The Physics of Baseball Turf

Introduction

Ball-surface interactions are a very important part of the game of baseball. Defensive players in the field position their body and glove in anticipation of catching a bouncing ball after it leaves the ground. The ability of the defensive player to correctly play the ball depends on the ball-surface interaction replicating the players past experiences. If the player's training has been on natural grass surfaces, the player's success when playing on synthetic turf will depend on the bounce of batted balls being similar for synthetic turf and natural grass. The design of a synthetic turf surface that meets the expectation of baseball players and coaches requires a knowledge of the physics of the ball-surface interaction. There is also a need to understand how these interactions will be different for infield hits and outfield hits. This article will discuss some of the physics involved and describe experimental techniques for comparing different synthetic turf products or synthetic turf to natural grass.

Ball Rebound

The baseball player will observe the incoming speed and incoming angle of a batted ball. The player will anticipate where to position his glove based on his experience with balls he has fielded with similar incoming speeds and angles. To allow the fielder to make the play, the ball rebound angle and rebound speed (Figure 1) should match the expectations of the fielder.

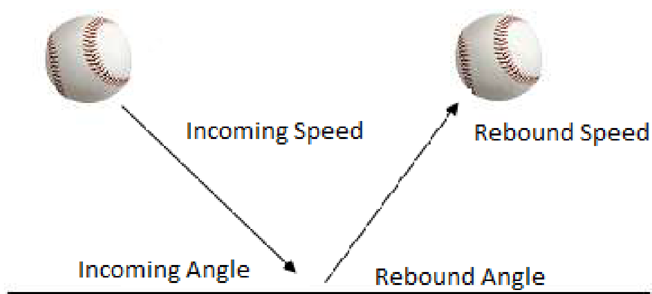


Figure 1. Baseball Rebound Parameters

The rebound speed and angle are influenced by the amount of the incoming energy of the ball being returned to the ball and by the friction forces between the ball and the surface.

Conservation of Energy

The energy contained in the incoming ball will either be absorbed by the surface or returned to the ball (Figure 2) except for the energy transformed into heat by friction between the surface of the ball and the turf surface. The energy returned will be in a force acting normal to the turf surface. A surface that has high shock absorption capability will return less energy to the ball and the rebound speed will be slower than when the interaction is with a surface that absorbs less energy.

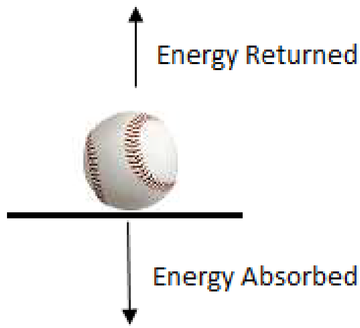


Figure 2. Energy Distribution After Impact

Surface Friction

The friction (F) between the ball and the turf surface will be a force that is opposite in direction to the incoming ball and parallel to the surface (Figure 3). The magnitude of the frictional force will depend on the incoming ball angle, the attraction between the surface of the ball with the surface of the turf, and the incoming speed of the ball. Low angle hits will have a stronger frictional interaction than high angle hits.

The scenario in Figure 3 assumes no spin on the ball with an incoming angle of θ. As the ball strikes the surface, the bottom of the ball will slow down due to the frictional force, but the top of the ball will continue at the incoming speed. This will create topspin on the ball. Having a spin on the incoming ball will, of course, change the amount of spin on the rebounded ball, but that is beyond the scope of this discussion. One observation that demonstrates the transfer of energy from the ball to the surface in synthetic turf is the splash of infill after the ball bounce. The surface of the ball that is rotating off the surface grabs infill particles and propels them in the direction opposite to the travel of the ball.

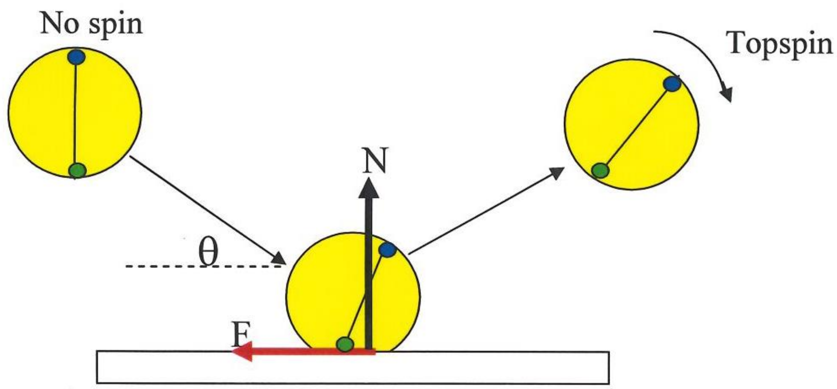


Figure 3. Frictional Force Acting on the Baseball During Contact

The location and time that the batted ball or rebounding ball will interact with the fielding player will depend on the forces acting on the ball in the air after it leaves the bat or surface. The forces acting on the ball in the air are shown in Figure 4.

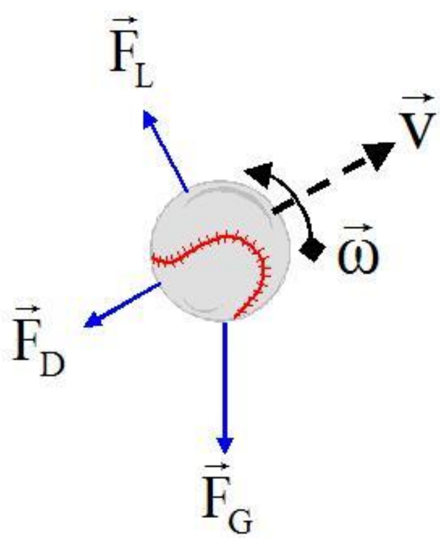


Figure 4. Forces Acting on a Baseball in the Air.

The forces that control the path of the ball are all vector quantities and defined below:

Velocity ($\vec{V}$) - the speed and direction of the ball resulting from an interaction with a bat or an interaction with the surface.

Force of Gravity ($\vec{F}_G$) a constant pull toward the ground

Drag ($\vec{F}_D$) Friction between the air and the surface of the ball. Drag acts in the opposite direction of the velocity. Drag will depend on the altitude, temperature, atmospheric pressure, and humidity.

Lift ($\vec{F}_L$) A force (called Magnus Forces) created by the interaction of the air with the spinning ball surface. The lift depends on the spin of the ball ($\vec{\omega}$). The lift force can be up or down depending on the direction of the ball spin.

Here are some general comments on baseball travel through the air:

1. Gravity is a constant pull downward. The longer the ball is in the air, the more it will be affected by gravity.
2. Drag will be lower at high altitudes, higher temperatures, lower atmospheric pressures, and lower humidity's.
3. Top spin creates negative lift and back spin creates positive lift. Batters often try to put back spin on a hit to create lift and allow the batted ball to go farther. A batted ball with no spin or top spin will have top spin after the interaction with the surface. A batted ball with top spin may have top or back spin after interacting with the surface. A surface that creates a large amount of top spin on the ball will cause ground balls to come to the fielder lower than surfaces that create less top spin.

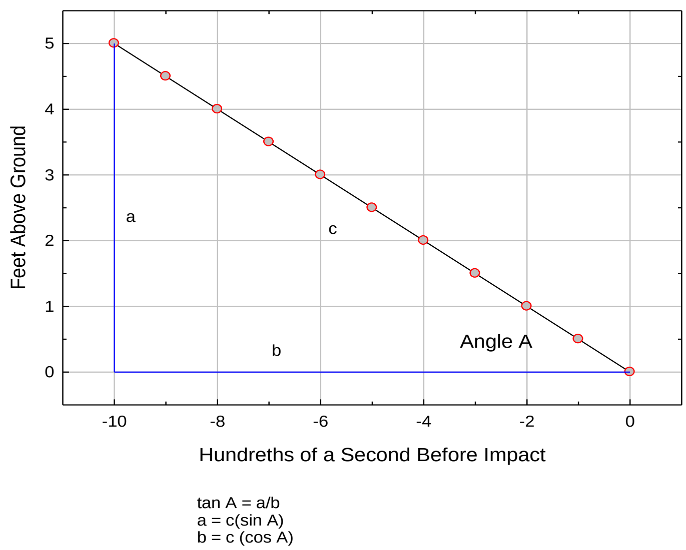
Simulation of Batted Ball Interacting with the Field Surface

To experimentally simulate batted ball interactions with a turf surface, a realistic incoming angle and incoming speed for the batted ball are needed. Dr. Alan Nathan, Professor Emeritus at the University of Illinois Department of Physics has created and shared an Excel spreadsheet (1) that calculates the position of a batted baseball after it leaves the bat. When the batted ball position has a vertical component of zero, the horizonal component will be the impact location measured from home plate. The equations in the spreadsheet calculate all forces acting on the ball in the air based on input information about the speed and angle of the ball leaving the bat as well as air properties (temperature, atmospheric pressure, relative humidity, and wind speed and direction). Professor Nathan used data from Major League Baseball's Statcast database for 2015 to get the average speed and spin of batted balls. He used atmospheric conditions of 78 ^{o}F, a stadium at sea level with no wind. With these parameters in the spreadsheet the exit angle of the ball from the bat can be varied to change the landing point of the baseball. In this way, infield grounders or fly balls to the infield or outfield can be simulated.

The University of Illinois spreadsheet calculates the position of the ball for every 0.01 seconds after impact with the bat. Due to the force of gravity acting on the ball, the path will be parabolic in nature, but for the last 0.1 second before impact, the 10 points produced can be analyzed as linear.

Plotting the last 10 points before impact (Figure 5) creates a right triangle. The values for the sides of the triangle (a and b) can be measured. Using trig functions, the ball travel distance (side c) and the impact angle (A) can be calculated. Knowing the time interval and ball travel distance, the ball speed can be calculated. The incoming angle and incoming speed for the selected locations now can be used as experimental inputs for ball rebound experiments.

Figure 5. Calculating Incoming Angle, Speed, Horizontal Velocity, and Vertical Velocity from Calculator Data



Measurable Ball - Surface Interactions

There are two main ball-surface interactions that can be studied. One will be the energy the surface absorbs or returns to the ball, which is measured as the coefficient of restitution (COR). The second will be the friction between the ball and the surface, measured as the coefficient of friction (COF). Both interactions will affect the pace (speed of the ball leaving the surface) and the bounce (the angle the ball leaves the surface). The predictability of these two interactions affect the players ability to effectively field the bouncing ball.

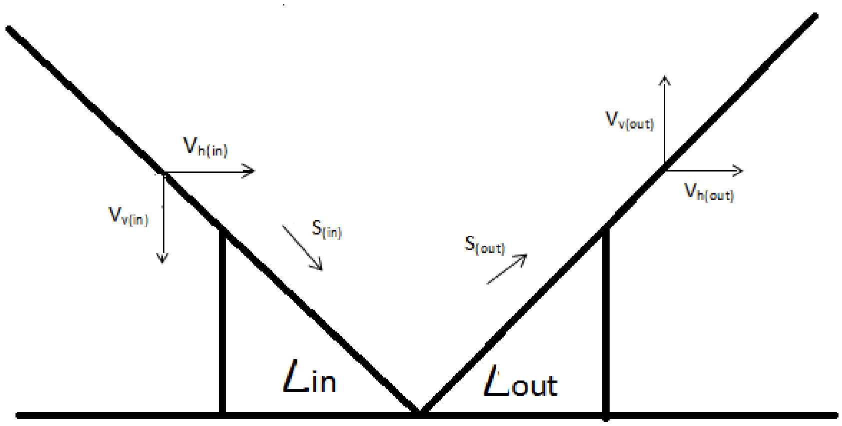
Experimental Testing of Baseball Bounce on Turf

Having determined the appropriate speed and incoming angle for batted balls striking the turf surface, experimental characterization of the surface can be accomplished by recording the path of a baseball shot onto the surface with a gas cannon or a baseball pitching machine (firing apparatus). Both these devices can deliver balls with no spin, simplifying the analysis. The flight of the ball is recorded on high speed video. The firing apparatus is positioned with the desired incoming angle and the ball speed is adjusted to match the desired incoming speed. The outlet of the firing apparatus and a device for stopping the baseball are positioned so there are enough high-speed video images to accurately measure the speed and angle of the ball just before and just after impact.

Data Analysis

The video images of the baseball before and after impact are analyzed to measure the incoming and outgoing speed and angle of the bouncing ball. These speeds and angles allow calculations of several important characteristics of the ball-surface interaction. Figure 6 shows the values that can be calculated.

Figure 6. Values derived from video data



$S_{(in)}$ = Incoming Speed
$S_{(out)}$ = Outgoing Speed
$V_{h(in)}$ = Incoming Horizontal Velocity
$V_{v(in)}$ = Incoming Vertical Velocity
$V_{h(out)}$ = Outgoing Horizontal Velocity
$V_{v(out)}$ = Outgoing Vertical Velocity
$\angle_{in}$= Angle between incoming baseball path and the ground
$\angle_{out}$ = Angle between outdoing baseball path and the ground

Four important parameters that characterize a surface can be derived from the data obtained from the video analysis. These parameters are Pace, Bounce, Coefficient of Restitution, and Coefficient of Friction. The formulas and parameters used for the calculations are shown below:

$$\text{Pace} = \frac{S_{(out)}}{S_{(in)}}$$

$$\text{Bounce} = \frac{\angle_{out}}{\angle_{in}}$$

$$\text{COR} = \frac{V_{v(out)}}{V_{v(in)}}$$

$$\text{COF} = \frac{V_{h(in)} - V_{h(out)}}{V_{v(in)} + V_{v(out)}}$$

Pace

Pace is a measure of how fast the ball comes off the surface relative to the incoming speed. If the pace of a synthetic surface is fast compared to natural grass, the player may not have his glove in position when the ball arrives. If the pace is slow compared to natural grass, the fielder may be waiting on the ball to get to his glove while the runner is getting on base. A surface with a fast pace will favor the team in the field by getting the ball to the fielder faster so that the play can be made at first base sooner.

Bounce

Bounce describes the angle the ball will bounce off the surface relative to the incoming angle. If the synthetic surface changes the spin of the ball, differently than natural turf, the bounce angle may be lower or higher than the fielder anticipates. Anticipating the wrong position for a bounce can cause mishandling of a ground ball. If that happens on natural turf, it is viewed as a “bad hop”. If it happens on synthetic turf, it is viewed as “bad turf”

Coefficient of Restitution

Synthetic turf surfaces that effectively absorb impact energy (a desirable attribute for American Football) will slow down the ball after the surface impact. One comment heard from players using this type of synthetic turf surface is that the surface “eats the bounce” of the ball. For infield and baseline areas, using a firmer turf surface with less energy absorption would be preferred. Balls hit to the outfield will come into the surface at high angles. It has been found that firm surfaces (such as the early AstroTurf knitted nylon baseball fields) returned too much energy to the ball and the bounce of a fly ball often sent the ball bouncing over the outfielder’s head or over the outfield fence. It is likely that different surfaces for the infield and outfield will be needed to optimize the performance of the turf.

Coefficient of Friction

The coefficient of friction will affect very low and very high angle hits less than mid-angle hits. Very low angle hits will spend little time in contact with the surface and may skip across the surface rather than grabbing the surface. High angle incoming balls will primarily be affected by the energy absorption and will have little horizontal movement across the surface. The mid-angle hits spend more time on the surface producing more friction with the surface. Matching the coefficient of friction of an experimental surface to a desired surface will be more important for mid-angle (infield grounder) hits than for very low or very high angle hits.

The Coefficient of Restitution and Coefficient of Friction are measures of the ball-surface interaction providing “knobs” the designer can turn. This allows the turf designer to measure improvements in performance resulting from modification of the turf.

Conclusions

For synthetic turf designers to be able to change the performance of synthetic turf for baseball to meet the needs of baseball players and coaches, appropriate characteristics of the surface must be experimentally measurable. Information provided in this report shows that experiments can be designed and conducted for hits to different ball landing locations in a baseball stadium. Use of a baseball firing apparatus and high-speed video recording equipment can provide rebound speeds and angles on different surfaces. The rebound data can be analyzed to provide quantifiable characteristics of the turf that allow modification of the surface to match the desires of the players and coaches.

1. Baseball Trajectory Calculator; A. M. Nathan, http://baseball.physics.illinois.edu/trajectory-calculator-new.html.