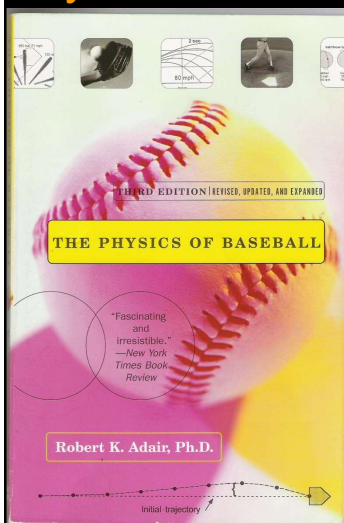


Science of Baseball with Some Strategy: Hitting, Pitching and Fielding

Horace Hines, Ph. D.

1

The Physics and Baseball by Robert Adair, Ph.D.



Models and analyzes the game – not an exact science
Gives lots of interesting estimates.

Air motion around a round ball with stiches is not well understood.

Action of an ash bat on a ball can only be approximated

2

2

References

- <http://webusers.npl.illinois.edu/~a-nathan/pob/>
 - Links to several good sites
- <http://lokeshdhakar.com/baseball-pitches-illustrated/>
- <http://phys.csuchico.edu/baseball/> David Kagan
 - Contains a number of links to demonstrations under the section "Some Baseball Papers from *The Physics Teacher*"
- *Data on Pitch movement -*
<http://www.brooksbaseball.net>

3

Outline

- Hitting example
- Pitching – Strike zone, Forces, ball movement,
- Hitting – Timing and bat
- Flight of the ball
 - Fielding a fly ball

4

Questions

- How many played baseball?
- How many have watched baseball?
 - How many watched the Giants win the World Series?
- How many baseball fans?
- How many Giants fans?

- Baseball is a complicated game with many different strategies dependent upon
 - Batter capabilities
 - Pitcher capabilities
 - Team fielding
 - Number of out / people on base

5

Hitting example setup Up to Oct. 22, 2012

- Giants vs Reds (best 3 out of 5)
 - Giants lost first 2 at home and went to Cincinnati
 - Had to win 3 in a row – at 50% → 1 in 8 probability
 - Giants won 3 in a row!!!

- Giants vs Cardinals (best 4 out of 7)
 - Giants almost out of playoffs – Cards 3, Giants 1
 - Must win 3 in a row – at 50% → 1 in 8 probability
 - Giants won 2 and need one more

6

Game 7 NLCS – Giants vs Cardinals

- Winner will take the series – must win
- Bottom of 3rd Inning- Cards 0, Giants 2
- Giants have bases loaded no outs
- Card's Joe Kelly (pitching) – good pitch
- Giant's Hunter Pence (hitting) – good hit?
- Pete Kozma (shortstop) – good fielder

7

Yogi Bera

“You can observe a lot by just watching.”

8

Hunter Pence Triple hit



9

Note bat flexes and breaks – First contact
SS sees contact, note ball position



10

Second contact – bat rebounds into ball

2



11

Third contact – rotation of bat hits ball off the end (spin to ball)

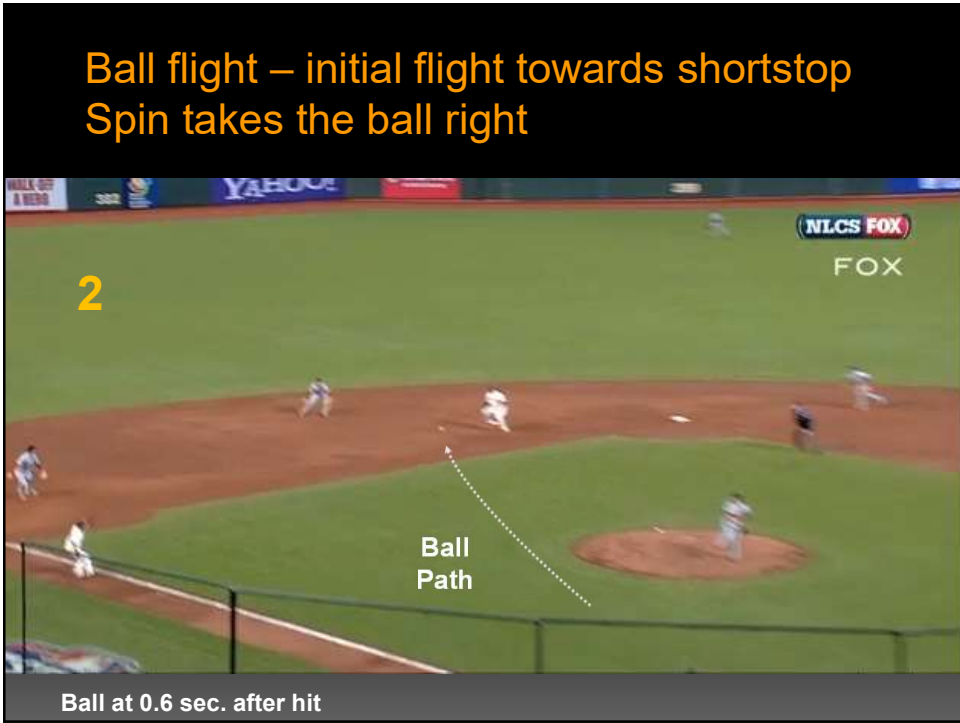
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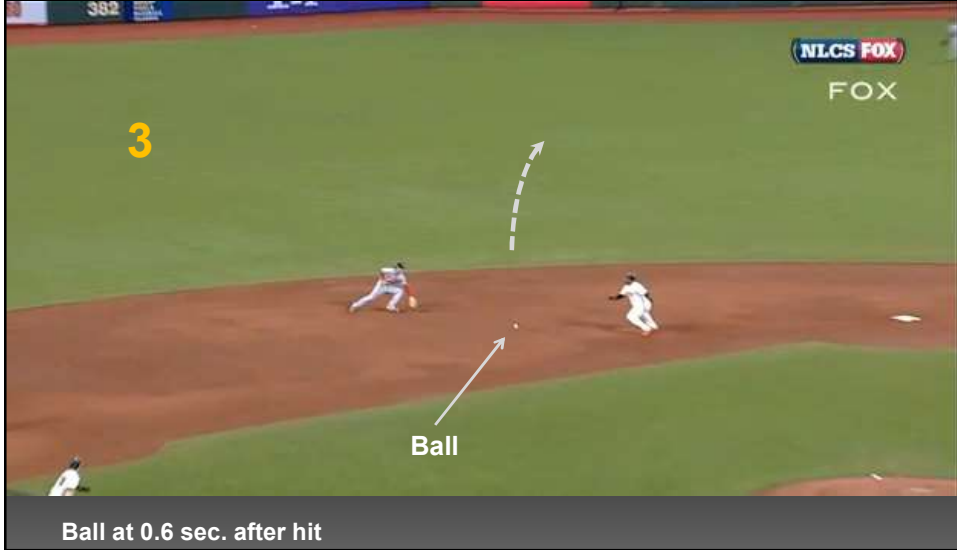


13

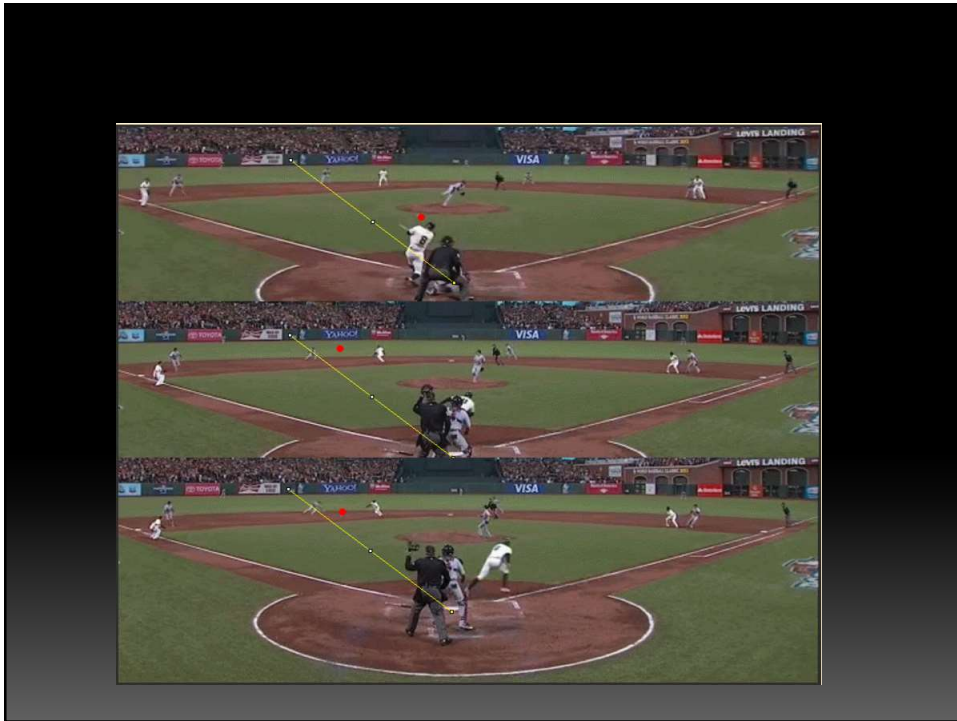


14

Ball flight – ball spins more to right into center field



15



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Outline

- Hitting example
- Pitching – Strike zone, Forces, and Ball movement,
- Hitting – Timing and bat
- Flight of the ball
 - Fielding a fly ball

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Pitching – Throw the ball in to or close to the strike zone

- What is the zone?
- What are forces on the ball?
- Why does the ball curve?
- What can pitchers accomplish with different pitches?

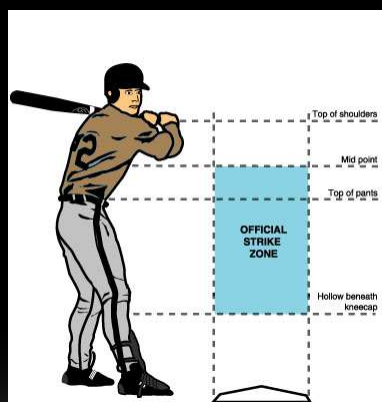
18

Strike zone since 1996



19

Strike Zone since 1996



- Area over home plate
 - Upper limit - horizontal line at the midpoint between the top of the shoulders and the top of the uniform pants, and
 - Lower level - line at the hollow beneath the knee cap."
- Determined when batter is prepared to swing.

Strike if any part of the ball passing through any part of the strike zone

20

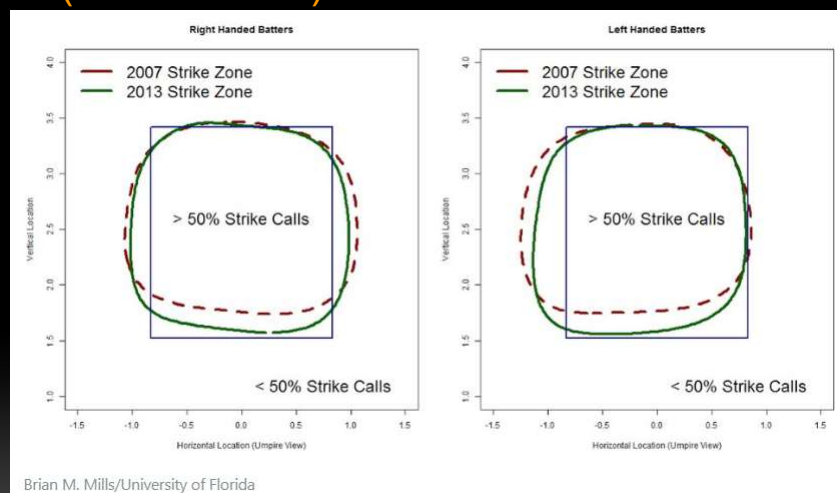
Changes to strike zone

Year	Zone	Reason
1876	Batter calls high, low, fair pitch	“First” definition
1887	Shoulders to knees	“Modern” definition
1889	Walk is 4 balls	
1950	Smaller -Armpits to top of knees	Increase scoring
1963	Larger -Top of shoulder to knees	Marris 60 home runs
1969	Smaller Armpits to top of knees	Pitcher domination
1988	Smaller -Midpoint between top of shoulders and belt to top of knees	Increase scoring
1996	Larger Expanded to bottom of knees	

http://www.baseball-almanac.com/articles/strike_zone_rules_history.shtml

21

“Strike” is what an umpire calls (catcher view)



Umpires 86.41% accurate ($SD = 0.014$) in 2014 PITCHf/x data.

<http://www.businessinsider.com/mlb-strike-zone-2014-9>

22

Baseball philosopher – Yogi Bera

Baseball is ninety percent mental
and the other half is physical.

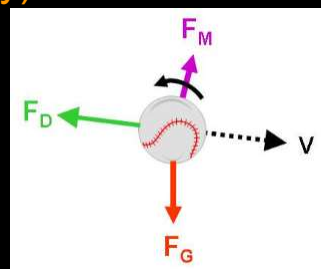
In theory, there is no difference between
theory and practice.

In practice there is.

23

Forces on ball (Change direction or velocity)

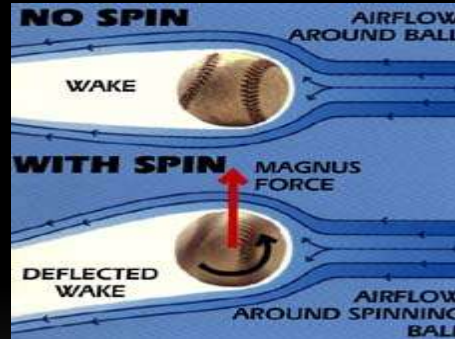
- **Gravity – downward motion**
 - Ball falls after thrown or hit (90 mph 27")
 - "Rising" fastballs fall but not as much
- **Drag – slows the ball (~ 8 mph)**
 - Ball pushes air out of the way – like swimmer in water
- **Spin – Magnus force**
 - Causes curving or "rising" motion since always perpendicular to the direction of motion (+/- 20")
 - Under-spin keeps hit in the air longer (+5" vs. gravity)
 - Over-spin causes ball to drop (-20" vs. gravity)



24

Why does a baseball change direction?

- Forces
 - Gravity – (down)
 - Spin – Magnus force perpendicular to spin and velocity
- Slows down
 - Air resistance
 - Fastball ~ 8 mph



$$\text{Magnus force} = S (\omega \times v)$$

Cross product of **angular velocity** vector (ω) and **velocity** vector (v) where S is dependent on the air resistance coefficient across the surface of the object.

http://w3.shorecrest.org/~Lisa_Peck/Physics/syllabus/phases/gases/gaswp05/justin1/home.html

25

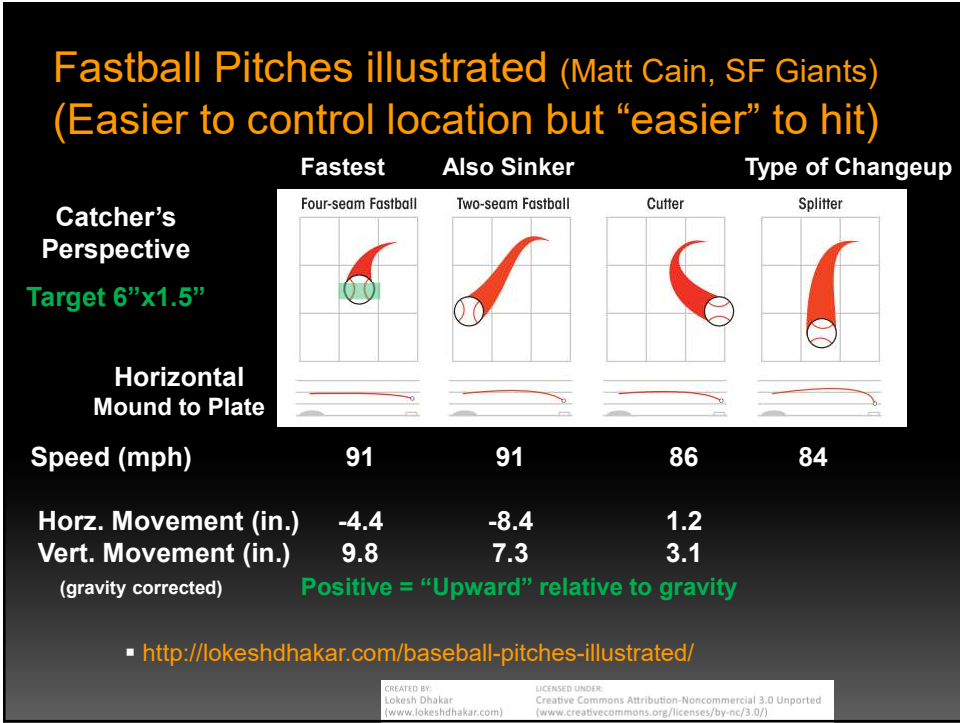
Pitch finger positions (on ball and seams)

- Break depends on finger locations; plus arm and wrist action; and finger pressure
- Fastballs and changeup put backspin – against gravity
- Hide ball to keep from telegraphing pitch

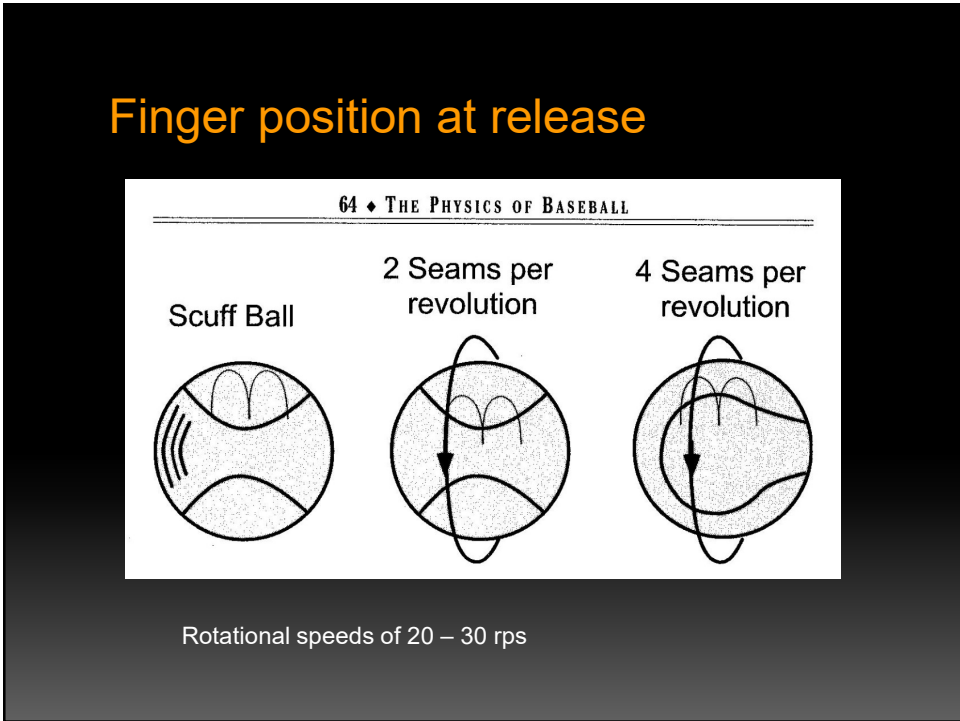


Rotational speeds of 20-30 rps
<http://redlegnation.com/2015/04/08/the-cincinnati-pitching-arsenal-repertoire-for-every-reds-starter/>

26



27

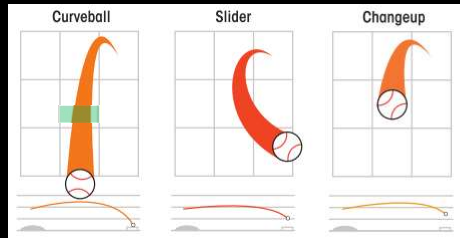


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Common Breaking Ball Pitches (controlling placement is the issue)

Batter's
Perspective

Horizontal
Mound to Plate



	Curveball	Slider	Changeup
Speed (mph)	77	86	86
Horz. Movement	6	2.7	-6.9
Vert. Movement	-5.5	2.2	3

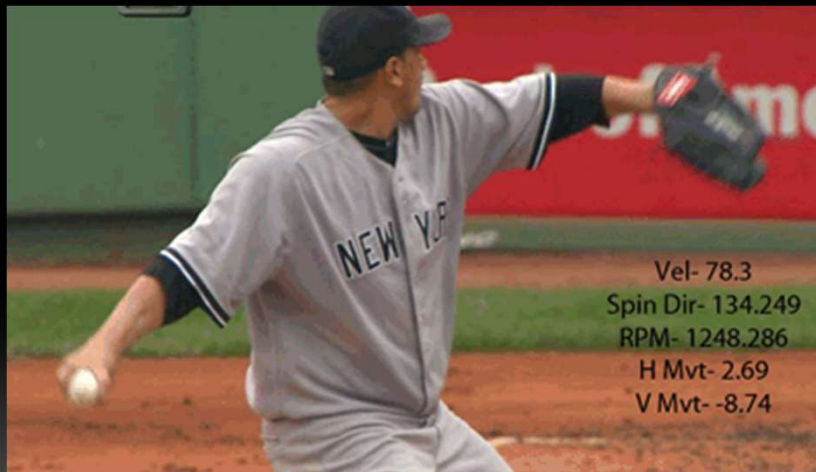
- <http://lokeshdhakar.com/baseball-pitches-illustrated/>
- <http://www.efastball.com/baseball/pitching/grips/average-pitching-speed-by-age-group/>

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Freddy Garcia Splitter



Vel- 78.3
Spin Dir- 134.249
RPM- 1248.286
H Mvt- 2.69
V Mvt- -8.74

<http://www.yankeeanalysts.com/2012/07/freddy-garcias-swing-ball-blowing-peoples-minds-42745>

30

Info to incorporate

	Fourseam	Change	Slider	Curve	Cutter	Slow Curve
4/16	90.93	82.76	0.00	73.17	86.66	0.00
5/16	92.19	83.80	0.00	75.21	88.06	0.00
6/16	91.90	84.40	0.00	76.11	88.28	0.00
7/16	91.31	84.89	0.00	75.93	87.56	0.00
8/16	91.57	84.31	0.00	74.87	87.42	0.00
9/16	91.98	84.40	0.00	76.17	87.38	70.38
10/16	92.27	84.75	0.00	77.49	87.90	0.00
	Fourseam	Change	Slider	Curve	Cutter	Slow Curve
2/17	91.36	86.44	0.00	77.56	87.30	0.00
4/17	92.45	84.20	0.00	78.72	88.18	0.00

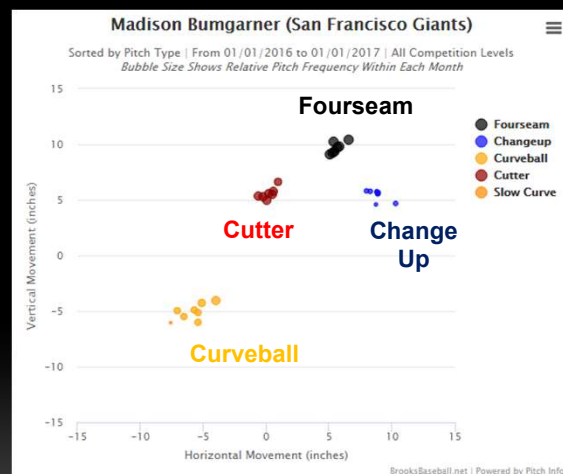
31

Pitch movement – Inches! (Madison Bumgarner– Giant’s left handed pitcher)

■ Catchers view



- Fourseam – 48%
 - Cutter – 33%
 - Changeup – 3%
 - Curveball -16%
- Batter goal < 1”

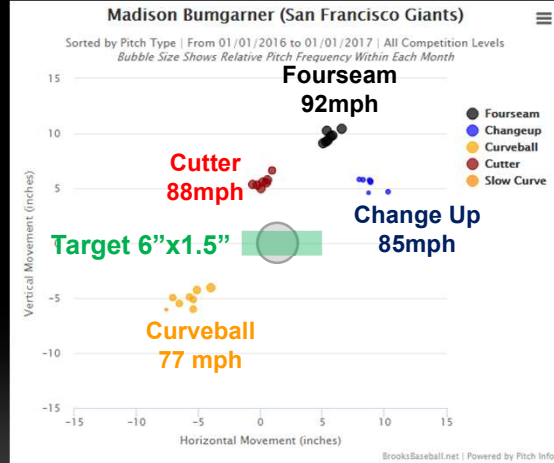
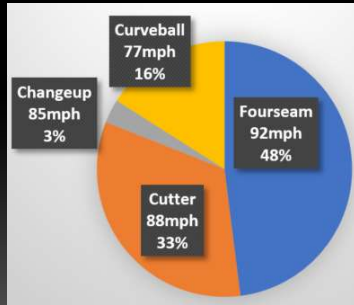


Movement from spin only!

32

Pitch movement – Inches! (Madison Bumgarner – Left handed pitcher)

■ Catchers view

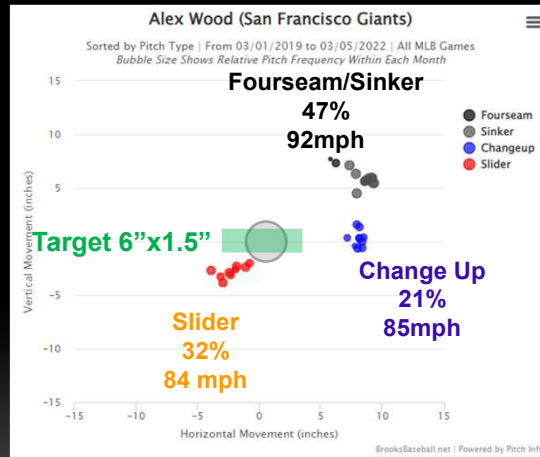


Batter goal < 6" horizontal by 1.5 vertical"
Movement from spin only!

33

Pitch movement – Inches! (Alex Wood – Left handed pitcher)

■ Catchers view



Batter goal < 6" horizontal by 1.5 vertical"
Movement from spin only!

34

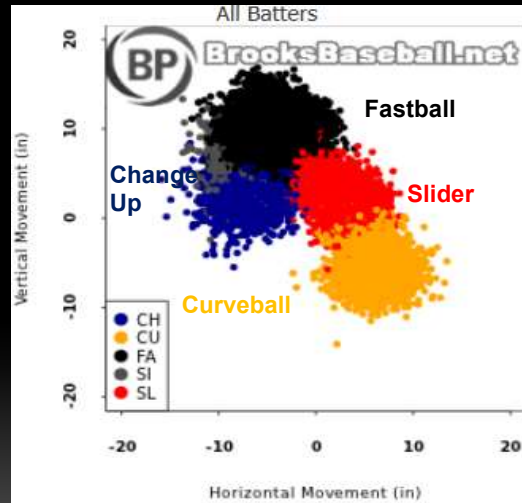
Pitch movement – Inches!

(Matt Cain – Giant's right handed pitcher)

- Catchers view



- Central location 0,0
 - Higher is less drop
 - Corrects 10" gravity drop
- Batter goal < 1"

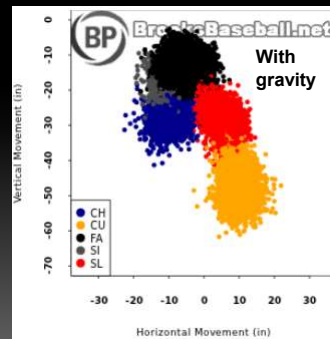
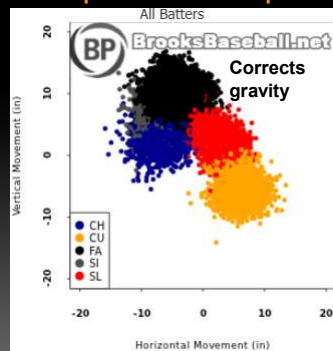


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Pitch movement

(Matt Cain – Giant's right handed pitcher)

- Catchers view
- Central location
 - Includes gravity
 - Ball thrown at center
 - "Up" is less drop



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Youtube slider video – note spin



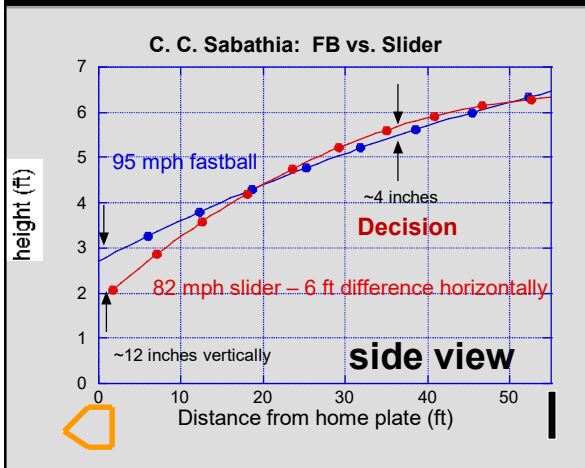
▪ http://www.youtube.com/watch?feature=player_detailpage&v=RHMS071GYw0

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What makes an effective slider

Josh Kalk, THT, 5/22/08

The Hardball Times



- **Fastball vs Slider**
- **Effective due to**
 - Appearance at up to 25' from batter
 - Velocity difference 13 mph (~ 6 ft.)
 - Vert. Movement ~12"

Nathan - APS-March10-v6 38

38

Pitching goal and strategy: Hitters off-balance (Timing & Location)

- At 0-0 (Balls-Strikes) pitcher is ahead
 - Use off-speed stuff early (change up, curve)
- Throw change up on any count – disrupt timing

- At 2-0 - Batter ahead (Fastball counts) throw 2-seam for strikes
- Runners in scoring position–low pitch → ground out

- **DON'T BE PREDICTABLE**
 - Change pitch level
 - Different sides of plate
 - Change speeds

http://www.thecompletepitcher.com/pitching_strategy.htm

39

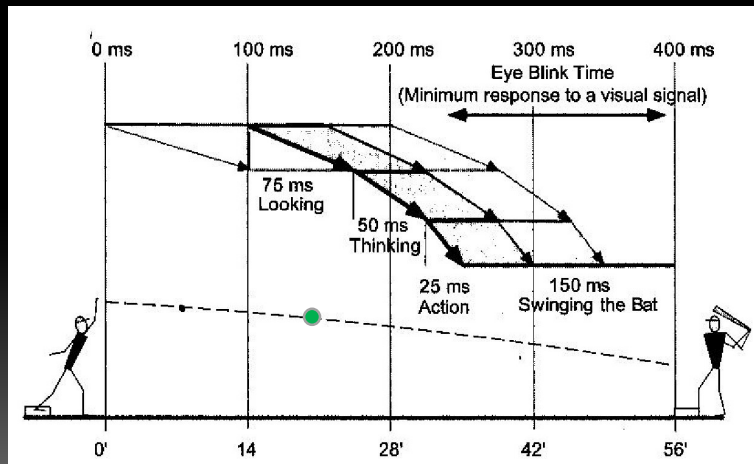
Outline

- Hitting example
- Pitching – Strike zone, Forces, movement,
- Seventh inning stretch
- Hitting – Timing and bat
- Flight of the ball
 - Fielding a fly ball

40

Timing of batter (90 mph pitch – 400 msec)

- Brain perceives where the ball used to be
 - 100 msec for images to get from eye to brain (14')
 - About 75 msec to decide and start swing!!
 - 150 msec to swing



41

Warren Spahn

“Hitting is timing. Pitching is upsetting timing.”



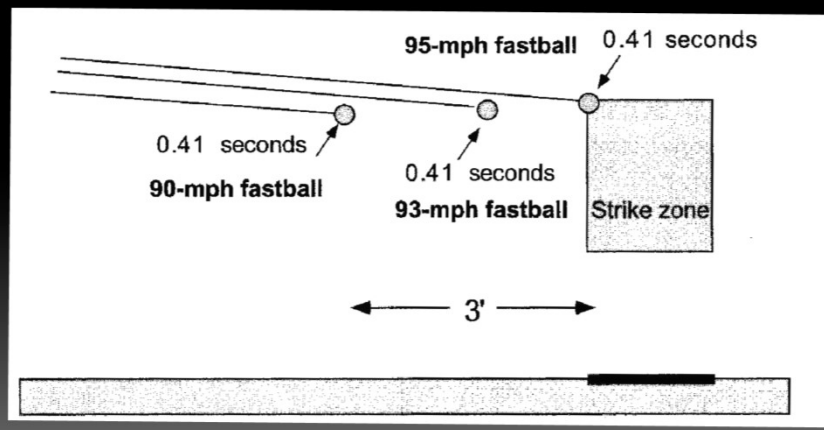
APS/DFD, Nov. 2009

42

42

What distance difference does speed make?

- Five mph = 36" distance difference



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Hitting – note ball deformation

- Change ball direction
- Add speed – energy transfer bat to ball
 - Velocity of pitch
 - Bat speed
- Timing – in front of body but not too far
- Location – sweet spot of bat
 - ~6" from end and ~6" wide
 - About 1.5" wide top-bottom
 - Home run - 100 mph ball hit at 29 ± 5 degrees.

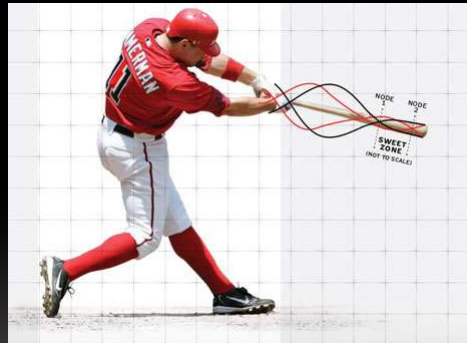


A remarkable photo showing the ball in contact with the bat (used with permission from the Champaign News-Gazette).

44

Ball – Bat and Swing Dynamics

- Batter
 - Bat speed
 - Bat mass – lighter is easier to position (32 oz. optimum)
 - Too light – less energy transfer
 - Too heavy – hard to swing
 - Sweet spot positioning (4.5-7" from end)

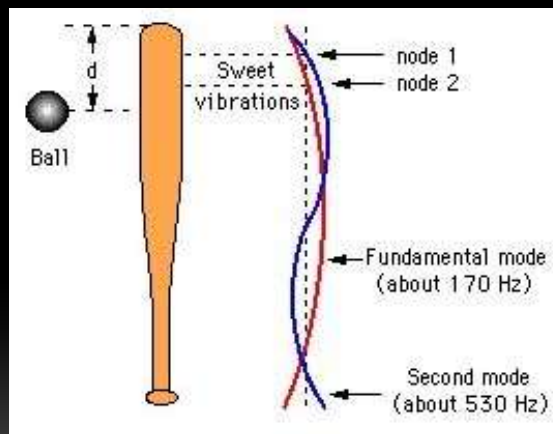


<http://www.popularmechanics.com/outdoors/sports/physics/4216783>

45

Bat "Sweet Spot" (6.7" (17cm) from end of bat)

- Collision causes bat to vibrate
- Vibrations absorb energy
- Hitter wants ball contact at sweet spot



46

Baseball Bat

- Batted Ball speed
 - $BBS = q * (\text{pitch speed}) + (1+q) * (\text{bat speed})$
 - Faster the pitch, faster the ball comes out
 - $Q =$ collision efficiency (about 0.2 at sweet spot)
- If q goes from 0.2 to 0.22 for 85 mph pitch, bat speed of 70 mph, gives 18 additional feet

47

BBCOR – Bounciness of ball-bat collision (Nathan)

- Bat and ball (50%) compression
- Trampoline effect
- $BBCOR_{\text{wood}} = 0.5$
- $BBCOR_{\text{metal}} = 0.55$
 - 5 mph faster – 40 ft.!
- MOI – add comments from comparing the performance of BB bats



A remarkable photo showing the ball in contact with the bat (used with permission from the Champaign News-Gazette).

http://baseballanalysts.com/archives/2010/01/comparing_the_p.php

48

Aluminum vs Wood Baseball bats

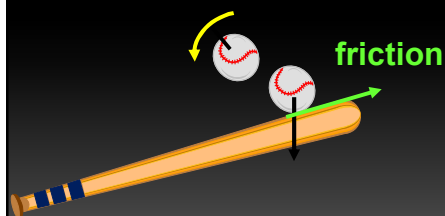
Parameter	Wood	Aluminum
Swing speed	Lower – heavier Weight at end of bat	Lighter Weight at hands
Energy transfer		Higher – greater coefficient of restitution
Size of sweet spot	Smaller – multiple vibrational modes or oscillations	Larger
Durability	Break (higher expense)	Don't break – save \$\$

2011 - NCAA required metal bats to perform like wood

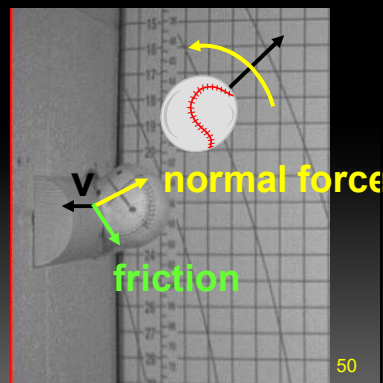
49

Putting Spin on Batted Balls

- Undercutting → backspin (ball in air longer)
- Overcutting → topspin (makes ball drop)
- In front or behind plate → sidespin
 - sideways foul ball



Nathan
APS/DFD, Nov. 2009



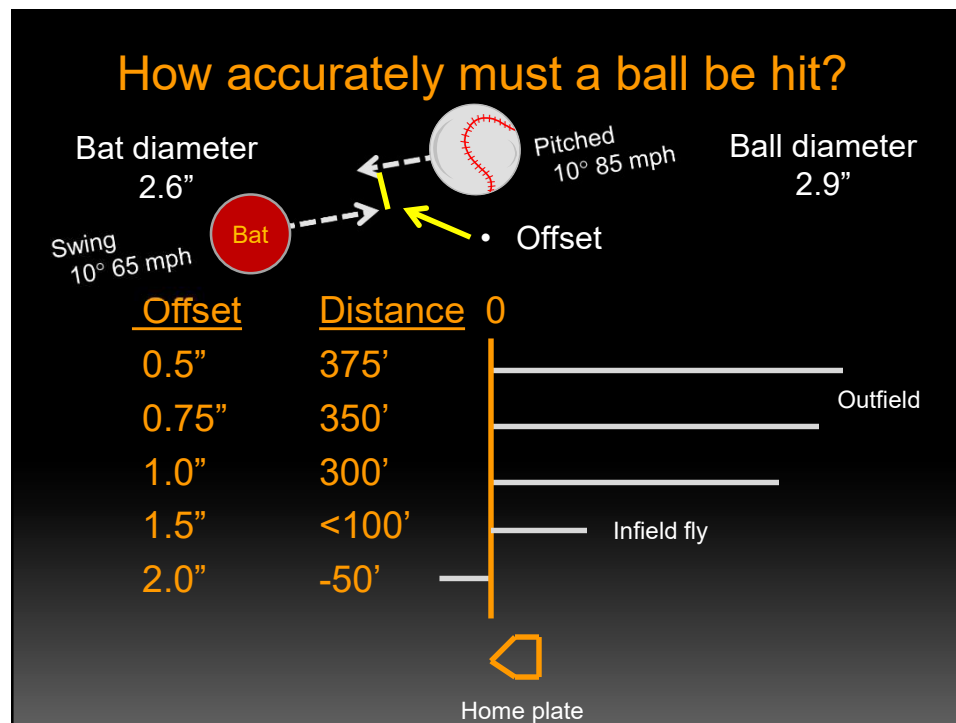
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50

Outline

- Hitting example
- Pitching – Strike zone, Forces, movement,
- Hitting – Timing and bat
- Flight of the ball
 - Fielding a fly ball

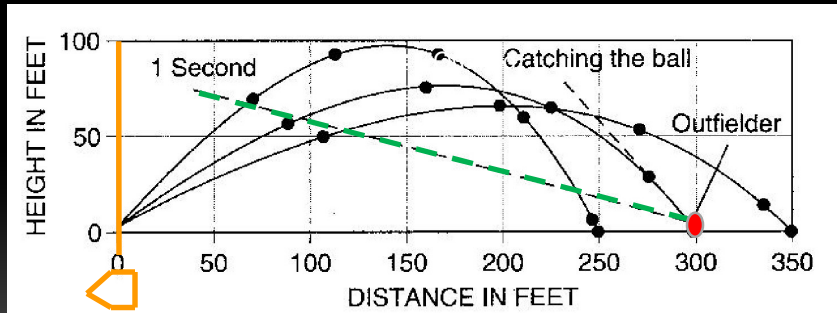
51



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Outfield fielding example

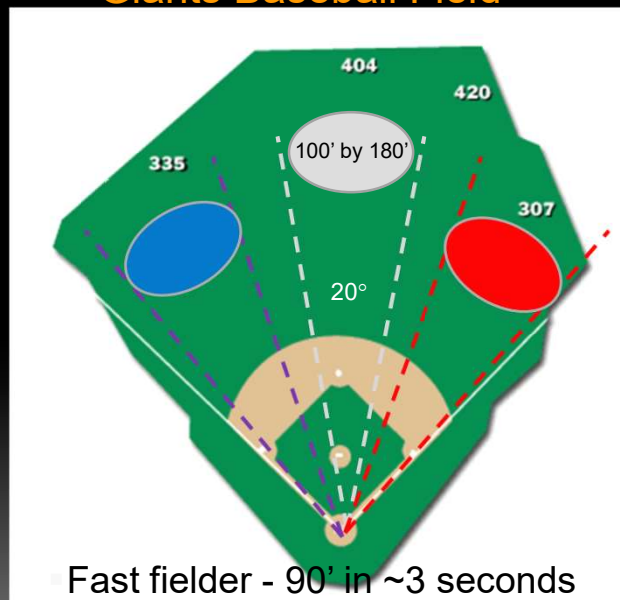
- Balls hit at fielder look same for first second
- Ball in air 4.5 to 5 seconds
- Fast fielder can cover ~90' in ~3 seconds



Home plate

53

Will ball be caught? Giants Baseball Field



Fast fielder - 90' in ~3 seconds

outfield coverage
for a line drive
(4.7 sec. hang
time)

Hang time (sec.)

- 250' 5.0
- 300' 4.6
- 350' 4.3

- Faster judging
of off line balls
- 90' to the side

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Summary

- Hitting example – sometimes strange things happen
- Pitching – disrupt timing, avoid bat sweet spot
 - Good pitching beats good hitting most of the time.
- Hitting – Difficult timing, position the bat sweet spot
 - If you only fail 70% then VERY successful!
- Flight of the ball – field is well covered

- Hope this makes baseball more interesting and enjoyable

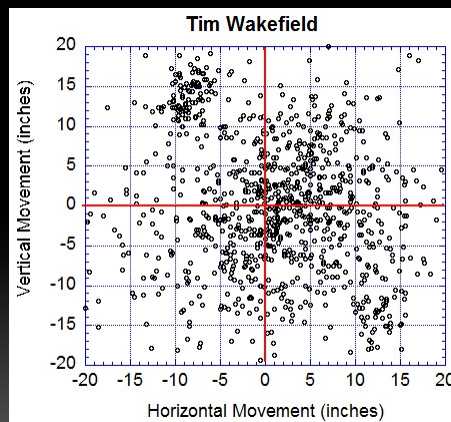
- Giants won the World Series in 2010, 2012 and 2014!!
- Go Giants in 2023



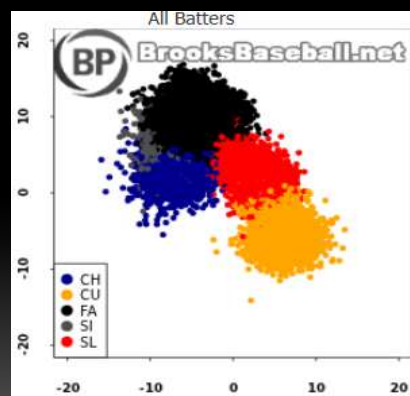
55

The Knuckleball

- Tim Wakefield - a knuckleball pitcher:
- Chaotic Movement



Matt Cain



56

56

Take home points

- Pitchers have multiple advantages over hitters
- Hitting the ball is hard
- Physics of baseball is difficult, not totally understood but interesting
- **Go Giants**