The Physics of the Longest Possible Homer

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How far can a major leaguer actually hit a ball? According to Baseball Almanac there have been many claims like these listed in table 1 below.

Date	Batter	Stadium	Distance
April 17, 1953	Mickey Mantle	Griffith Stadium, Washington	565 ft
May 6, 1964	Dave Nicholson	Comiskey Park, Chicago	573 ft
June 8, 1926	Babe Ruth	Navin Field, Detroit	600 ft
Sept. 10, 1960	Mickey Mantle	Briggs Stadium, Detroit	600 ft
May 22, 1963	Mickey Mantle	Yankee Stadium, New York	620 ft
April 14, 1976	Dave Kingman	Wrigley Field, Chicago	630 ft

Table 1: Baseball Almanac's list of the longest homers

Since 2006 ESPN Home Run Tracker has scientifically calculated the distance for every homer. At the end of 2015 they have data for a bit in excess of 48,000 round-trippers. There have only been about 275,000 homers hit since 1900. Remarkably, ESPN Home Run Tracker has data for more than 17% of all homers ever launched.

The longest on ESPN Home Run Tracker? A blast by Adam Dunn in Chase Field in Arizona on September 27, 2008 with the roof closed totaling 504 feet. This is the only homer in excess of 500 feet in the entire collection. The second longest was 498 feet by Matt Holliday in the rarified air of Coors Field. There have only been about fifty long balls of 475 feet or more since 2006.

Simple(?) Statistics

We can make an estimate of the number of homers ever hit that were longer than 500 feet by saying that this happens roughly one in 48,000 times. Since 1900 there have been about 275,000 so there may have been six homers hit in excess of 500 feet.

We can go a little deeper with the statistics before we delve into the physics. If you toss a coin the chances of heads are 50/50. If you toss two coins, there is a 25% chance you'll get no heads, a 50% chance you'll get one head, and a 25% chance you get two heads. You can continue doing this with more and more coins. If you want to know how to calculate the odds each time google "Binomial Distribution."

Figure 1 is a chart showing the results of tossing ten coins at a time and repeating the task 5000 times. As you would guess, the mostly like situation – the tallest bar – is at five heads. Four heads or six heads are equally likely, but less likely than five. It is so unlikely that all ten coins come up heads that you can't even see it on the graph. This will probably happen about five times out of the 5000 tosses.

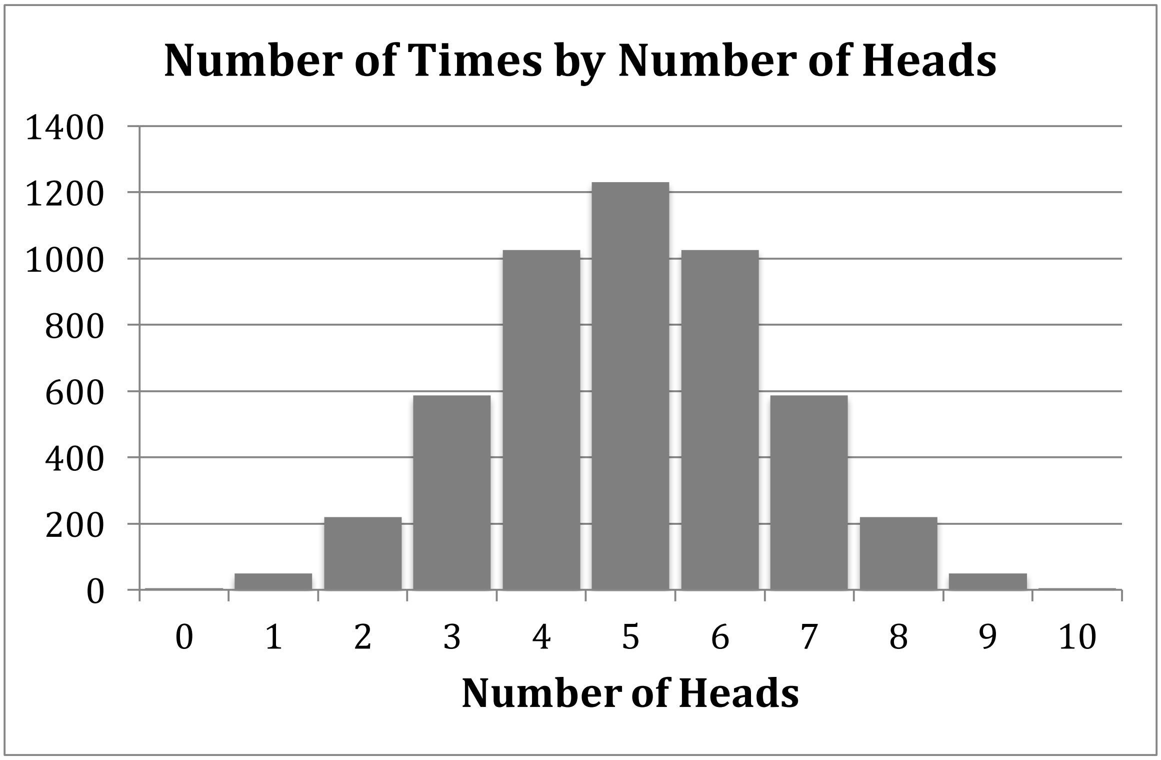

Figure 1: The results for tossing ten coins 5000 times listed by the number of heads in each toss.

What does this have to do with home runs? Well, Figure 2 is a chart tabulating the nearly 5000 homers listed on ESPN Home Run Tracker in the year of Dunn's blast - 2008. This chart looks remarkably similar to the coin toss chart above. Some of the similarity is because of a bit of trickery on my part. However, it illustrates a point I'm trying to make.

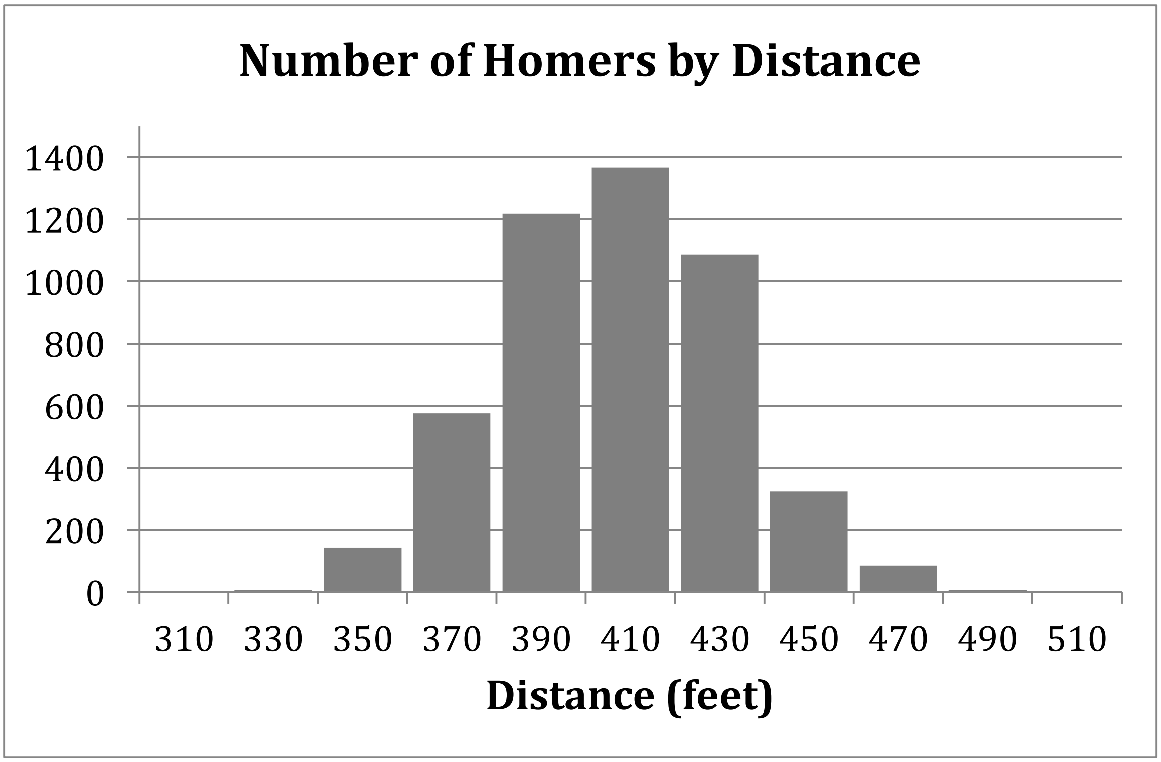

Figure 2: The results for tossing ten coins 5000 times listed by the number of heads in each toss.

The shape of the coin toss chart has several names: "Normal Distribution" or "Normal Curve" or simply "The Curve" – as in "Do you grade on the curve?" So, your teacher was grading based upon the statistical rules for coin tossing as opposed to the quality of your work – very reassuring! Anyhow, there is a very well known method for estimating the probability of an event from the normal distribution.

For the Dunn Dinger, the chance estimated by the distribution is only 0.0013%. That's pretty darn small. Another way of thinking about it is that it is equivalent to one 504ft bomb out of every 79,000 home runs. At this rate you would only expect about three shots of this length out of all the homers ever hit.

For Mickey's 565 footer from table 1 the chances are only 0.000000002% or one in 50 billion homers. Those odds are even longer than the probability of hitting the Mega Millions Jackpot!

Statistics is fun as far as it goes, but there are subtle differences between the coin toss and the homer charts. The coin toss chart is completely symmetric. It is just as hard to toss only three heads as it is to get seven. However, 370 foot homers are far more likely than 450 foot blasts. In fact, longer homers are always harder to hit than shorter ones.

Some of the discrepancy is due to the fact that a 370 footer is not always a homer, but no park can contain a 450 footer. However, more 370 footers fly balls counted as homers would result in an even more skewed chart. There must be something deeper going on. The asymmetry of the curve hints at some physical explanation – let's explore.

Simple(?) Physics

Newton's Laws tell us the ball will do what it does because of the forces that act on it. The sketch shows these forces as solid straight arrows. The dashed arrow represents the velocity of the ball, while the circular arrow indicates the backspin on the ball.

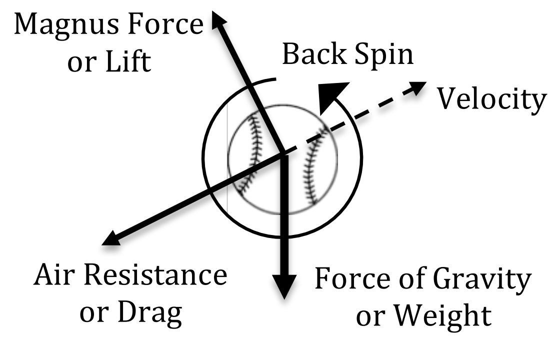

Figure 3: The forces on a ball inflight with backspin are lift, drag, and weight.

There are two things that exert forces on a long fly ball; Earth pulls it down and the air pushes it around. Gravity is relatively straight forward, but the force air exerts on the ball is complex and subtle. That's part of the reason that the force exerted by the air is usually considered as two distinct forces, the drag (or air resistance) and the lift (or Magnus force).

The gravitational force or weight always pulls the ball downward. Rule 1.09 requires the weight to be "not less than five nor more than 5 1/4 ounces." In other words, the weight of the ball is between 0.31 and 0.33 pounds. The batter has no control over the force of gravity on the ball.

Air resistance or drag always acts opposite the velocity of the ball. Drag, as the name implies, slows the ball down. It is caused by the ball having to move the air in front of it out of the way. You have experienced air drag every time you stuck your hand out the window of a moving vehicle. The force the air exerts on your hand can be quite strong at highway speeds that incidentally are around the average speed of a homer in flight. A batter has no control over the drag – the harder they hit it, the more drag there will be.

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 the sketch is moving mostly up the page and slightly to the left, matching the direction of the lift.

The backspin on a well-hit fly ball will result in an upward Magnus force or lift. This lift will keep the ball from falling as fast as gravity demands. So a fly ball can, under the right circumstances, travel further at the same speed if it has more backspin. The Magnus force is the one force the batter has some control over by creating more backspin.

In summary, the drag will tend to slow the speed and lower the distance of a fly ball. On the other hand, backspin on the ball will result in an upward Magnus force helping the ball stay in the air longer and, under the right conditions, go further.

For the simplified model we'll discuss here, the distance a ball will travel before hitting the ground depends upon the speed it leaves the bat (launch speed), the angle it leaves the bat (launch angle), and the amount of backspin on the ball.

To create backspin, the ball must collide with the top half of the bat as shown in Figure 3. The frictional force between the bat and ball will cause the ball to develop backspin, while the perpendicular (often called "normal") force will cause the ball to head off toward the outfield.

If the center of the ball collides with the center of the bat, there will be little frictional force. The result will be a line drive with almost no backspin. On the other extreme, when the bottom of the ball collides near the top of the bat, the result will be a ball headed toward the backstop with lots of backspin. The point is, there must be some connection between the launch angle of the ball and the resulting backspin.

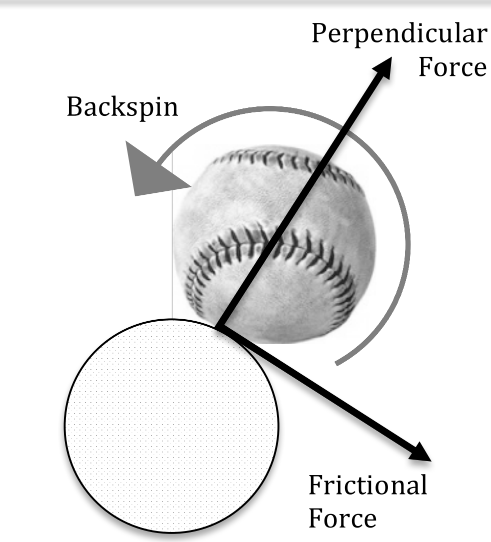

Figure 4: The ball moving to the left collides with the top half of the bat.

In addition, the outgoing speed of the ball depends upon where it strikes the bat. If the center of the ball collides with the center of the bat, the ball will head off with the largest speed, but it will have too low a launch angle for a homer. On the other hand if the ball strikes higher up on the bat, the ball will have a higher launch angle, but less speed.

The point is that not all high-speed launches will be homers. Table 2 is the data from MLB's Statcast Leaderboard from the 2015 showing all balls hit with recorded speed over 116 mph. Only three of the twenty-nine are long balls.

Velocity (mph)	Batter	Result
120.3	Stanton, Giancarlo	Single
119.7	Stanton, Giancarlo	Double
119.2	Stanton, Giancarlo	Home Run
119.0	Cruz, Nelson	Single
118.5	Stanton, Giancarlo	Home Run
118.5	Stanton, Giancarlo	Single
117.7	Trout, Mike	Single
117.3	Stanton, Giancarlo	Single
117.3	Stanton, Giancarlo	Double
117.1	Stanton, Giancarlo	Single
117.1	Gonzalez, Carlos	Field Out
117.0	Stanton, Giancarlo	Single
116.7	Gonzalez, Carlos	Single
116.6	Ramirez, Hanley	Field Out
116.6	Davis, Chris	Double
116.5	Rodriguez, Alex	Home Run
116.5	Trumbo, Mark	Single
116.5	Ramirez, Hanley	Single
116.4	Stanton, Giancarlo	Field Out
116.3	Stanton, Giancarlo	Field Out
116.3	Stanton, Giancarlo	Single
116.3	Bautista, Jose	Field Out
116.2	Soler, Jorge	Double
116.1	Stanton, Giancarlo	Double
116.1	Stanton, Giancarlo	Single
116.1	Garcia, Avisail	Double
116.1	Peralta, David	Field Out
116.0	Peguero, Carlos	Single
116.0	Harper, Bryce	Double

Table 2: The fastest balls off the bat from MLB's Statcast Leaderboard for 20015

So, it takes a very special combination of launch speed, launch angle, and backspin to clear the fences. All three of these parameters depend upon where the bat collides with the ball.

Alan Nathan and others conducted experiments to work out the details of the collision. Applying their findings to a fastball coming in a 100mph with a 2000rpm backspin colliding with a bat moving horizontally at 75mph gives the results in the table 3.

Center-to-center height (in)	Launch Speed (mph)	Launch Angle (deg)	Backspin (rpm)	Landing Distance (ft)
0	123.9	-2.5	-398	48.8
0.2	123.5	3.2	817	227.2
0.4	122.5	8.9	2031	458.9
0.6	120.9	14.7	3245	516.7
0.8	118.6	20.6	4459	513.2
1	115.7	26.7	5673	484.0
1.2	112.1	33.2	6887	438.3
1.4	107.7	39.9	8102	381.1
1.6	102.4	47.3	9316	311.8

Table 3: The launch speed, launch angle backspin and total distance for a 100mph with 2000rpm of backspin colliding with a bat moving horizontally at 75mph.

The first column is the vertical distance between the center of the ball and the center of the bat. So for the case of the bat striking the ball dead center, it has the highest launch speed, the launch angle is slightly negative due to the backspin from the pitch, and the ball develops topspin causing it to land in the infield.

As the center-to-center height increases, the launch speed drops slowly as the launch angle and backspin rise. The distance the ball goes at first increases to a bit over 500 feet. Then it decreases because it is hit at too high a launch angle.

You might notice the calculated backspin just keeps getting bigger and bigger. Most physicists, even the ones that made the measurements to build this theory of the ball-bat collision, believe these spins to be too large. Also, most measurements indicate that a batter can't get the bat quite up to 75 mph and fastballs rarely exceed 100 mph. So, if anything these homerun distances are over estimates.

Table 4 below is for a curveball thrown at 85 mph thrown with 2000rpm of topspin and the bat moving horizontally at 75 mph. The results a very similar and again we see the maximum distance a bit over 500 feet.

Center-to-center height (in)	Launch Speed (mph)	Launch Angle (deg)	Backspin (rpm)	Landing Distance (ft)
0	119.8	2.6	398	156.6
0.2	119.6	8.0	1508	395.7
0.4	118.8	13.4	2618	489.1
0.6	117.4	19.0	3728	505.3
0.8	115.4	24.6	4838	489.5
1	112.7	30.5	5948	455.3
1.2	109.4	36.7	7058	408.6
1.4	105.2	43.3	8168	350.4
1.6	100.2	50.4	9278	282.7

Table 4: The launch speed, launch angle backspin and total distance for a curveball thrown at 85 mph thrown with 2000rpm of topspin and the bat moving horizontally at 75 mph.

Let's double-check these results by using data from ESPN Home Run Tracker. The top five launch velocities for 48,000 homers at ESPN Home Run Tracker are listed in the Table 5. It is interesting to note that Dunn's homer is not even on the list.

Date	**Batter**	**Distance (ft)**	**Launch Speed (mph)**	**Launch Angle (deg)**
4/19/06	Reggie Abercrombie	485	122.1	28.3
4/20/10	Mark Reynolds	481	122.3	27.4
7/19/08	Jeremy Hermida	441	122.3	21.7
10/2/09	Wladimir Balentien	495	122.3	27.5
5/21/12	Giancarlo Stanton	462	122.4	25.3

Table 5: The five highest launch speeds from ESPN Home Run Tracker.

The launch angles for these blasts are all much higher than the calculated values from the theory. This is another indication that the backspin from the theory is an over estimate.

One could argue The Mick simply hit the ball harder than anyone before or after. If so, how much harder would have had to hit it to go say 600 feet? Using the mean values of around 4000rpm and 21.2˚, the speed off the bat would have to have been 137mph. It seems pretty unlikely that Ole Number Seven could have hit the ball 12% faster than anyone has in the last 48,000 homers.

The predictions of the physics despite the issue of over-estimated backspin, is remarkably consistent with the results from ESPN Home Run Tracker at least as far as the maximum possible homer. It seems that the limit is somewhere a bit above 500 feet.

So, it seems that 600 footers are out of the question. One factor we haven't taken into account is a stiff outgoing wind. Let's examine that issue.

Simple(?) Weather

If you read about wind for a while, you'll stumble across the Beaufort Scale developed in 1805 by Sir Francis Beaufort of the U.K. Royal Navy. I guess meteorologists are as crazy about numbers as baseball nuts. This fellow categorized winds as indicated in the chart below.

Scale Value	Speed (mph)	Name	Conditions
0	< 1	Calm	Smoke rises vertically.
1	1-3	Light air	Smoke drifts and leaves rustle.
2	4-6	Light breeze	Wind felt on face.
3	7-10	Gentle breeze	Flags extended, leaves move.
4	11-16	Moderate breeze	Dust and small branches move.
5	17-21	Fresh breeze	Small trees begin to sway.
6	22-27	Strong breeze	Large branches move, wires whistle, umbrellas are difficult to control.
7	28-33	Near gale	Whole trees in motion, inconvenience in walking.
8	34-40	Gale	Difficult to walk against wind. Twigs and small branches blown off trees.
9	41-47	Strong gale	Minor structural damage may occur (shingles blown off roofs).
10	48-55	Storm	Trees uprooted, structural damage likely.
11	56-63	Violent storm	Widespread damage to structures.
12	64+	Hurricane	Severe structural damage to buildings, wide spread devastation.

It stands to reason that a tailwind would propel a ball further. Here's the physics. Both the drag and the Magnus force depend upon the speed of the ball with respect to the air. As a result, both forces are smaller with a tailwind. So, the ball feels less lift tending to shorten the flight but it also feels less drag so the ball moves faster.

Which effect is more dominant? Here's the key idea. The drag force depends upon the square of the speed while the lift depends only on the speed to the first power. So, the drag gets smaller faster than the lift gets smaller. Thus, the ball will go further with a tailwind.

With that in mind, below is a plot of the distance travelled by a homer with launch speed 122mph, launch angle 27˚, and 3000rpm backspin. You can see the distance increases by a bit over four feet for every mph of wind.

Figure 5: Home run distance versus wind speed for a launch speed 122mph, launch angle 27˚, and 3000rpm backspin.

To manage a 600-foot shot, Mickey would have had to hit the ball just right with a Beaufort Scale "strong breeze" blowing at 22mph directly behind the ball. Believe it or not, you can look up the wind speed for Detroit on Sept. 10, 1960. The maximum speed was only 10mph NNE, which was in from centerfield although the ball was hit to right. At best, the ball went 550 feet.

Let's look at Dave Nicholson's 573-foot bomb on May 6, 1964 in Comiskey Park, Chicago. The average wind that day was 18mph SSW – a "fresh breeze" according to Beaufort. The wind was indeed blowing toward leftfield where the ball cleared the roof. There were gusts up to 32mph. Looking at the graph, a ball could actually go about 630 feet if it caught a 30mph tailwind. So, I guess that one could have happened.

What of the famous 502-foot "red seat" homer by Ted Williams? David Ortiz, a prodigious power-hitter and an amateur physicist (who knew?) was recently asked about it, "The red seat - cough — bull — cough. I don't think anyone has ever hit one there. I went up there and sat there one time. That's far, brother."

“Maybe the wind helped, but it had to be a hurricane behind it,” Ortiz claimed correctly. Well, it wasn’t a hurricane at 64-plus mph, instead there was a tailwind of about 20 mph that day, more than enough to get it there. In summary, statistical evidence as well as the underlying physics limits the longest homerun to a bit over 500 feet in still air. A well-struck ball can gain an additional 4 feet or so for every mile per hour of wind speed assuming the ball was hit in a direction to provide a tailwind.

Why don’t we see those long homers anymore? The most likely answer Is that ballparks are taller and more enclosed. The outfield seats in most parks were once very much lower than the grandstand and open to the elements. In modern parks there are huge video boards, gigantic ads, and even restaurants that block the wind.

If the actual configuration of the stadium isn’t enough to reduce the wind, the average height of buildings around the parks has grown over time. Thus, acting as additional windbreaks. If this explanation is correct, the era of homers much over 500 feet may have ended.

References

Alan Nathan has a nice discussion of the Mantle homer at Griffith’s Stadium on his web site: http://baseball.physics.illinois.edu/mantle565.html.

ESPN Home Run Tracker at: http://www.hittrackeronline.com

MLB.com Statcast Leaderboard is at http://m.mlb.com/statcast/leaderboard#exit-velo

Alan M. Nathan et al., “Spin of a batted baseball,” Procedia Engineering 34 (2012) 182 – 187 Available at http://baseball.physics.illinois.edu/ProcediaEngineering34Spin.pdf

"Ted Williams, Fenway Park, June 9, 1946" at ESPN Home Run Tracker! Link: http://www.hittrackeronline.com/historic.php?id=1946_2

“Ted Williams’s blast remains Fenway Park benchmark,” by Alex Speier, Boston Globe, July 13, 2015. Link: http://www.bostonglobe.com/sports/2015/07/13/why-aren-there-more-foot-home-runs/RYL4nuQcFltbTsf0lwABiK/story.html?event=event25#