Fun with PitchFX

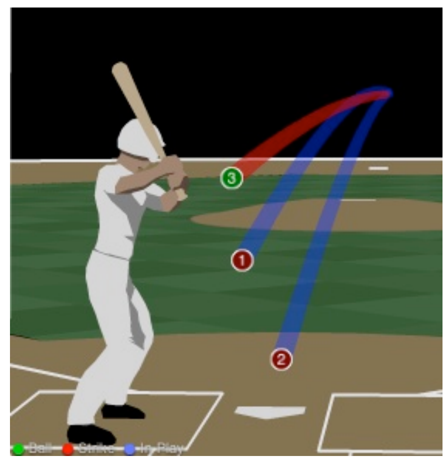
What is this about?

Thanks to a company called Sportsvision and Major League Baseball you can get the initial position, initial velocity, and average acceleration of any pitch thrown in the big leagues. The video technology that tracks pitches is called PITCHf/x. This activity will show you how to calculate many quantities associated with pitches using the kinematic equations.

What do I need?

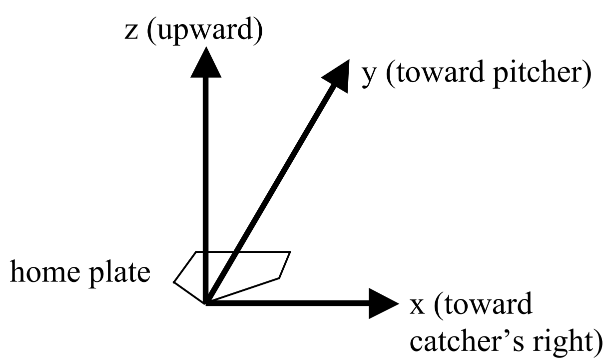
You will need an internet connected computer and a calculator. You should be familiar with the use of the kinematic equations in two or three dimensions.

What will I be doing?



First, go to mlb.com, click on "Scoreboard." Choose a game and click on "Gameday." You will see an image like the one on the right. The trajectory of each pitch is shown. You will get to use the same data MLB uses to calculate the trajectory of the pitches. You will get to choose from several noteworthy pitches from 2007 or later.

To get your data go to http://phys.csuchico.edu/baseball/POBActivities/pitchfx/. Click on one of the pitches described on the page. The data you need will appear along with a photo and a link to video of the pitch.



The coordinate system used for the data is shown at the right. It has an origin at the back point of home plate on the ground. The x-axis points to the catcher's right. The y-axis is toward the pitcher. The z-axis is oriented upward.

Notice that pitches are moving in the negative y-direction. An outside pitch to a right handed batter will have a positive x while an inside pitch to a right hander will have a negative x.

Start by finding the initial speed of the ball (at y=50.0ft). In 3-dimensions the initial speed is the magnitude of the initial velocity vector. Using the components are listed in the table, take the square root of the sum of their squares,

$$v_o = \sqrt{v_{ox}^2 + v_{oy}^2 + v_{oz}^2} = \underline{\hspace{8cm}}$$

You will need to convert from ft/s to mph. If you did it right, you got the value listed at the bottom of the internet page.

Now, find the components of the final velocity of the pitch when it reaches the front of home plate (y=1.417ft) by using the kinematic equations. Since we know the initial and final y-values we can get the y-component of the velocity using the kinematic equation,

$$v_y^2 = v_{oy}^2 + 2a_y(y - y_o)$$

Note that we want the negative value of the root to agree with the coordinate system. Plug in the values,

$$v_y = -\sqrt{v_{oy}^2 + 2a_y(y - y_o)} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

You should get a value around about 100ft/s.

The time of flight must be found to get the other velocity components. Using another kinematic equation,

$$v_y = v_{oy} + a_y t \Rightarrow t = \tfrac{v_y - v_{oy}}{a_y} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

Did you get around 0.4s?

Now we can find the other two velocity components using the time of flight and kinematic equations for the other two axes,

$$v_x = v_{ox} + a_x t = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$v_z = v_{oz} + a_z t = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

These values will be much smaller than v_y and they depend upon what kind of pitch you chose (i.e. curve, slider,…).

Now that we have all three components, we can calculate the final speed,

$$v = \sqrt{v_x^2 + v_y^2 + v_z^2} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_,$$

which should agree with the value at the bottom of the internet page.

Now, let's find the x and z positions of the ball when it reaches the front of home plate using the kinematic equations,

$$x = x_o + v_{ox}t + \tfrac{1}{2}a_x t^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$z = z_o + v_{oz}t + \tfrac{1}{2}a_z t^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

These values should agree with the data at the bottom of the internet page.

We can go further and look at the forces involved in the motion of a major league pitch. Given the weight of a baseball is 0.320lbs, we can find the x, y, and z components of the force exerted on the ball by the air during its flight. Since the components of the acceleration are given in as items 20, 21, and 22 in the table, we can use Newton's Second Law along each direction. Along x and y the only force is due to the air,

$$F_x = ma_x = mg\left(\frac{a_x}{g}\right) = (0.320)\left(\frac{a_x}{32.174}\right) = \underline{\hspace{3cm}}$$

$$F_y = ma_y = mg\left(\frac{a_y}{g}\right) = (0.320)\left(\frac{a_y}{32.174}\right) = \underline{\hspace{3cm}}.$$

Along z gravity is also in play,

$$F_z - mg = ma_z \Rightarrow F_z = mg + mg\left(\frac{a_z}{g}\right) = mg\left(1 + \frac{a_z}{g}\right) = (0.320)\left(1 + \frac{a_z}{32.174}\right) = \underline{\hspace{3cm}}.$$

Now, find the magnitude of the force caused by the air,

$$F_{air} = \sqrt{F_x^2 + F_y^2 + F_z^2} = \underline{\hspace{5cm}}.$$

The largest force is in the y-direction and is predominantly air drag. The upward or downward force on the spinning ball in the z-direction is mostly created by the backspin or topspin about the x-axis while the force in the x-direction is mostly from the sidespin about the z-axis. These forces are due to the Magnus force. It is amazing to realize that major league pitchers can spin a ball fast enough and give it sufficient velocity that the total force caused by the air is about the same as the weight of the ball.

What did I learn?

You have learned how to get data on the motion of real pitches from Major League games. You can now see how to calculate information about the trajectory of a pitch. In Major League games the forces of air drag and the Magnus force are quite large and very much effect the motion of a pitch.

What else should I think about?

With the PITCHf/x data set, intricate studies of the flight of real pitches in actual game situations can be thoroughly examined. Alan Nathan's "The Physics of Baseball" web site is a great place to start if you want to get a sense of what intrepid souls are doing with PITCHf/x data.

Catch it in the Web!

- Physics of Baseball by Alan Nathan
  (http://webusers.npl.uiuc.edu/~a-nathan/pob/pitchtracker.html)
  This site has tons of information as well as many links to other sites that use Pitchf/x.

- Major League Baseball: About GameDay
  (http://mlb.mlb.com/mlb/gameday/index.jsp)
  There are some great explanations of Pitchf/x. The "video tour" explains how Pitchf/x data is collected and used in GameDay.

- BrooksBaseball.net PitchFX Tool by Dan Brooks
  (http://www.brooksbaseball.net/pfx/)
  You can get to Pitchf/x data through this web site. It is a bit easier than going through the pages at MLB.com.

Going deep!

You can actually get data for any pitch throw since 2007 directly from MLB.com. First, go to http://gd2.mlb.com/components/game/mlb/. Click on any year 2007 or later, then on the month, then on the day, then on the specific game, and finally on pbp (play-by-play). At this point you have a choice to search for a pitch by the pitcher that threw it or the batter when it was thrown. Either way, you will see a collection of files labeled with a six-digit number (e.g. 123456.xml). There is a unique six-digit number for each player. You can get the names associated with the numbers by going back to the screen where you clicked on pbp and instead click on either batters or pitchers. When you finally get to the pitch you want you will see a screen full of entries like this:


```
– <player id="434665">
  – <atbat inning="6" num="53" b="0" s="0" o="1" batter="461235" stand="L" b_height="6-0" pitcher="434665" p_throws="R" des="Brandon Moss
    grounds out, second baseman Brandon Phillips to first baseman Javier Valentin. " event="Ground Out" brief_event="Groundout">
      <pitch des="In play, out(s)" type="X" id="414" x="110.73" y="153.69" sv_id="080814_210721" start_speed="93.0" end_speed="85.7"
      sz_top="3.380" sz_bot="1.500" pfx_x="-5.782" pfx_z="6.960" px="-0.397" pz="2.094" x0="-1.225" y0="50.000" z0="6.229" vx0="4.241"
      vy0="-136.094" vz0="-7.552" ax="-10.825" ay="30.341" az="-19.069" break_y="23.8" break_angle="25.6" break_length="5.0" pitch_type="FA"
      type_confidence="1.1313741483044553"/>
    </atbat>
  – <atbat inning="6" num="54" b="3" s="2" o="2" batter="456665" stand="R" b_height="5-11" pitcher="434665" p_throws="R" des="Steve Pearce
    flies out to left fielder Chris Dickerson. " event="Fly Out" brief_event="Fly out">
```


This mess contains all the numbers you need to know. The data about each pitch begins with "<pitch." Transfer the information about your pitch into the table on the next page.

No.	Quantity	Value	Units	Description
1	des			A comment on the action resulting from the pitch.
2	type			B=ball, S=strike, X=in play
3	id			Code indicating pitch number
4	x=		pixels	x-pixel at home plate
5	y=		pixels	z-pixel at home plate (yes, it is z)
6	start_speed		mph	Speed at y0=50ft
7	end_speed		mph	Speed at the front of home plate y=1.417ft
8	sz_top		ft	The z-value of the top of the strike zone as estimated by a technician
9	sz_bot		ft	The z-value of the bottom of the strike zone as estimated by a technician
10	pfx_x		in	A measure of the "break" of the pitch in the x-direction.
11	pfx_z		in	A measure of the "break" of the pitch in the y-direction.
12	px		ft	Measured x-value of position at the front of home plate (y=1.417ft)
13	pz		ft	Measured z-value of position at the front of home plate (y=1.417ft)
14	x0		ft	x-position at y=50ft
15	y0		ft	Arbitrary fixed initial y-value
16	z0		ft	z-position at y=50ft

17	vx0		ft/s	x-velocity at y=50ft
18	vy0		ft/s	y-velocity at y=50ft
19	vz0		ft/s	z-velocity at y=50ft
20	ax		ft/s/s	x-acceleration assumed constant.
21	ay		ft/s/s	y-acceleration assumed constant.
22	az		ft/s/s	z-acceleration assumed constant.
23	break_y		ft	Another measure of the "break."
24	break_angle		deg	Another measure of the "break."
25	break_length		in	Another measure of the "break."

Having all this data let's you calculate the "break" of a pitch. The break is caused by the spin on the ball. First, we will figure out where the batter might expect a non-spinning ball to be when it gets to home plate. A typical batter doesn't get a sense of the motion of the pitch until the ball is about 40ft away from home plate. Let's find the time it takes the ball to get to y=40ft using the kinematic equation,

$$y = y_o + v_{oy}t_{40} + \tfrac{1}{2}a_y t_{40}^2.$$

Solving for the time.

$$t_{40} = \frac{-v_{oy} \pm \sqrt{v_{oy}^2 - 2a_y(y_o - y)}}{a_y}$$

We will need to use the minus sign in front of the square root,

t_{40} = ____________________.

You should get a number slightly below 0.1s. Now let's find the x and z components of the position and velocity when the pitch gets to y=40ft. The x-position and velocity are,

$$x_{40} = x_o + v_{ox}t_{40} + \tfrac{1}{2}a_x t_{40}^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$v_{x40} = v_{ox} + a_x t_{40}, = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ .$$

The z-position and velocity are,

$$z_{40} = z_o + v_{oz}t_{40} + \tfrac{1}{2}a_z t_{40}^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$v_{z40} = v_{oz} + a_z t_{40} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

Now that the batter has a sense of the position and velocity of the ball, he can begin to plan his swing. The batter has plenty of experience dealing with the force that the air exerts on the ball due to the drag of air resistance. Therefore, the batter might expect the ball to arrive at home plate at the usual rate determined by the actual y-component of the velocity he can estimate at y=40ft and typical air resistance. The remaining time of flight from y=40ft can be found from by subtracting the total time from the time to get to y=40ft,

$$t_h = t - t_{40} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_,$$

which should be around 0.3s. The batter has a much more difficult time estimating the spin the pitcher put on the ball. The spin causes the air to exert additional forces on the ball due to the Magnus Effect. Assuming the air had no effect on the motion of the ball in the x and z directions starting at the point y=40ft, we can find the x and z-positions of the ball when it gets to the front of home plate. Along the x-direction there would be no acceleration so,

$$x_{noair} = x_{40} + v_{x40}t_h + \tfrac{1}{2}a_x t_h^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

Along the z-axis there would only be gravity,

$$z_{noair} = z_{40} + v_{z40}t_h + \tfrac{1}{2}a_z t_h^2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

This is where a non-experience batter might think the pitch will be if it had no spin.

One way to analytically define the break is the difference between where the ball actually arrives and where is would have arrived without any spin. The actual x and z positions are in the table as items 12 and 13. So, this definition of break can now be calculated for the x and z directions.

$$x_{break} = x - x_{noair} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$z_{break} = z - z_{noair} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

Convert these values to inches,

$x_{break} =$ ________________________ $z_{break} =$ ________________________.

These values are should be very close to the pfx_x and pfx_z values (items 10 and 11 in the table). This method of calculating the "break" of the pitch is somewhat arbitrary. Other methods are possible and the last three pieces of data in table 1 (items 23, 24, and 25) refer to a different method.