The Physics of Pitching In The Wind

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Recently, I was sitting in front of the tube watching the Giants play the Phillies at Citizens Bank Park. In the top of the fifth, Cole Hamels fired a fastball. Gregor Blanco was barely able to foul it off. It was the fastest four-seamer Hamels had thrown all day inspiring Giants broadcaster Mike Krukow to comment,

"One thing pitchers like, and you don't see it very often in this ballpark, they like winds at their back. You know, wind at your back is just like a golfer with the wind at his back in the tee box. You feel like you can hit the ball farther. Well, the same thing for a pitcher. They think they can throw harder and you can."

Well Kruk (rhymes with "Duke"), I never made it very far playing baseball so I don't really know what pitchers think or why they think it. Some coaches even claim pitchers are better off not thinking. However, what I do have to offer is the knowledge to examine the physics of pitching in the wind. Let me start by reviewing the forces that act on the ball on its journey from pitcher to catcher.

Forces on a Pitched Baseball

There are two things that exert forces on a pitch in flight. The gravitational force is exerted by Earth. This steady downward inescapable pull is highly structured and predictable. In contrast, the forces air exert on the ball are complex and subtle. They give rise to the beauty and nuance of pitching.

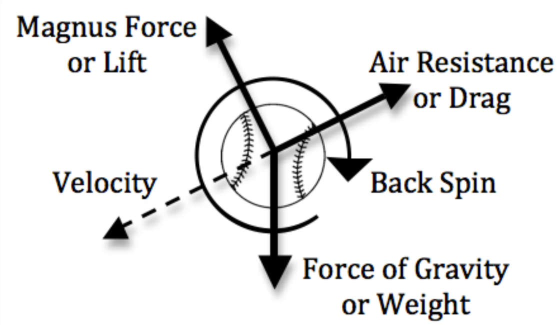

Figure 1: The forces on a ball in flight with backspin are lift, drag, and weight.

Figure 1 shows three forces acting on a typical four-seam fastball [ref. 1] – one from gravity and two from the air. They are shown as solid straight arrows. The velocity is represented by the dashed arrow while the backspin on the fastball is indicated by the circular arrow.

The gravitational force or weight pulls the ball downward. The weight depends the mass of the ball as well as the mass and size of Earth. Even Hall of Fame pitchers known for outstanding control have no ability to adjust these variables.

The effect air has on the ball is usually thought of as two distinct forces. Air resistance or drag acts opposite the velocity of the ball [ref 2]. Drag, as the name implies, slows the ball down. The drag grows as the square of the speed of the ball through the air. Again, the pitcher really has no sway as far as the drag is concerned.

If they throw it faster, there will be more drag. Try as they may, they can't change the Laws of Physics.

The other force exerted by the air is the Magnus force or lift. It is always perpendicular to the velocity and is in the direction of the spinning motion of the front of the ball as it moves through the air. Due to the spin, the front of the ball in figure 1 is moving mostly up the page and slightly to the left, matching the direction of the lift. The lift is responsible for the "hop" on a typical fastball causing the ball to drop more slowly than if gravity were acting alone.

The lift is not always upward. A curveball for instance has mostly topspin – opposite to the backspin in figure 1. The result is the oxymoronic "downward lift." So, the ball falls more rapidly than gravity alone requires. In baseball speak, it "drops off the table." To avoid the confusion associated with the word "lift," I usually use the term Magnus force.

Magnus force depends upon the speed of the ball through the air and the rate the ball is spinning. Unlike gravity and drag, the pitcher can control the Magnus force. In fact, the spin is the primary mechanism by which the pitcher manipulates the trajectory of the ball. The differences between a fastball, a curve, a slider, a sinker are all due to varying the amount and direction of the spin put on the ball linked with the speed it is thrown.

You will probably be surprised to note that for a typical Hamel's fastball, the drag is almost equal to the weight of the ball. The lift is about two-thirds of the weight of the ball. Now you can understand why the motion of a pitch in flight can be so dramatic. The forces on the ball are comparable to the force pulling it toward Earth!

Passing Wind

In 2007, Mike Fast wrote a brief article in his blog Fast Balls [ref. 3] listing average wind speeds by ballpark. He claimed the speeds range from zero in indoor parks to 17mph at AT&T Park in San Francisco. Citizens Bank in Philly comes in a little above average at 10mph. The box score for the game in question records the wind at 11mph in from centerfield.

It is unclear where these numbers are measured exactly. While every MLB game has a wind speed listed in the box score, I've never seen anyone with an anemometer [ref. 4] wandering around the field before or during the game. Hold on a second – I just can't let that word go by unnoticed. An anemometer is that twirling gizmo with four cups. How is it pronounced anyway? a-nemo-meter, an-emo-meter, an-e-mo-mom-meter? Actually nowadays they eschew the four cups and use an electronic device. Whatever…back to business.

However they get the wind speed, we can rest assured it is not measured on the mound. The mound is reasonably well protected from wind by the structure of the stadium compared to centerfield for example. Considering all of these unknowns, it is unclear what values to use for the wind speed during a pitch. For lack of anything better, let's consider wind speeds up to 10mph – at least it's a round number.

Now back to Cole Hamels' fastball. It turns out that three weeks earlier he pitched in Miami with the roof closed – no wind. Using the PITCHf/x data from that day [ref. 5] we learn he threw 47 four-seam fastballs averaging 92.2mph. They ranged from 89.3mph to 95.0mph. In the matchup with the Giants, Hamels tossed 74 fastballs averaging 94.0mph and ranging from 91.7 to 96.2mph. So, the data would indicate he got about a 2mph bump in speed due to the wind.

I can hear you howling already! That doesn't prove anything. Maybe Hamels had the flu in Miami…he is nine and thirteen against the Marlins lifetime…perhaps he threw harder because he hates the Giants…it may have just been your basic case of "home cooking"…who knows. In fact, his manager Ryne Sandberg said of his performance, "He was missing off the plate and threw a lot of pitches. He wasn't the sharpest he's been." Hamels left in the fifth having given up three runs.

A Mighty Wind

Since you insist, I'll look at the question more analytically. We can use the data from the game in Miami and the Laws of Physics to calculate the effect of wind on the pitches. This is relatively easy to do using Alan Nathan's Trajectory Calculator [ref. 6]. The calculator requires the initial x, y, and z-positions of the ball as well as the initial speed and direction of the pitch. The average values for the fastballs in the Miami game can just be entered into the Trajectory Calculator.

The challenge then becomes estimating the spin on the ball. The Miami data tells us the average position of the fastballs at home plate. By adjusting the values for the backspin and the sidespin until they produce the correct position at the plate, we can establish reasonable values for the spins. A backspin of 1314rpm and a sidespin of 876rpm seemed to do the trick, although they are smaller that the PITCHf/x estimates.

The Trajectory Calculator has a place to enter the wind speed and direction… problem solved! Figure 2 is a graph of the final speed of the ball versus the wind speed. Negative wind speeds are at the back of the pitcher while positive wind speeds are in the pitcher's face. The final speed of the ball at the front of the plate increases about 2mph for every 10mph of wind speed at the pitcher's back.

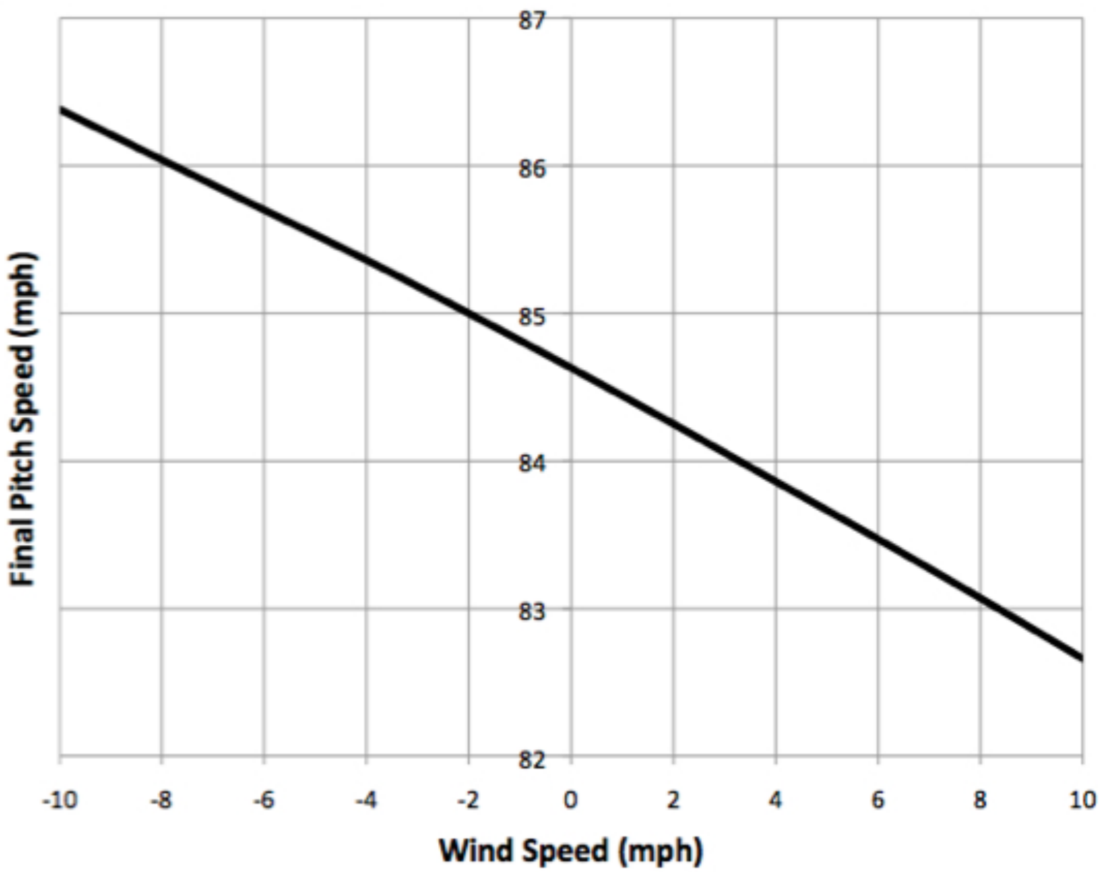

Figure 2: Final pitch speed versus wind speed. Negative wind speeds are at the pitcher's back while positive speeds are in his face.

The drag force is proportional to the speed the ball moves through the air, *not the speed the ball moves with respect to the ground*. When the ball moves with the wind, it is moving *more slowly* with respect to the air, therefore the drag force is reduced. The lower drag force allows the ball to maintain its speed as it makes its way to home.

So, Kruk it looks like you're right! The final speed of Hamel's fastball will be measurably higher with the wind at his back. It should be noted that we haven't really explained why his start speed was also higher on the day in question. This turns out to be the more likely reason that his fastball was 2mph quicker against the Giants.

We can go further with the Trajectory Calculator and examine the effect of the head or tail wind on the flight path of the ball. Figure 3 shows the side view of the four-seamer for wind speeds from 10mph at the pitcher's back (-10mph) to 10mph in the pitcher's face (+10mph) in 5mph increments. The central curve is for no wind. The inset is a blow-up of the curves near home plate.

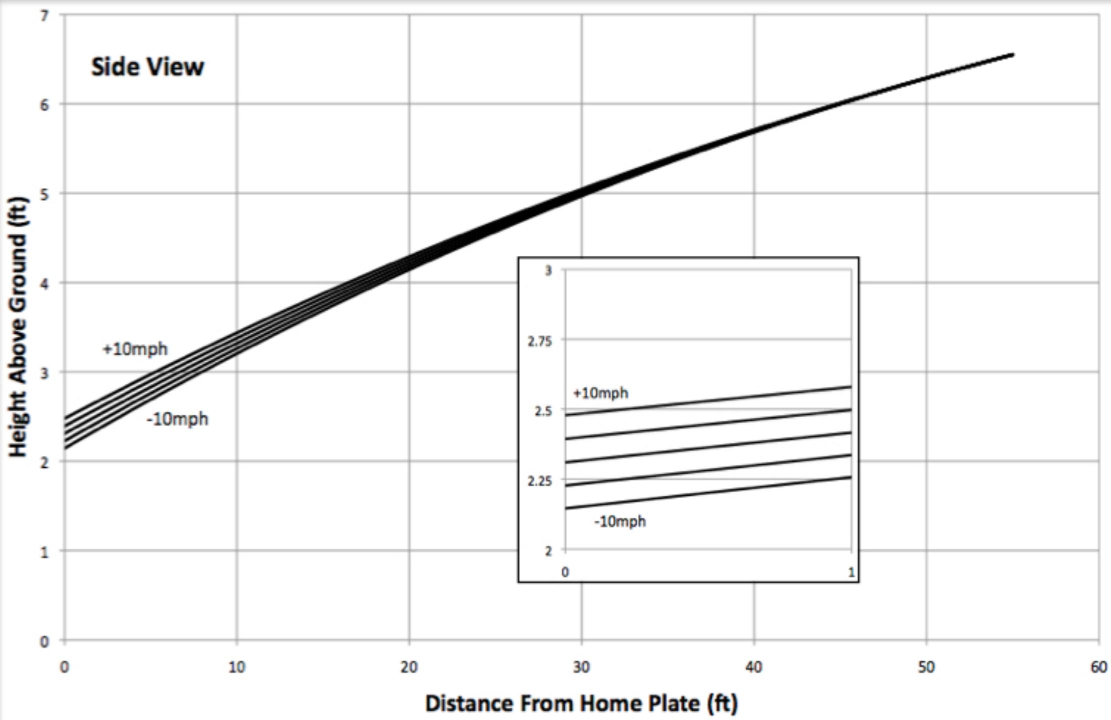

Figure 3: The side view of the trajectory by wind speed. The inset is a close-up of the path near home plate.

Strangely, these fastballs have more sink with the wind at the pitcher's back. The ball will drop about 2 inches for every 10mph of wind speed. You might think the opposite since the wind carries the ball along faster, it should sink less – but that's not so and here's why.

Just like the drag force, the lift force is proportional to the speed the ball moves through the air. The air speed will be less than in still air for a wind at the pitcher's back. With less lift, the ball drops more rapidly due to gravity. In other words, a fastball traveling downwind has less "hop" or "rise."

Figure 4 shows the top view for the same pitches. Again, 10mph at the pitcher's back is negative while 10mph in the pitcher's face is positive and the inset is a blow-up of the trajectory near home plate.

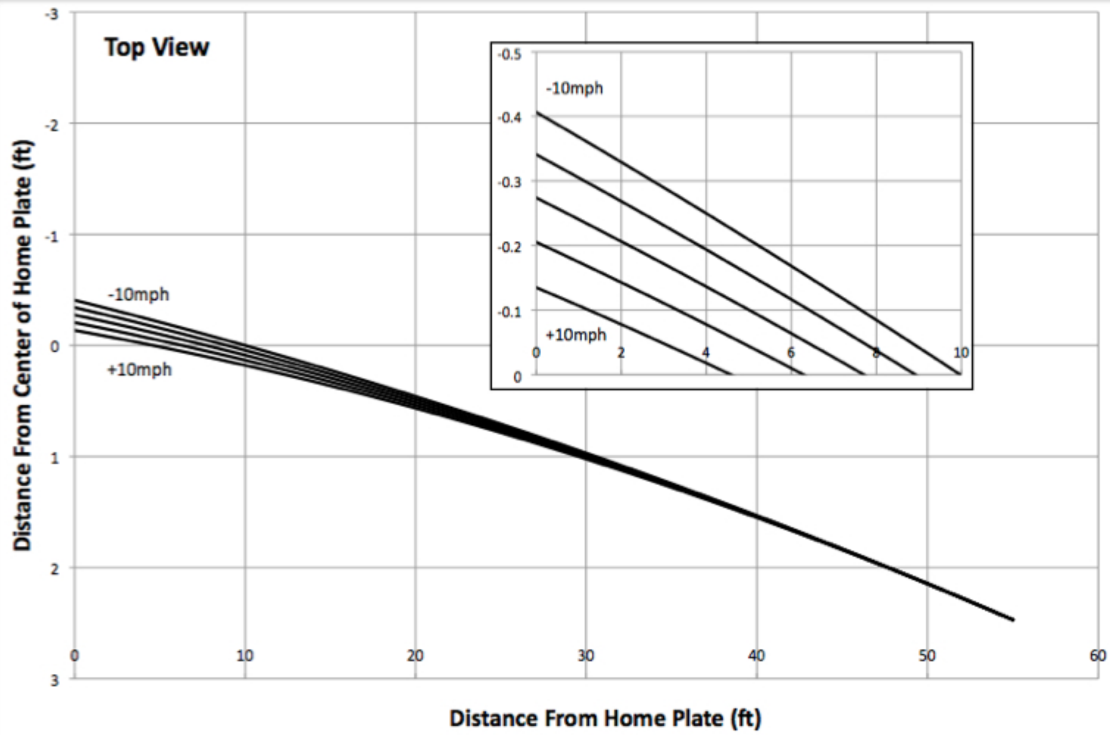

Figure 4: The top view of the trajectory by wind speed. The inset is a close-up of the path near home plate.

The data shows a ball thrown downwind will have a straighter horizontal trajectory than a ball thrown into the wind. Again, we see the effect of the reduced Magnus force due to the reduced speed between the air and the ball. The net effect is a bit smaller than the vertical motion. In this case about 1.5 inches for every 10mph of wind speed. The horizontal change should be smaller than the vertical change since the sidespin is less than the topspin.

So how about that Kruk? A tailwind will speed-up a pitch and give it more sink at the cost of less break. Conversely, a headwind will slow the pitch, but accentuate the “hop” and break. Your golf analogy was perfect. If you tee off with a tail wind, the ball goes faster and straighter. If you hit your drive into the wind, it goes slower and your hook or slice is more pronounced.

It’s not clear which type of wind is better for a given pitcher. My personal suspicion? Break is more important than speed, so pitching into the wind might be a better choice. In the extreme example, knuckleballers generally prefer to pitch into the wind.

Ill Wind

As mentioned earlier, the mound is reasonably well protected by the structure of the stadium from winds blowing either in from or out to centerfield. However, in some parks it is conceivable that a wind blowing in from left might follow the contour of the stands. It would become a crosswind between the pitcher and the plate as it makes its way around the park and out to right field.

Then again, maybe not, but the Trajectory Calculator gave us some intriguing results for pitching downwind. So, let's see if it is just as interesting to look at the effect of a crosswind on the path of a pitch.

The final speed of the pitch at home only increases by 0.4mph as the wind switches from first to third at 10mph to third to first at 10mph. It is not surprising that the final speed is nearly unchanged since the wind is blowing across the ball's path not along it.

The question is whether that 0.4mph change is real or just a numerical artifact from the Trajectory Calculator. The sidespin of the ball should be interacting with the wind to create a small Magus force along the line between the mound and home.

This is hard to follow, but keeping in mind that Hamel's is a lefty. When the wind is toward third, the side of the ball facing the wind has some spin toward the mound. The Magnus force will be away from the plate slowing the ball down. The opposite is true when the wind is blowing toward first. So, at least the 0.4mph increase is the right direction for these pitches.

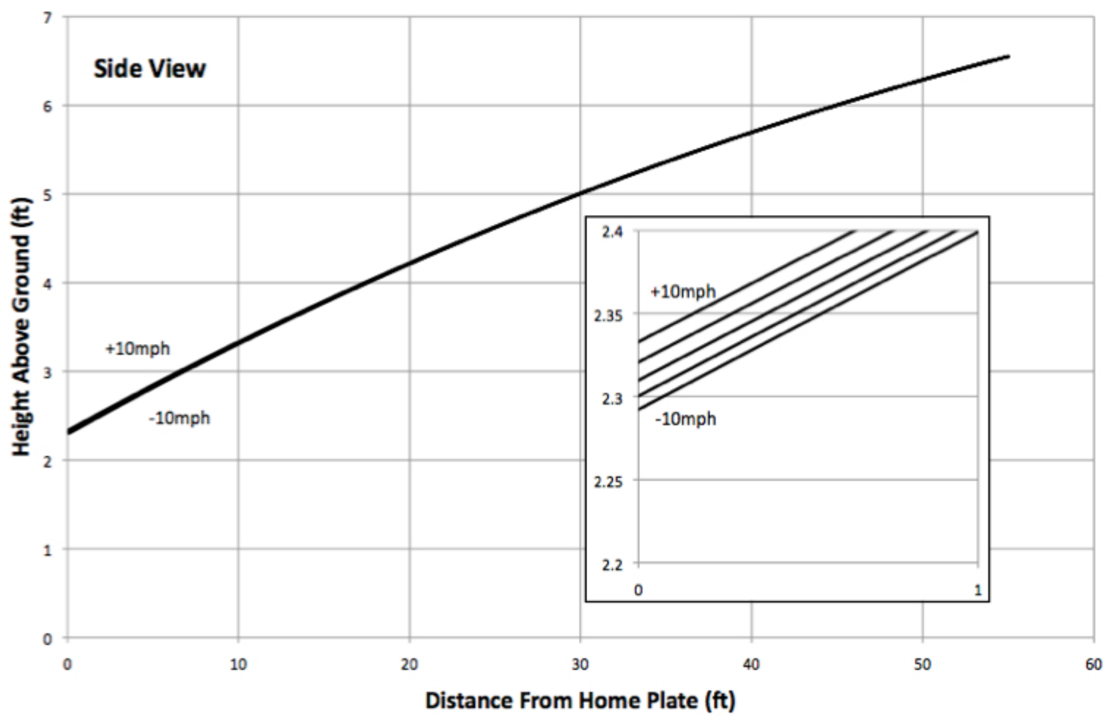

Figure 5: The side view of the crosswind trajectory by wind speed. The inset is a close-up of the path near home plate.

Figure 5 is the side view of the trajectories of the Hamel's fastball with the crosswind along the line from third to first at varying speeds. 10mph from first toward third is negative while 10mph third to first is positive. Since the wind is moving pretty much across the trajectory of the ball, the side views of all the trajectories are very close to the same.

The inset shows the difference to be about 0.04 feet (0.5 inches) over the velocity change of 20mph. If you assume the differences between the paths are due to the 0.4mph speed increase explained earlier, a quick estimate does produce a height difference of a fraction of an inch. Maybe the reduction in speed from the Trajectory Calculator is really due to the Magnus force.

As you probably guessed, the biggest effect of a crosswind is the horizontal position of the ball as it crosses the plate. Figure 6 shows a variation of about half a foot over the 20mph range or 3 inches per every 10mph. This is the largest change due to the wind we've seen yet.

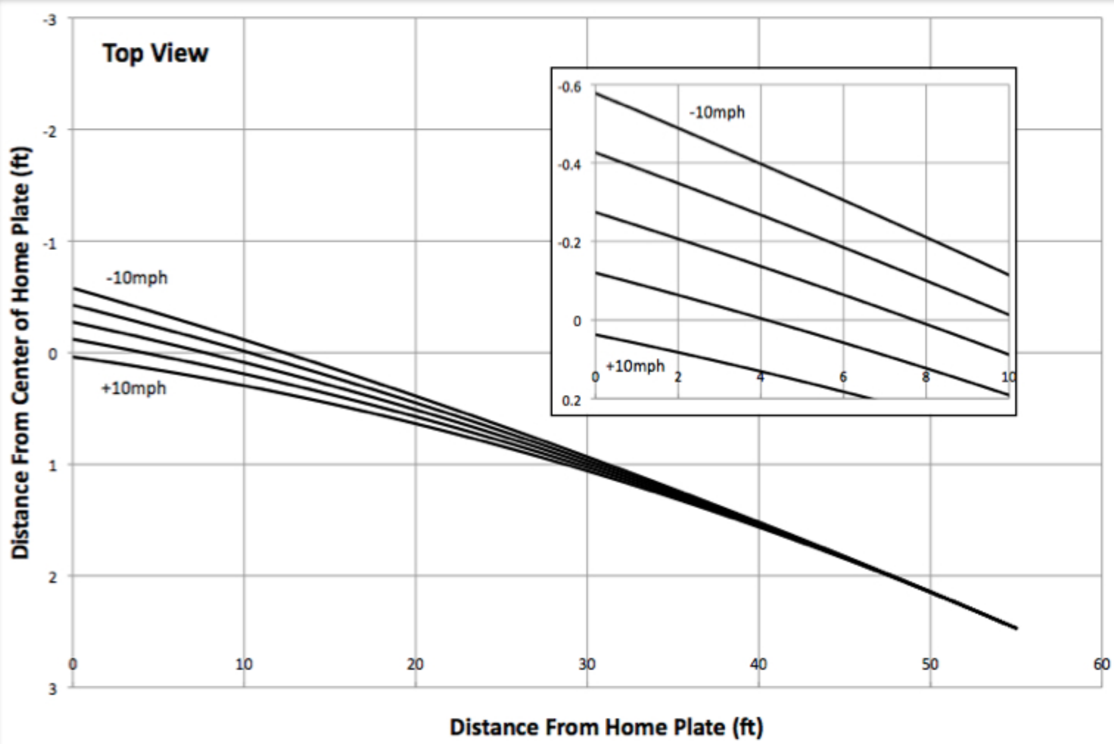

Figure 6: The top view of the crosswind trajectory by wind speed. The inset is a close-up of the path near home plate.

Usually, the horizontal break of a pitch is due to sidespin and Magnus force – here it is also due to the drag. Hamels had released the ball with a small fraction of the its velocity toward third – on average 6mph. When the wind blows toward third at 10mph, the ball is only moving through the air at 4mph.

On the other hand, when the wind blows toward first the ball is moving at 16mph with respect to the wind. Since the drag depends upon the square of the speed, the force due to the wind will be not four-times larger, but rather *sixteen-times* bigger. That's why the -10mph trajectory is much straighter than the +10mph one.

The crosswind was a bit more complicated. Are you still with me Kruk? In summary, the crosswind hardly changes the speed to the plate or the vertical motion of the ball, but makes relatively large changes in the horizontal break. Just as for the head or tail wind, it is not obvious which type of crosswind is better for a given pitcher.

Breaking Down Wind

Since you are one of the hearty souls still hanging in there, I thought I would provide a special treat. Figure 7 is the catcher's view of the situation. It summarizes what we've learned from the previous discussions.

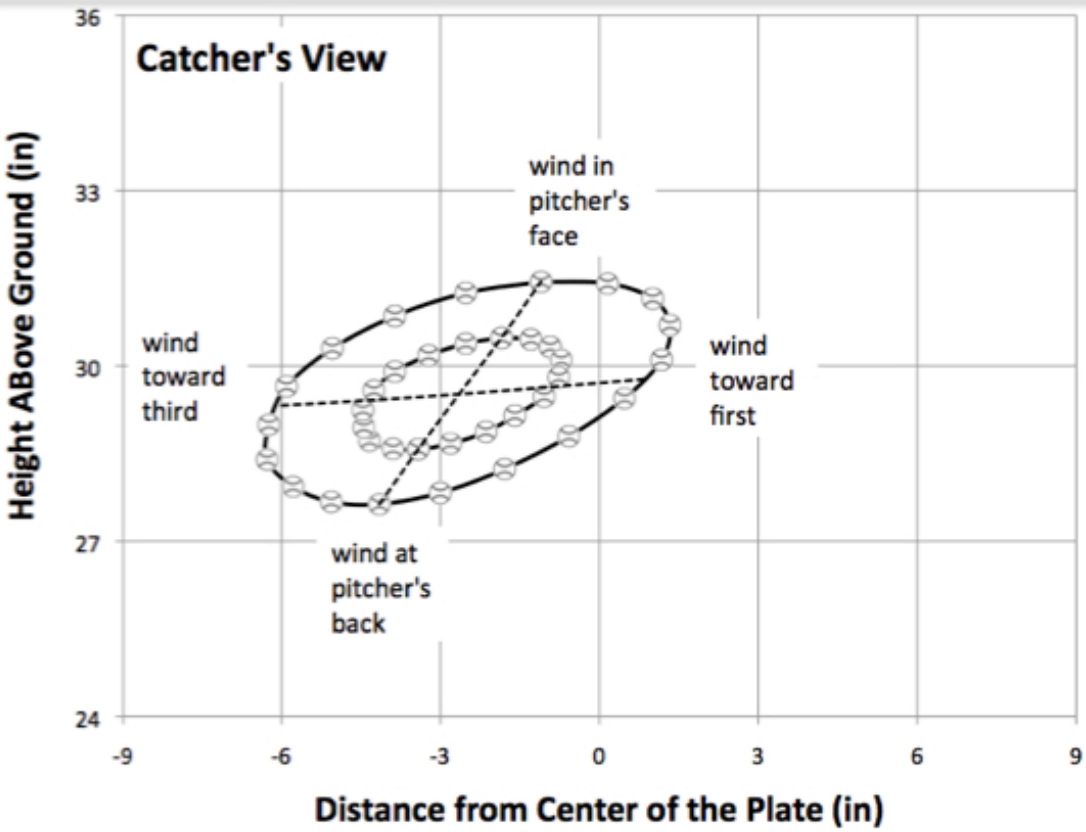

Figure 7: The catcher's view for different wind speeds and directions. The inner ring is for the 5mph wind speed and the outer ring for 10mph.

The location of Hamel's four-seamer with no wind is at the intersection of the dashed lines. The inner ring shows the pitch location for a 5mph wind from different directions as indicated on the plot. The outer ring is for a 10mph wind.

The dashed lines are the two cases we've considered in detail. The more vertical dashed line is for the wind either at the pitcher's back or in his face. The more horizontal dashed line indicates the crosswind situation.

Since home plate is 17 inches wide, the horizontal scale extends to one-half inch beyond the plate on both sides (the baseballs in figure 7 are not to scale). The catcher's view illustrates the magnitude of the deviations in trajectory due to the wind. The horizontal variations at 10mph are almost half the width of the plate.

The crosswind affects the horizontal location of the pitch more strongly than the vertical. The head/tail wind affects the vertical position most strongly. The crosswind has a larger overall effect on pitch location than the head/tail wind.

Perhaps these wind-driven effects are sufficiently large that you data miners out there might want to figure out which pitchers should throw which pitches on windy days. The COMMANDf/x [ref. 7] folks might want to see if command suffers on windy days. I'm handing you the ball here because, at this point I have reached the limit of my skills.

So Kruk, next time you're commenting on why the pitcher seems to be having control problems you can just break into the old folk song…"The answer, my friend, is blowing in the wind…."

References

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