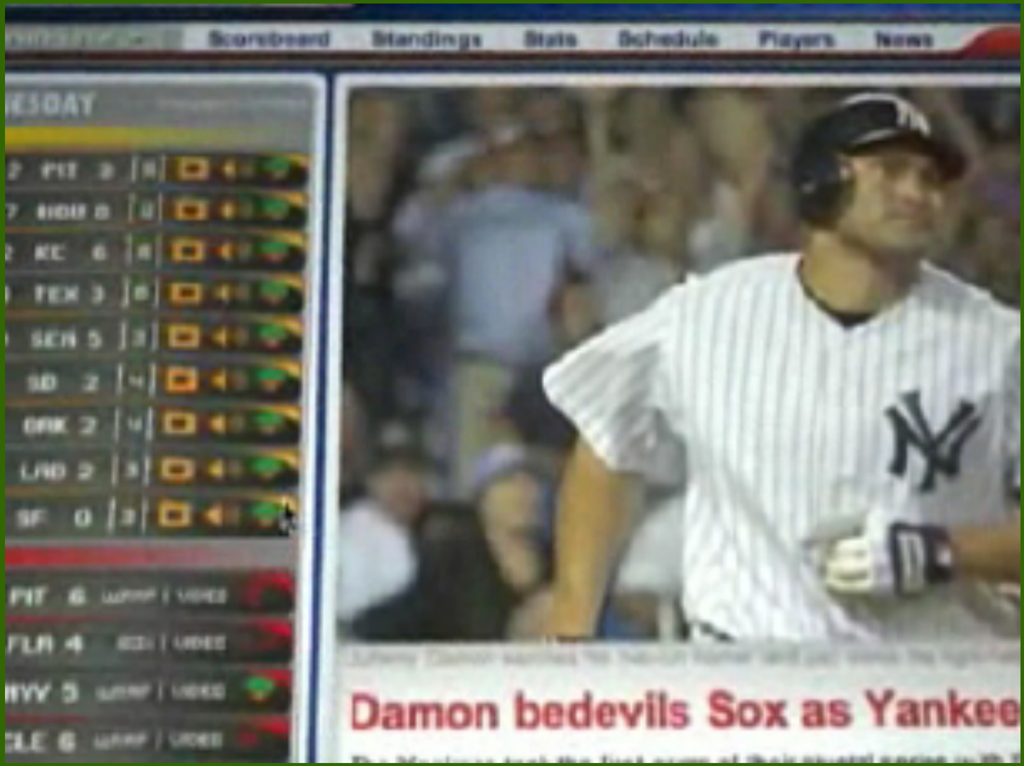
Pitch Physics to Your Students: Using PITCHf/x Data from Major League Basbeball

David Kagan
Department of Physics
California State University, Chico

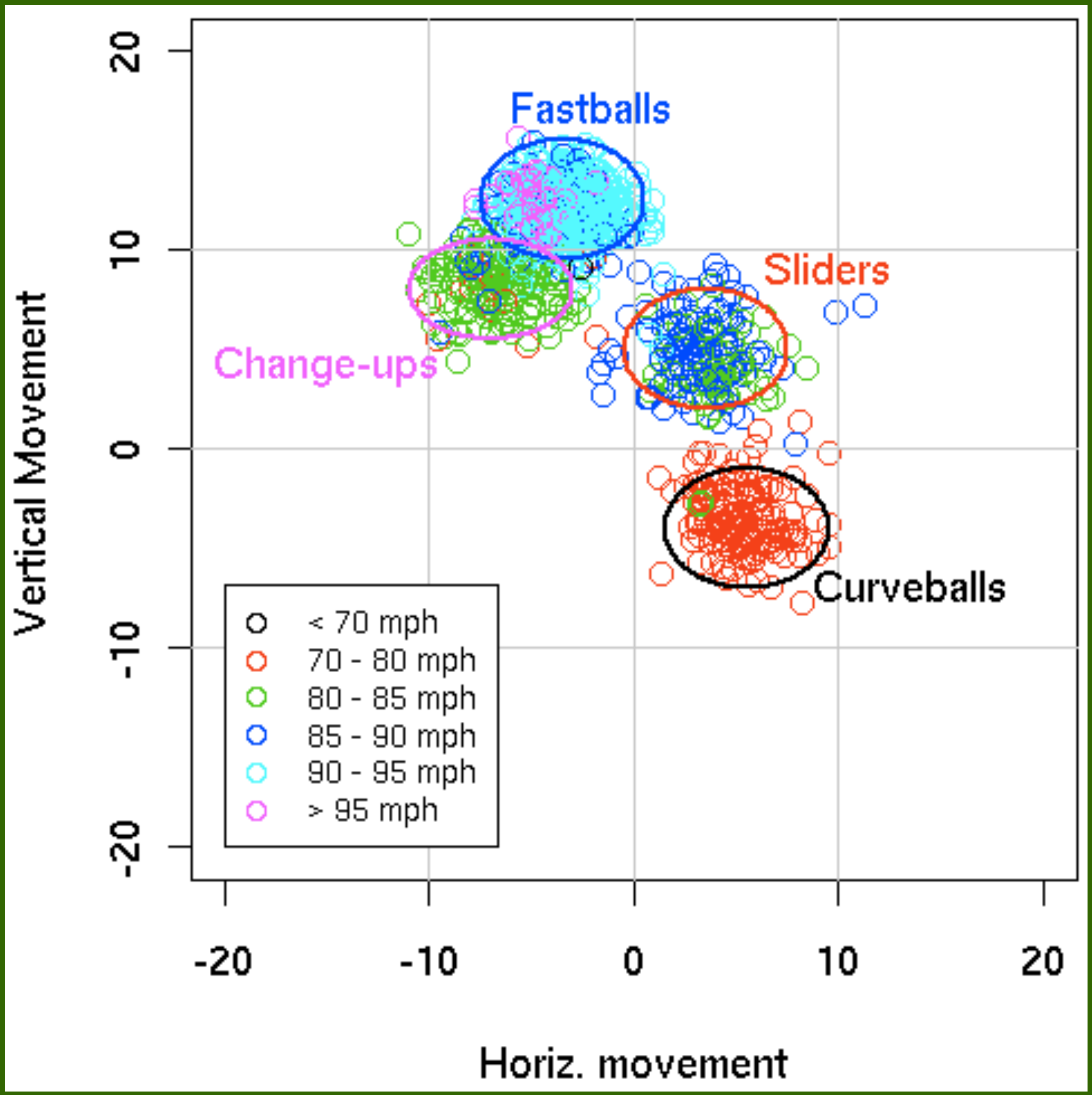
How PITCHf/x Works

How PITCHf/x Works

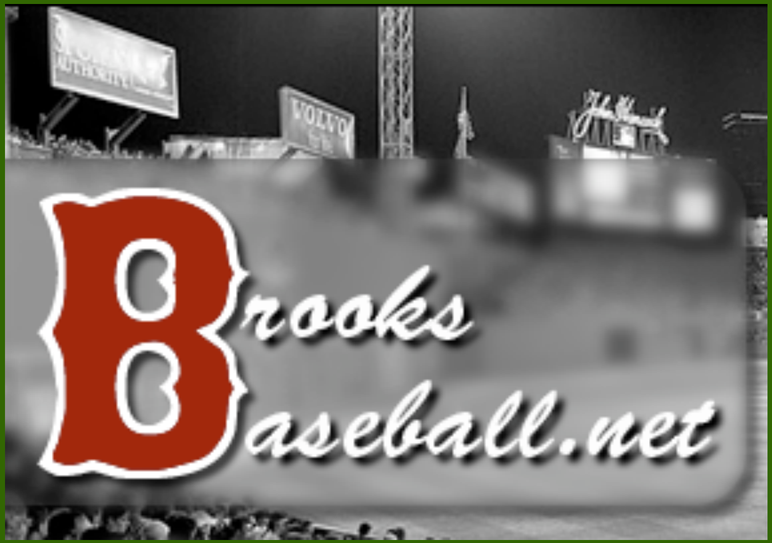
MLB Gameday


Scoreboard
Standings
Stats
Schedule
Players
News
Damon bedevils Sox as Yankee

Stat-heads Have A Field Day



Stat-heads Have A Field Day



Stat-heads Have A Field Day

Getting the Data

- 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).
- 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.

Getting the Data

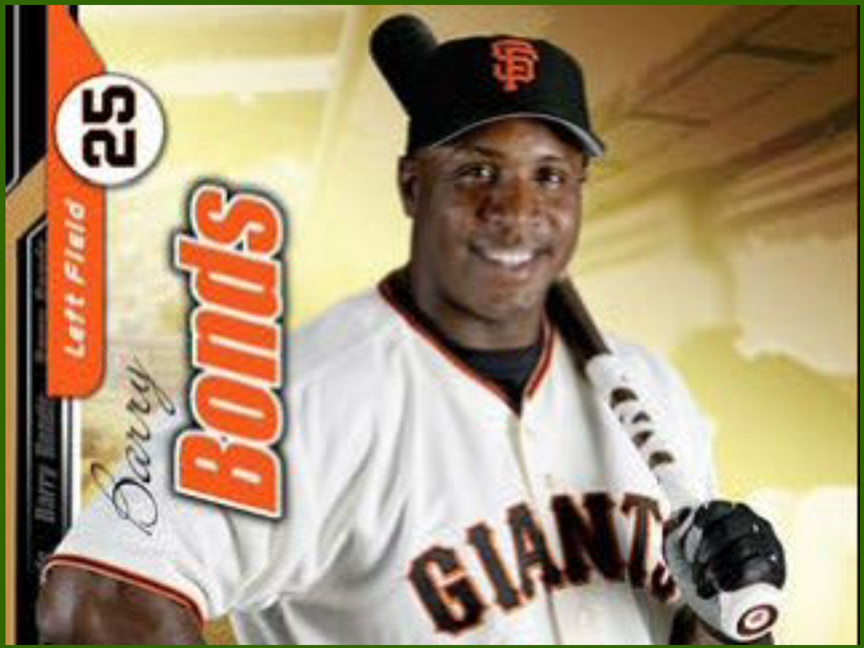
- You will be in a data file that looks like this:


```
- <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">
```

A Fun Pitch to Study

A Fun Pitch to Study

Not Just a Slugger…



An Example

Here's the data….


```xml
<atbat num="46" b="3" s="2" o="1" batter="111188" pitcher="407194" des="Barry Bonds homers (23) on a fly ball to
right center field. " stand="L" event="Home Run" score="T">
  <pitch des="Ball" id="365" type="B" x="159.66" y="118.29" start_speed="84.1" end_speed="77.7" sz_top="3.836"
  sz_bot="1.79" pfx_x="6.762" pfx_z="10.279" px="-1.798" pz="3.681" x0="1.306" y0="50.0" z0="6.852"
  vx0="-9.683" vy0="-122.951" vz0="-4.355" ax="10.389" ay="23.528" az="-16.307" break_y="23.8"
  break_angle="-26.7" break_length="5.1"/>
  <pitch des="Ball" id="366" type="B" x="153.65" y="178.73" start_speed="74.2" end_speed="70.0" sz_top="3.836"
  sz_bot="1.79" pfx_x="3.301" pfx_z="-1.723" px="-1.613" pz="1.093" x0="1.619" y0="50.0" z0="6.637" vx0="-7.872"
  vy0="-108.406" vz0="-3.976" ax="3.973" ay="16.921" az="-34.174" break_y="23.9" break_angle="-5.0"
  break_length="11.7"/>
  <pitch des="Called Strike" id="367" type="S" x="122.75" y="155.42" start_speed="84.8" end_speed="79.3"
  sz_top="3.836" sz_bot="1.79" pfx_x="8.742" pfx_z="8.711" px="-0.765" pz="2.094" x0="1.657" y0="50.0"
  z0="6.628" vx0="-8.769" vy0="-123.907" vz0="-7.441" ax="13.81" ay="21.027" az="-18.339" break_y="23.9"
  break_angle="-32.4" break_length="5.9"/>
  <pitch des="Foul" id="368" type="S" x="121.89" y="146.79" start_speed="84.1" end_speed="78.1" sz_top="3.836"
  sz_bot="1.79" pfx_x="7.687" pfx_z="9.036" px="-0.673" pz="2.43" x0="1.677" y0="50.0" z0="6.566" vx0="-8.152"
  vy0="-122.873" vz0="-6.332" ax="11.844" ay="22.547" az="-18.177" break_y="23.8" break_angle="-28.4"
  break_length="5.8"/>
  <pitch des="Ball" id="369" type="B" x="155.36" y="163.19" start_speed="75.3" end_speed="71.0" sz_top="3.836"
  sz_bot="1.79" pfx_x="3.443" pfx_z="-2.438" px="-1.659" pz="1.658" x0="1.536" y0="50.0" z0="6.647" vx0="-7.964"
  vy0="-110.169" vz0="-2.869" ax="4.283" ay="17.337" az="-35.133" break_y="23.9" break_angle="-5.3"
  break_length="11.6"/>
  <pitch des="Foul" id="370" type="S" x="131.33" y="159.74" start_speed="76.1" end_speed="71.8" sz_top="3.836"
  sz_bot="1.79" pfx_x="2.481" pfx_z="-2.3" px="-0.925" pz="1.884" x0="1.622" y0="50.0" z0="6.705" vx0="-6.349"
  vy0="-111.367" vz0="-2.747" ax="3.162" ay="17.2" az="-35.032" break_y="23.9" break_angle="-3.8"
  break_length="11.2"/>
  <pitch des="In play, run(s)" id="371" type="X" x="0" y="0" start_speed="84.1" end_speed="77.2" sz_top="3.836"
  sz_bot="1.79" pfx_x="8.68" pfx_z="9.55" px="-0.012" pz="2.743" x0="1.664" y0="50.0" z0="6.597" vx0="-6.791"
  vy0="-123.055" vz0="-5.721" ax="13.233" ay="25.802" az="-17.54" break_y="25.2" break_angle="-32.1"
  break_length="5.9"/>
  <runner id="111188" start="" end="" event="Home Run" score="T" rbi="T" earned="T"/>
</atbat>
```


The pitch!

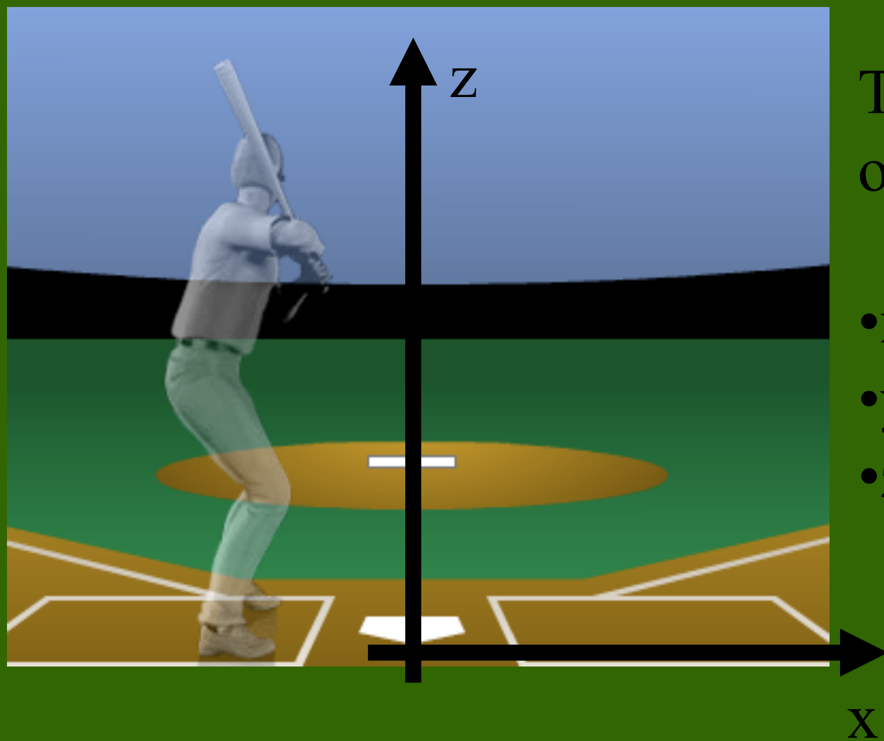
An Example

Here's the data in a readable table

No.	Quantity	Value	Units	Description
1	des	In play, run(s)		A comment on the action resulting from the pitch.
2	type	X		B=ball, S=strike, X=in play
3	id	371		Code indicating pitch number
4	x=	112.45	pixels	x-pixel at home plate
5	y=	131.24	pixels	z-pixel at home plate (yes, it is z)
6	start_speed	84.1	mph	Speed at y0=50ft
7	end_speed	77.2	mph	Speed at the front of home plate y=1.417ft
8	sz_top	3.836	ft	The z-value of the top of the strike zone as estimated by a technician
9	sz_bot	1.79	ft	The z-value of the bottom of the strike zone as estimated by a technician
10	pfx_x	8.68	in	A measure of the "break" of the pitch in the x-direction.
11	pfx_z	9.55	in	A measure of the "break" of the pitch in the z-direction.
12	px	-0.012	ft	Measured x-value of position at the front of home plate (y=1.417ft)
13	pz	2.743	ft	Measured z-value of position at the front of home plate (y=1.417ft)
14	x0	1.664	ft	x-position at y=50ft
15	y0	50.0	ft	Arbitrary fixed initial y-value
16	z0	6.597	ft	z-position at y=50ft
17	vx0	-6.791	ft/s	x-velocity at y=50ft
18	vy0	-123.055	ft/s	y-velocity at y=50ft
19	vz0	-5.721	ft/s	z-velocity at y=50ft
20	ax	13.233	ft/s/s	x-acceleration at y=50ft assumed constant.
21	ay	25.802	ft/s/s	y-acceleration at y=50ft assumed constant.
22	az	-17.540	ft/s/s	z-acceleration at y=50ft assumed constant.
23	break_y	25.2	ft	Another measure of the "break."
24	break_angle	-32.1	deg	Another measure of the "break."
25	break_length	5.9	in	Another measure of the "break."

Kinematic data

An Example



The origin is at the back point of home plate.

•x-axis - to the catcher's right
•y-axis - toward the pitcher
•z-axis - vertically upward

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

An Example

Problem 1: Find the initial speed of the ball (at y=50.0ft) in mph.

In 3-dimensions the initial speed is the magnitude of the initial velocity vector. Since the components are listed below we take the square root of the sum of their squares,

$$v_o = \sqrt{v_{ox}^2 + v_{oy}^2 + v_{oz}^2}$$

$$v_o = \sqrt{(-6.791)^2 + (-123.055)^2 + (-5.721)^2}$$

$$v_o = 123.375\,ft/s = 84.1mph$$

5	y=	131.24	pixels	z-pixel at home plate (yes, it is z)
6	start_speed	84.1	mph	Speed at y0=50ft
7	end_speed	77.2	mph	Speed at the front of home plate y=1.417ft
8	sz_top	3.836	ft	The z-value of the top of the strike zone as

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

An Example

Problem 2: Find the components of the final velocity of the pitch when it reaches the front of home plate (y=1.417ft).

Since we know the initial and final y-values we can get the y-component of the velocity using the kinematic equation,

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

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

$$v_y = -\sqrt{(-123.055)^2 + 2(25.802)(1.417 - 50.00)}$$

$$v_y = -112.408\, ft/s$$

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

v_x = ?

v_y = -112.408ft/s

v_z = ?

An Example

Problem 2: Find the components of the final velocity of the pitch when it reaches the front of home plate (y=1.417ft).

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

$$v_y = v_{oy} + a_y t$$

$$t = \frac{v_y - v_{oy}}{a_y}$$

$$t = \frac{-112.408 - (-123.055)}{25.802}$$

$$t = 0.4127s$$

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

v_x = ?

v_y = -112.408ft/s

v_z = ?

An Example

Problem 2: Find the components of the final velocity of the pitch when it reaches the front of home plate (y=1.417ft).

Having the time of flight and using kinematic equations for the other two axes,

$$v_x = v_{ox} + a_x t = -6.791 + (13.233)(0.4127) = -1.330\, ft/s$$

$$v_z = v_{oz} + a_z t = -5.721 + (-17.540)(0.4127) = -12.960\, ft/s$$

$$t = 0.4127 s$$

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

v_x = ?1.330ft/s

v_y = -112.408ft/s

v_z = ?12.960ft/s

An Example

Problem 2: Find the components of the final velocity of the pitch when it reaches the front of home plate (y=1.417ft).

The final speed is the magnitude of the final velocity vector. Taking the square root of the sum of the squares,

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

$$v = \sqrt{(-1.330)^2 + (-112.408)^2 + (-12.960)^2}$$

$$v = 113.160\, ft/s = 77.2 mph$$

5	y=	131.24	pixels	z-pixel at home plate (yes, it is z)
6	start_speed	84.1	mph	Speed at y0=50ft
7	end_speed	77.2	mph	Speed at the front of home plate y=1.417ft
8	sz_top	3.836	ft	The z-value of the top of the strike zone as

t = 0.4127s

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

v_x = -1.330ft/s

v_y = -112.408ft/s

v_z = -12.960ft/s

An Example

Problem 3:Since a typical batter doesn't get a sense of the motion of the pitch until the ball is about 40ft away from home plate, find the time to get there and the x and z components of the position and velocity when it arrives.

The time can be found using the kinematic equation,

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

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

$$t_{40} = \frac{-(-123.055) - \sqrt{(-123.055)^2 - 2(25.802)(50-40)}}{(25.802)} = 0.08197s$$

$$t_{40} = 0.08197s$$

t = 0.4127s

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

t_{40} = 0.08197s

x_{40} = ?

v_{x40} = ?

z_{40} = ?

v_{z40} = ?

An Example

Problem 3: Since a typical batter doesn't get a sense of the motion of the pitch until the ball is about 40ft away from home plate, find the time to get there and the x and z components of the position and velocity when it arrives.

The x-position and velocity can now be found,

$$x_{40} = x_o + v_{ox}t_{40} + \tfrac{1}{2}a_x t_{40}^2 = 1.664 + (-6.791)(0.08197) + \tfrac{1}{2}(13.233)(0.08197)^2 = 1.152\,ft$$

$$v_{x40} = v_{ox} + a_x t_{40} = -6.791 + (13.233)(0.08197) = -5.706\,ft/s$$

as can the z-position and velocity,

$$z_{40} = z_o + v_{oz}t_{40} + \tfrac{1}{2}a_z t_{40}^2 = 6.597 + (-5.721)(0.08197) + \tfrac{1}{2}(-17.540)(0.08197)^2 = 6.069\,ft$$

$$v_{z40} = v_{oz} + a_z t_{40} = -5.721 + (-17.540)(0.08197) = -7.159\,ft/s$$

t = 0.4127s

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

t_{40} = 0.08197s

x_{40} = 1.152ft

v_{x40} = -5.706ft/s

z_{40} = 6.069ft

v_{z40} = -7.159ft/s

An Example

Problem 4: Now that the batter has a sense of the position and velocity of the ball, he can begin to plan his swing. If the ball only felt gravity in the z-direction and no force in the x-direction from this point on, where would it cross home plate.

The time of flight from y=40ft can be found from by subtracting the total time from the time to get to y=40ft,

$$t_h = t - t_{40} = 0.4127 - 0.08197 = 0.3307s$$

$t = 0.4127s$ $t_h = 0.3307s$

$x_o = 1.664ft$	$v_{xo} = -6.791ft/s$	$a_x = 13.233ft/s^2$
$y_o = 50.00ft$	$v_{yo} = -123.055ft/s$	$a_y = 25.802ft/s^2$
$z_o = 6.597ft$	$v_{zo} = -5.721ft/s$	$a_z = -17.540ft/s^2$

$t_{40} = 0.08197s$

$x_{40} = 1.152ft$

$v_{x40} = -5.706ft/s$

$z_{40} = 6.069ft$

$v_{z40} = -7.159ft/s$

An Example

Problem 4: Now that the batter has a sense of the position and velocity of the ball, he can begin to plan his swing. If the ball only felt gravity in the z-direction and no force in the x-direction from this point on, where would it cross home plate.

Along the x-direction there would be no acceleration,

$$x_{noair} = x_{40} + v_{x40}t_h + \tfrac{1}{2}a_x t_h^2 \Rightarrow x_{noair} = 1.152 + (-5.706)(0.3307) = -0.735\,ft$$

Along the z-axis there would only be gravitational acceleration,

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

$$z_{noair} = 6.069 + (-7.159)(0.3307) + \tfrac{1}{2}(-32.174)(0.3307)^2 = 1.942\,ft$$

$t = 0.4127s$ $t_h = 0.3307s$ $x_{noair} = -0.735ft$ $z_{noair} = 1.942ft$

$x_o = 1.664ft$	$v_{xo} = -6.791ft/s$	$a_x = 13.233ft/s^2$
$y_o = 50.00ft$	$v_{yo} = -123.055ft/s$	$a_y = 25.802ft/s^2$
$z_o = 6.597ft$	$v_{zo} = -5.721ft/s$	$a_z = -17.540ft/s^2$

$t_{40} = 0.08197s$

$x_{40} = 1.152ft$

$v_{x40} = -5.706ft/s$

$z_{40} = 6.069ft$

$v_{z40} = -7.159ft/s$

An Example

Problem 5: Batters describe the effect of spin on the ball as the "break." One way to analytically define the break is the difference between where the ball actually arrives and where is would have arrived only feeling gravity. Find the break along the x and z directions.

The actual x and z positions are in the data table.

12	px	-0.012	ft	Measured x-value of position at the front of home plate (y=1.417ft)
13	pz	2.743	ft	Measured z-value of position at the front of home plate (y=1.417ft)

px = -0.012ft pz = 2.743ft

t = 0.4127s t_h = 0.3307s x_{noair} = -0.735ft z_{noair} = 1.942ft

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

t_{40} = 0.08197s

x_{40} = 1.152ft

v_{x40} = -5.706ft/s

z_{40} = 6.069ft

v_{z40} = -7.159ft/s

An Example

Problem 5: Batters describe the effect of spin on the ball as the "break." One way to analytically define the break is the difference between where the ball actually arrives and where is would have arrived only feeling gravity. Find the break along the x and z directions.

This definition of break can now be calculated for the x and z directions.

$$x_{break} = px - x_{noair} = -0.012 - (-0.735) = 0.723\,ft = 8.68\,in$$

$$z_{break} = pz - z_{noair} = 2.743 - 1.942 = 0.801\,ft = 9.61\,in$$

10	pfx_x	8.68	in	A measure of the "break" of the pitch in the x-direction.
11	pfx_z	9.55	in	A measure of the "break" of the pitch in the y-direction.

px = -0.012ft pz = 2.743ft

t = 0.4127s t_h = 0.3307s x_{noair} = -0.735ft z_{noair} = 1.942ft

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

t_{40} = 0.08197s

x_{40} = 1.152ft

v_{x40} = -5.706ft/s

z_{40} = 6.069ft

v_{z40} = -7.159ft/s

A Word About Forces

Problem 6: Given the weight of a baseball is 0.320lbs, find the x, y, and z components of the force exerted on the ball by the air during its flight.

Use Newton's Second Law along each direction. Along x and y the only force is due to the air,

$$F_x = ma_x = mg\left(\frac{a_x}{g}\right) = (0.320)\left(\frac{13.233}{32.174}\right) = 0.132lbs$$

$$F_y = ma_y = mg\left(\frac{a_y}{g}\right) = (0.320)\left(\frac{25.802}{32.174}\right) = 0.257lbs$$

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

F_x = 0.132lbs

F_y = 0.257lbs

F_z = ?

A Word About Forces

Problem 6: Given the weight of a baseball is 0.320lbs, find the x, y, and z components of the force exerted on the ball by the air during its flight.

Along z gravity is also in play,

$$F_z - mg = ma_z \Rightarrow F_z = mg + mg\left(\frac{a_z}{g}\right) = mg\left(1 + \frac{a_z}{g}\right) = (0.320)\left(1 + \frac{-22.232}{32.174}\right) = 0.146 lbs$$

The magnitude of the force caused by the air is,

$$F_{air} = \sqrt{F_x^2 + F_y^2 + F_z^2} = \sqrt{(0.132)^2 + (0.257)^2 + (0.146)^2} = 0.324 lbs$$

The force exerted by the air is about equal to the weight!

x_o = 1.664ft	v_{xo} = -6.791ft/s	a_x = 13.233ft/s^2
y_o = 50.00ft	v_{yo} = -123.055ft/s	a_y = 25.802ft/s^2
z_o = 6.597ft	v_{zo} = -5.721ft/s	a_z = -17.540ft/s^2

F_x = 0.132lbs

F_y = 0.257lbs

F_z = 0.146lbs

Summary

- PITCHfx data can provide a wealth of interesting real world problems (and answers) for your students.

Resources

For more ideas of how to use baseball to teach physics, check out….

phys.csuchico.edu/baseball