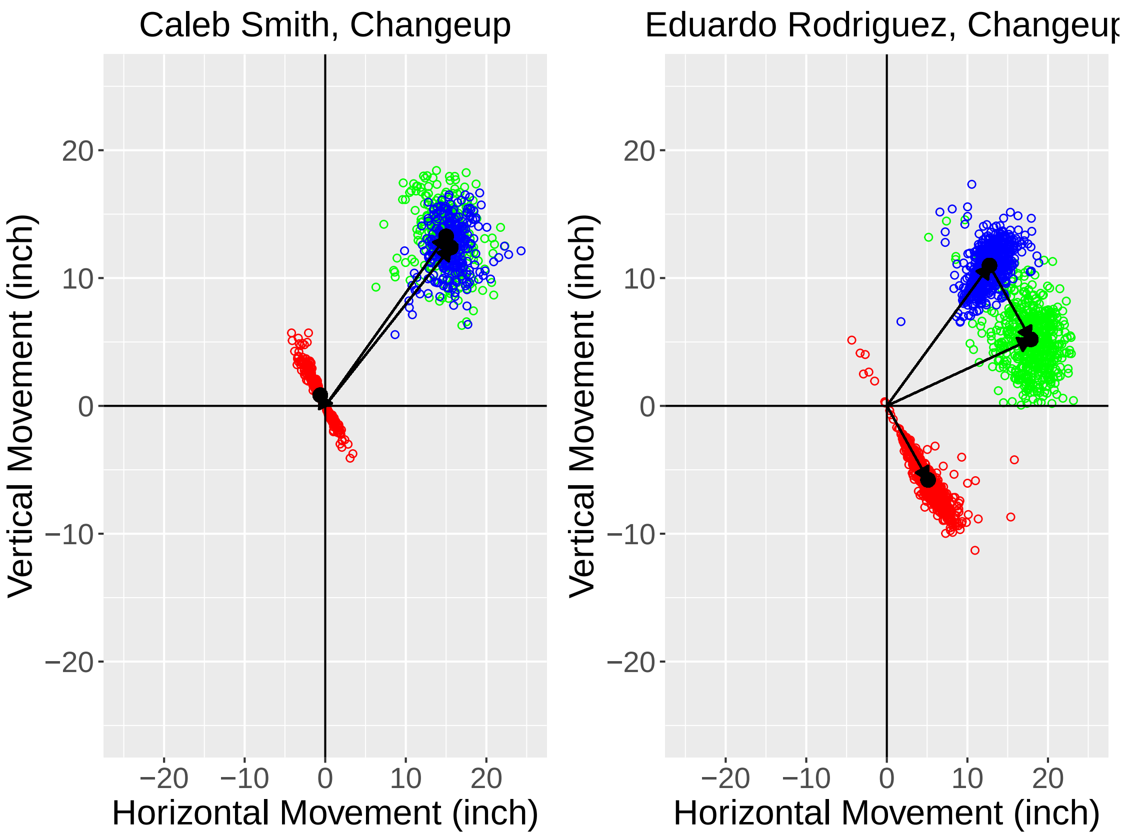

FIG. 6: Movement plots for changeups thrown by Caleb Smith (L) and Eduardo Rodriquez (R), both left-handed pitchers. Hawkeye data showing seam orientation confirm that Smith throws a 4S and Rogriguez a 2S.[10] The color coding and arrows have the same meaning as in Fig. 1.

the movement depends on spin efficiency. As expected the lift movement (primarily Magnus) decreases as the spin efficiency decreases, while the side movement (entirely SSW) increases. The net result is that the total movement stays relatively constant as the spin efficiency decreases from 1.0 to 0.9, yet the movement direction shifts arm-side from the Magnus direction by about 23°. The essential result is that it is possible to obtain an arm-side shift of the movement direction by introducing a small amount of gyrospin without a significant loss in total movement. It is not hard to imagine how this feature might play a role in pitch design.

The equivalent set of plots for fastballs is shown in Fig. 8. As with sinkers, the lift movement shows the expected decrease with decreasing spin efficiency. However, the increase in side movement is much less rapid, resulting in small shifts in the movement direction, with the magnitude of the movement essentially indistinguishable from that due to lift alone. For fastballs, unlike for sinkers, it does not seem possible to use a small amount of gyrospin to obtain a shift in the movement direction without suffering a loss in total movement.

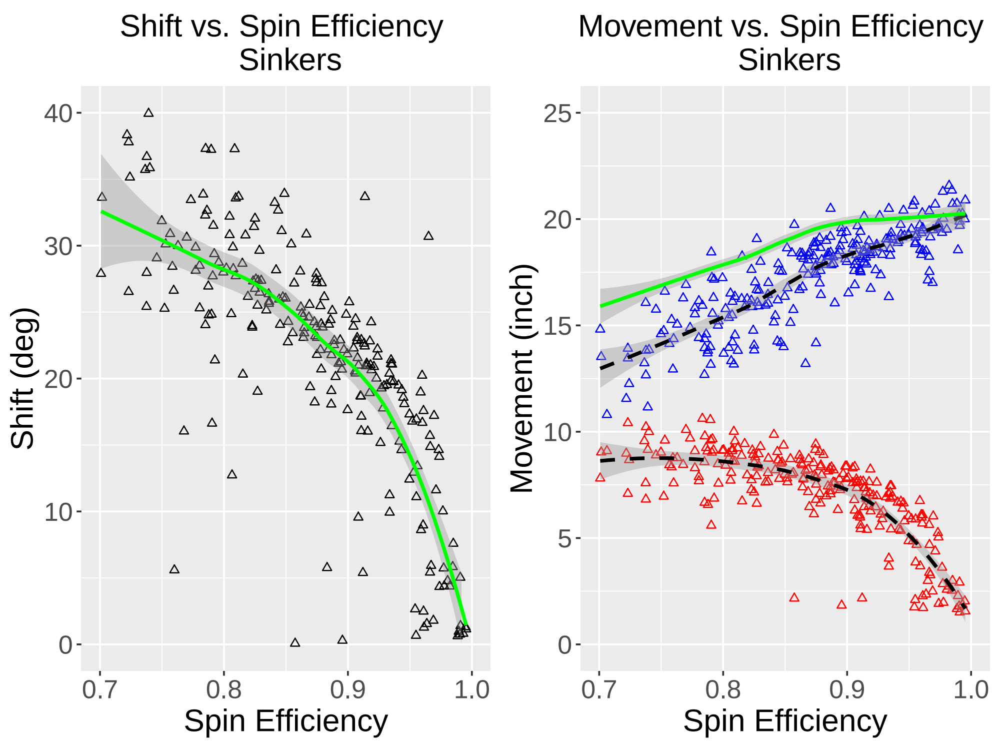

FIG. 7: Left: Magnitude of the shift of the movement direction vs. spin efficiency for sinkers (black points), along with a smooth trendline (green curve). Right: Movement vs. spin efficiency for sinkers. The blue points are the lift movement (Magnus); the red points are the side movement (SSW). The black dashed lines are smooth curves through the data. The solid green curve is a smooth trendline for the total (or actual) movement. In both plots, each point is an average for pitchers throwing at least 100 sinkers.

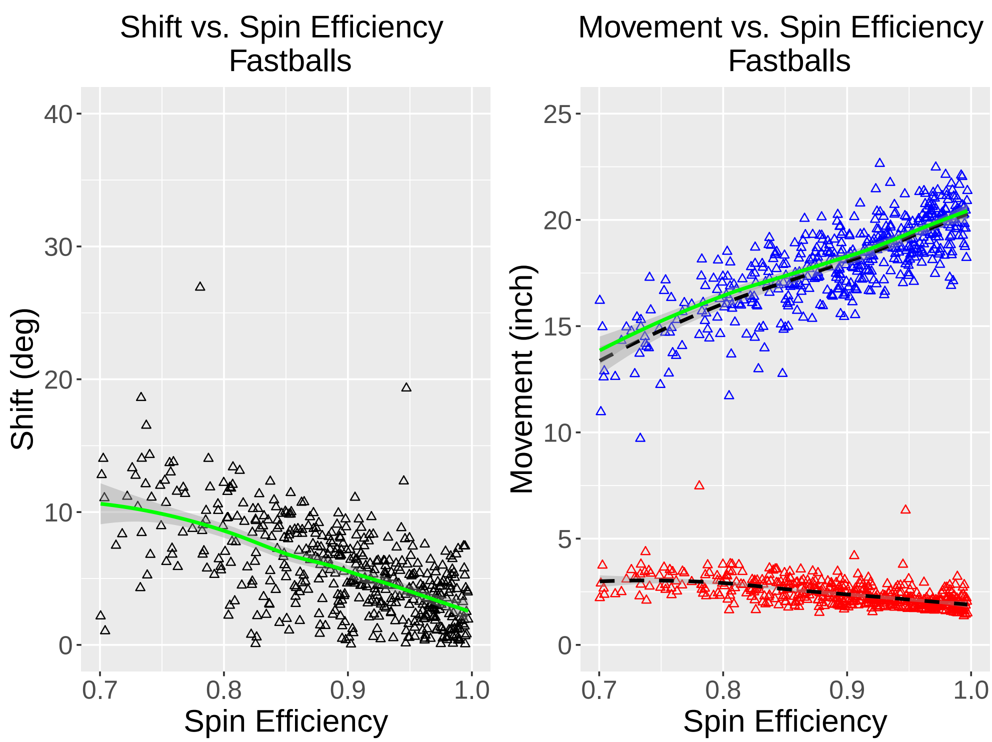

FIG. 8: Same as in Fig. 7 for fastballs.

V. SUMMARY

In summary, this article has used the previously established formalism for separating the movement into lift and side components to study some interesting features of the seam-shifted wake using Hawkeye data from the 2021 MLB season. These features include the differences between 2S and 4S orientations for fastballs, sinkers, and changeups, as well as the role of gyrospin.

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[1] For a series of blog posts about SSW, see Seam Shifted Wakes.

[2] Barton Smith, Alan Nathan, and Harry Pavlidis, Not Just About Magnus Anymore, Baseball Prospectus, November 5, 2020.

[3] Alan M. Nathan, What Is The Hawkeye Spin Data Teaching Us? I: Determining Magnus and non-Magnus Movement, January 5, 2020 (unpublished).

[4] Alan M. Nathan, What Is The Hawkeye Spin Data Teaching Us? II: Lift and Side Forces, January 22, 2020 (unpublished).

[5] G. Healey and L. Wang. Analyzing the Side Force on a Baseball Using Hawk-Eye Measurements, January 13, 2021 (unpublished).

[6] Alan M. Nathan, Movement Template.

[7] Alan M. Nathan, What Is Hawkeye Teaching Us About Baseball Pitches?, SABR Analytics Presentation, March 2021. Click here for the PowerPoint slides or here for the video.

[8] Eno Sarris, Kyle Hendricks Has Two Changeups, FanGraphs, October 20, 2015.

[9] Tom Tango, The two changeups of Kyle Hendricks., Twitter Thread, March 20, 2021.

[10] Tom Tango, Statcast Mollweide Projection: Kyle Hendricks, Twitter Thread, April 19, 2022.