

# Applications of Baseball Models in Slow Pitch Softball

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**Abstract.** This study addresses the lack of physics-related research in youth slow-pitch softball by contrasting its ball sizes and ways of throwing with baseball, and applying mature physical methods (analysis for bats' sweet spots, and force-based ball motion modeling). The research aims to provide theoretical support for hitting strategies and to serve for more reasonable training, bridging the gap for this youth-dominated sport. For a home run (60 m from home plate to the outfield edge), the ball needs an initial speed of at least 25.02 m/s, requiring a minimum force of 2502 N with a bat-ball contact time of 0.002 s. Additionally, it is found that hitting near the sweet spot minimizes energy loss from bat vibration, and a launch angle close to 35 degrees above the horizon is optimal for achieving the 60 m range (due to practical force-generation limits). These findings offer practical references for optimizing hitting techniques and training intensity in youth slow-pitch softball.

**Keywords:** Sweet spot; Mode; Projectile; Momentum conservation.

## 1. Introduction

Baseball is a sport that integrates strategy, skill, and teamwork, exerting a unique charm with broad global influence. At the professional level, Major League Baseball (MLB) stands as the pinnacle of the game, sustained by robust broadcasting, merchandising, and live-event revenues that highlight its commercial strength and cultural reach. Equally important, baseball flourishes in educational settings: from elementary schools to universities, it remains one of the most popular sports, where students develop fundamental motor skills, cooperation, and resilience. Well-established youth leagues and scholastic competitions create a clear pathway from grassroots participation to advanced play, providing adolescents with ample opportunities to engage in the sport [1].

While slow-pitch softball (SPS) is derived from modified baseball rules—most notably a reduced pitching speed delivered with an underhand, high-arc motion and the use of a larger, more visible ball—these adjustments substantially lower the sport's entry barrier and make it especially suitable for youth and beginners. The slower pitch and larger ball increase reaction time and contact rate, building confidence while reinforcing core batting mechanics, timing, and safe catching/throwing fundamentals with a reduced risk of injury. Shorter basepaths and simplified base-running in many SPS formats (e.g., no leading off or stealing) lessen collisions and cognitive load, so coaches can emphasize teamwork, communication, and situational awareness. In school and community settings, SPS is easier to organize and staff because pitching is less specialized, equipment costs are modest, and mixed-ability or co-ed lineups can participate meaningfully; importantly, the skills developed—swing plane control, glove work, footwork, and rules comprehension—transfer naturally to regulation baseball for athletes who progress to higher levels.

The rules of baseball and SPS align in core aspects: both contain offensive and defensive teams. The batter (in the offensive team) is the person who uses the bat to hit the ball) stands near home plate [2]. After hitting the ball, batters are supposed to run through first, second, and third bases in sequence, and score by safely returning to home plate. For “defenders”, they can eliminate batters by fly out, force out, tag out, or pitch out (Fly out means the defenders catch the ball before it first lands) [3-4].

However, differences between the two balls exist. A standard baseball field has 27.43 meters of base paths. The distance from the pitcher's plate center to home plate's apex is 18.44 meters. Outfield obstacles (fences, nets, spectators) must be at least 76.20 meters from home plate; the distance from home plate's apex to the ends of the first or third baselines is at least 97.54 meters; and the distance from home plate through second base to the outfield boundary is at least 121.92 meters.

In contrast, the field of SPS has no strict standardization. In this article, we assume the whole SPS field resembles a quarter circle with its infield base paths to be 18 meters, a 12.73-meter pitcher-to-home plate distance, and a 60-meter home plate-to-outfield distance.

Additionally, a standard baseball has a circumference between 22.9 and 23.5 cm (9 and 9.25 inches) and weighs between 141.8 and 148.8 grams, while a softball is about 30.4 cm (12 inches) in circumference and weighs 178 to 198.4 grams.

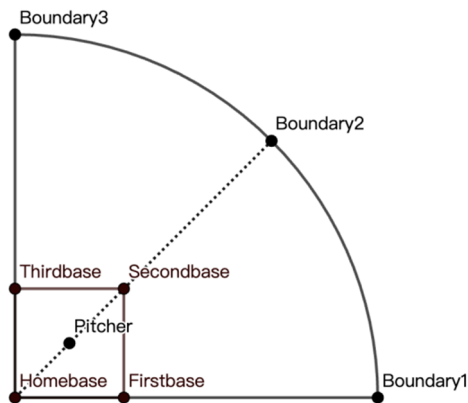


Fig. 1 Reference of Baseball and SPS Field Position

As a team sport, batters use different hitting styles to help teammates get scores. Three basic hit types exist:

- Fly ball: Follows a steep parabola, flying far above human height. A “home run” (landing beyond the field) allows all baserunners to score safely;
- Line drive: Follows a shallow parabola, flying near human height;
- Ground ball: Hit at an angle below the horizontal, bouncing within meters of contact.

\*Notification: In SPS, a catch (“defensers” catch the ball before it touches the ground) can effectively eliminate the batter.

Nowadays, Scholars professional baseball have been extensively analyzed, for example: Rod cross [1] studied bats’ “sweet spots” (optimal hitting points on the bat which requires less force for maximum distance the ball can reach); Beijhl et al. [2] modeled baseball flight dynamics; Ravindra et al. [3] explored the physics of baseball bats.

However, few studies are dedicated to SPS. Therefore, this research bridges the gap by adapting baseball’s mature physical analysis methods (including bat and ball impact mechanics, ball’s trajectory characteristics), and aims to provide theoretical support for SPS hitting strategies and training.

## 2. Experimental Methods

### 2.1 Determining The Sweet Spots

Modal analysis describes a structure’s inherent vibration properties. An object’s natural frequency is calculated via:

$$f = \sqrt{\frac{k}{m}} \tag{1}$$

Where  $f$  is the natural frequency of the object,  $k$  is the stiffness, and  $m$  is the mass.

Stiffness  $k$  can be calculated via:

$$k = \frac{3EI}{L^3} \tag{2}$$

where  $E$  is the elastic modulus in Pa (For aluminum alloy,  $E$  is  $7 \times 10^{10}$  Pa),  $I$  is the moment of inertia for the bat, and  $L$  is the length.

The moment of inertia  $I$  can be calculated via:

$$I = \frac{\pi}{64} (d_{\text{outer}}^4 - d_{\text{inner}}^4) \quad (3)$$

Since the aluminum alloy material in the bat is a ring, using  $d_{\text{outer}}$  to represent the outer diameter of the bat's cross section,  $d_{\text{inner}}$  to represent the inner diameter of the cross section.

Through the calculations above, the natural frequency of the bat can be obtained. Generally, the first and second modes will have a larger energy distribution during vibration; therefore, the first and second order modes are the core points to study.

Rod Cross used piezoelectric ceramics to detect bat surface deformations. For precision, Rod tested a Louisville Slugger model R161 bat (which is 84 cm long, 6.67 cm thick at end diameter, 0.885 kg of mass, 27.6 cm distance from center of mass to the head) and a piezoelectric ceramic disk (which is 9 mm in diameter, 0.3 mm in thickness, 1.8 g of mass, light enough to make no significant impact on bat during vibration).

Sensors were mounted on the bat head, near the center of mass, and on the handle. When the bat vibrates from impact, the ceramic disk deforms, generating a piezoelectric effect and an alternating voltage signal. This signal is transmitted to an oscilloscope, which records the waveform, frequency, and amplitude.

By comparing signals from different positions, we analyze vibration nodes (no vibration points), vibration modes (e.g., the fundamental and the second ones), and their distribution. These reveal how bat vibration relates to hitting position.

Through experiments and theory, Rod Cross found that, in the fundamental mode, the bat's frequency stabilizes at 170 Hz, with a vibration node 17 cm from the bat's head. In this mode, the vibration of the bat exhibits a specific energy distribution and propagation pattern, which is the fundamental vibration mode during the batting process. In the second mode, frequency rises to 330 Hz, with nodes situated at 5 cm and 13 cm from the bat's head. Compared to the fundamental mode, its energy transmission and attenuation differ significantly. During impact, the second mode interacts with the fundamental mode. The two modes collectively determine the vibration pattern of the bat. Hitting the ball at a node minimizes energy loss caused by vibration, thus maximizing the ball's kinetic energy, which means that with the same batting force and angle, the baseball can fly further.

The excitation and interaction of the two vibration modes at different hitting positions jointly determine the vibration characteristics of the bat during the hitting process, and the formation of the sweet spot is closely related to the node positions and vibration characteristics of these two vibration modes.

## 2.2 Force Analyze During Bat-Ball Motion

We model the baseball as a point mass and the bat as a rigid line segment confined to a plane. Unless otherwise noted, air resistance and spin-induced forces are neglected. Let  $m$  be the ball's mass and  $g$  the gravitational acceleration. An MLB pitch-hit sequence is divided into three stages:

·During pitching: The ball is acted on by gravity  $W_G=mg$  (downward) and the pitcher's forward hand force  $F_{\text{hand}}$  (approximately horizontal). At the instant of release, the hand force vanishes, defining the initial position and velocity for free flight, as shown in Fig. 2.

·In flight: After release, only gravity acts on the ball; with drag neglected, the trajectory is purely ballistic (parabolic), as shown in Fig. 3.

·At impact: Upon contact, the ball experiences gravity and the bat's contact force  $F_{\text{bat}}$ , applied roughly along the bat axis. Over a short contact time, this force produces an impulse that changes the ball's velocity from the pre-impact value to a post-impact exit speed  $v_0$  at launch angle  $\theta$ . Because  $|F_{\text{bat}}|$  during impact is orders of magnitude larger than  $W_G$ , gravity's effect within the collision interval is negligible. It resumes governing the subsequent flight, as shown in Fig. 4.

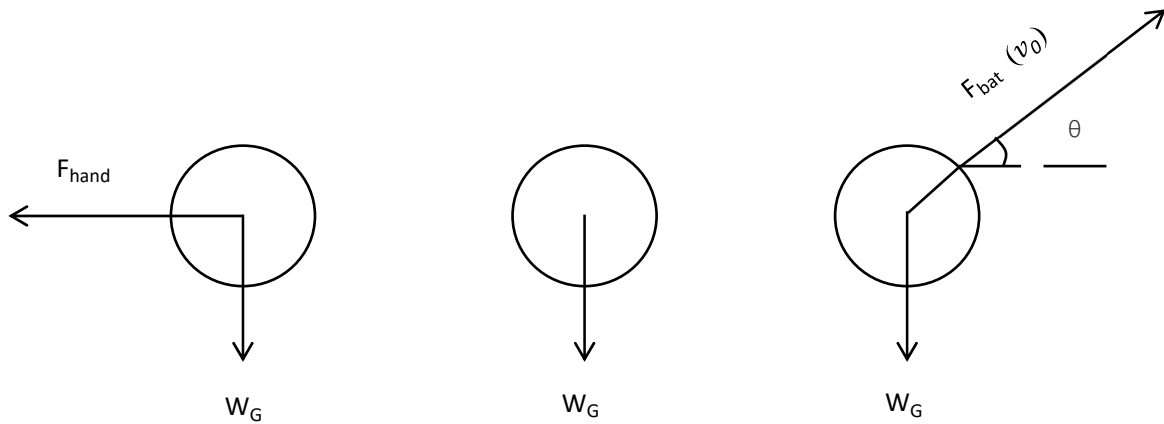


Fig.2 Stage1: During pitching

Fig.3 Stage 2: In flight

Fig.4 Stage 3: At impact

### 3. Application in SPS Context

#### 3.1 Identifying The Sweet Spots

Assume a youth SPS bat, which is 34 inches (about 86 cm) long and made of aluminum alloy, weighs around 850 grams. It has a hollow tube structure: the outer diameter at the grip,  $d_{b,o}$  (bottom end) is 2.5 cm, and the outer diameter at the top end  $d_{t,o} = 7$  cm. The aluminum layer is roughly 3 mm thick ( $d_{outer} - d_{inner} = 3$  mm). For simpler calculations, we use an average outer diameter of  $d_{a,o} = 5$  cm and an inner diameter of  $d_{a,i} = 4.4$  cm for the bat's cross-section.

Feeding these data into the relevant stiffness and natural frequency formulas, we find the bat's stiffness is 43,500 N/m and its natural frequency is 226.26 Hz. This result aligns fairly well with Rod Cross's experimental findings (small differences come from varying bat parameters and the use of an average cross-section).

Using the principle that "the first order vibration node has zero amplitude," the sweet spot of the Louisville Slugger model R161 bat lies at roughly 66-70% of the bat length from the bottom end [1]. Thus, we can determine that the sweet spot of this SPS ball bat is 25.8–29.2 cm from the barrel tip.

#### 3.2 Motion Analysis of SPS

For this analysis, we make the following assumptions:

Both the pitch from the pitcher and the ball hit by the batter move along the straight line between home plate and the pitcher's spot.

1. We set the batter's position as the origin. The line connecting the batter and the pitcher is the x-axis (with the direction from the batter to the pitcher as positive), and the height above the ground is the y-axis (upward as positive).
2. When the bat hits the ball, the angle between the bat's force and the horizontal is  $\theta$  (as shown in Fig.4). Additionally, the initial speed direction of the hit ball is the same as the force direction, and the initial speed is called  $v_0$ .
3. Since most SPS players are amateur youths, we ignore factors like air resistance and the ball's spin.
4. When swinging the bat, the angle should be no more than  $35^\circ$  (Angles over  $35^\circ$  make it very hard for the batter to exert force on the ball).

A home run is the best way to score. As mentioned before, the distance from home plate to the field edge in SPS is 60 m. We break the ball's speed at impact into horizontal ( $v_x$ ) and vertical ( $v_y$ ). (The initial horizontal and vertical velocity can be expressed in terms of  $v_0$  respectively in formula (4))

$$v_x = v_0 \times \cos \theta \tag{4}$$

$$v_y = v_0 \times \sin \theta \quad (5)$$

In SPS, the ball's movement after being hit is like a projectile. Its horizontal range  $x$  can be written as:

$$x = \frac{\sin(2\theta) \times v_0^2}{g} \quad (6)$$

When  $\sin(2\theta)=1$  (that is,  $\theta = 45^\circ$ ), the ball can reach the furthest horizontal position for a given initial speed. But because of the  $35^\circ$  limit, when  $\theta=35^\circ$ , the needed initial speed is the smallest, when trying to hit a home run. Theoretically, the minimum initial speed  $v_{0min}$  is 25.02 m/s.

Suppose a 12-inch softball weighing 200 grams is still in front of the batter. Using the momentum conservation formula:

$$F\Delta t = m\Delta v \quad (7)$$

With a real bat-ball contact time of 0.002 s, the batter needs to push the ball with at least 2502 N of force to hit a home run.

## 4. Conclusions

Hitting the ball with the sweet spot means the ball loses the least energy to bat vibration, so it has the most kinetic energy. When trying to find out the bat's sweet spot in daily training, we have no access to locate it as precisely as Rod Cross's method of finding the sweet spot with piezoelectric ceramics. But trainees can roughly find it by how the "hit" feels: hitting near the sweet spot means less vibration in the arms and wrists, and it's easier to hit further. Trainees can also find the sweet spot through the bat's design: the sweet spot is usually about one-third of the bat's length from the barrel.

For batters, hitting near the sweet spot with an angle as close to  $45^\circ$  above the horizon as possible is the easiest way to make a further horizontal displacement. But in real games, the ball isn't still when it reaches the batter: it's coming towards them. So, batters need to exert more force on the bat than the 2502 N calculated above. Besides, factors like air resistance and the ball's spin are not considered: it would be more challenging to hit a home run in a real situation. And since the ball flies in a parabola after pitching, it has a vertical velocity when arriving at the batter, which means even a small mistake, like the ball touching the bat's edge, thus bouncing high, can change the game.

This study has a limitation: it considers only home runs as the target distance in the motion analysis. MLB data show that only 6% of well-hit balls end as home runs, underscoring how rare they are—requiring near-optimal combinations of exit speed, launch angle, timing, and park conditions. In SPS, home runs are likely even rarer because pitches are underhand and slower, the ball is larger and softer with a lower COR, and field dimensions vary and are often relatively deep. Using homers as the benchmark, therefore, emphasizes extreme outcomes and may overstate practical performance. Future work should map batted-ball distance to run value across distance/angle bins, incorporate park-adjusted thresholds and environmental factors (wind, altitude, temperature), and report metrics such as expected bases or run expectancy.

## References

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