Research the sweet spot on a baseball bat based on optimization algorithms

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Received 1 March 2014, www.cmnt.lv

Abstract

With the popularity of baseball, numerous studies have been conducted to find methods to improve performance during a baseball match. However, it's still unclear that how the batter should hit a ball so that the batted ball speed is largest. In other words, where is the sweet spot that maximum energy is transferred to the ball when it's hit? In our paper, we take three factors into consideration to determine position of sweet spot. We build three models to confirm corresponding factors: (1) relationship between batted ball speed and distance from hit point to pivot point when the pivot point is fixed, (2) loss of energy caused by vibration of bat, (3) loss of energy caused by rotation of bat. At last, by considering the above three models to get the final energy of ball. We find that the COP (Centre of Percussion) point is just the sweet spot. What's more, by considering variation of mass, centre of mass and moment of inertia of bat after corking a bat, we get the new position of COP. Our conclusion is that when a batter does the same work to the two types of bat, corking a bat doesn't change batted ball speed dramatically. Therefore, "corking" doesn't enhance performance during baseball match even though it may lead to better control of the bat. At last, by statistical processing to results of baseball match in the last more than 30 years, we find that the aluminium bat shows a marked increase in hit-ball speeds. So different materials have different behaviours during a match. In addition to that, we also give reasons why Major League Baseball prohibits metal bats according to our model.

Keywords: optimization algorithms, sweet spot, mathematical modelling

1 Introduction

A commonly accepted fact is that baseball became the one of most popular activity all over the world. The most important equipment of baseball is ball and bat. The balls in the games are same, and then the Competition Results mainly depend on the bats which players use. The key factor to measure the bat performances is the batted ball speed. Then, how to make it? Here, a problem is inevitably involved in “the sweet spot of a baseball bat”. But what and where is the "sweet spot" on a baseball bat? How to locate the sweet spot?

A lot of researches have been done to explain and find the sweet spot. One saying is that a sweet spot is a place, often numerical as opposed to physical, where a combination of factors suggests a particularly suitable solution. In the context of a bat or similar sporting instrument, sweet spot is often believed to be the same as the centre of percussion [1]. The other saying says that the sweet spot in a baseball bat is an impact point, or a narrow impact zone, where the shock of the impact, felt by the hands, is reduced to such an extent that the batter is almost unaware of the collision. At other impact points, the impact may be felt as a painful sting or jarring of the hands, particularly if the impact occurs at a point well removed from the sweet spot [2].

Whereas, it is a pity that there is no exact theory to explain why this spot is on the fat part of a baseball bat rather than the barrel end of it. The first task of our paper is to locate the position of sweet spot.

Of course, some players believe that "corking" a bat enhances the "sweet spot" effect, is it right or wrong? What's more, does the material out of which the bat is constructed matter to the bat performance?

In order to solve these problems, we divide our work into several steps. Our steps are as follows:

1) Building model to confirm the relationship between batted ball speeds and distance from hit point to pivot point when the pivot is fixed.
2) Building model to confirm loss of energy caused by vibration of bat in the process of impact between bat and ball, that is, the maximum energy should be transferred to the ball. Moreover, the batter should feel least sting during collision.
3) Building model to determine loss of energy caused by rotation of bat in the process of collision between bat and ball.
4) By a comprehensive analysis, get the preliminary conclusion of where should the sweet spot be.
5) By augmenting our method, confirm "corking" a bat whether enhances the "sweet spot" effect.
6) By analysing influential factors of sweet spot, make sure whether different materials making up a bat has different effects on performance of a baseball match.

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2 Notations and Assumptions

2.1 NOTATIONS

I : Moment of inertia I about the pivot point;
ω_1 : Angular velocity of bat before impact; 1
ω_2 : Angular velocity of bat after impact;
V : Speed of ball before impact;
V_2 : Speed of ball after impact;
r : Distance between pivot point and a random point on the bat;
M : Mass of the ball;
M_1 : Mass of the bat;
l : Distance from the barrel end to the pivot point.

2.2 ASSUMPTIONS

1) Shape of bat is symmetrical, regular and the density of wood one is uniform;
2) Work done by the batter to the normal bat and the corked one is uniform;
3) With the corking problem, the node with the zero displacement which is gained in the vibration model and COP is the same on;
4) Loss of energy caused by vibration and offset will be negligible when the hit point is the sweet point.
5) Loss of energy caused by inelastic collision is identical to the normal wood bat and corked one.
6) Cork or rubber corked to the bat is a cylinder with the uniform density and its centre of mass is in the centre shaft of bat.

3 Locations of sweet spot on a baseball bat

Trying to locate the exact sweet spot on a baseball bat is not as simple a task as it might seem, because there are a multitude of factors having effect on selection of position of sweet spot on a baseball bat. What we take into consideration includes: (1) distance between hit point and pivot point; (2) bat's vibration caused by hitting a ball; (3) bat's rotation caused by hitting a ball.

3.1 STEP ONE OF SOLUTION

As a sweet spot, there is no doubt that the batted-ball speed is relatively high, if not; no one in the normal state will choose it as an impact location. When an impact between bat and ball happens, no matter the bat is stationary or locomotors, there is no doubt that there will be a batted-ball speed, and the problem is that in which position that the batted-ball speed is the largest. Our task is to find that position.

For the bat, we only take torque into account when analysing the motion of bat. In the transient moment (usually 1 Ms) of impact between bat and ball, our model decomposes the motion of bat into translational part and rotational part about the pivot point.

When computing, we suppose the translational speed of bat is the pivot point is 0. As to the centre of gravity is far from the knob end of bat and the mass of the knob end is lighter than the barrel end, so this suppose doesn't change the kinetic energy of bat dramatically.

Then by applying the Angular Momentum Conservation Law, we can get:

$$I\omega_1 - MrV = I\omega_2 + MrV_2 . \tag{1}$$

We assume energy in this model is also conservative. Though there exists loss of energy caused by inelastic collision, it is uniform in every point of bat, so it has little effect on the location of sweet spot and can be neglected. So we can get

$$\frac{1}{2}I\omega_1^2 + \frac{1}{2}MV^2 = \frac{1}{2}I\omega_2^2 + \frac{1}{2}MV_2^2 . \tag{2}$$

According to Equations (1) and (2), we can eliminate, and then we can acquire:

$$MV^2 = \frac{M^2r^2\left(V+V_2\right)^2}{I} - 2\omega_1 Mr\left(V+V_2\right) + MV_2^2 . \tag{3}$$

As we all know, V is a constant value once an impact happens. Thus, the right side of Equation (3) is constant. Then, we consider the relationship between V_2 and r.

Thus, according to Equation (4), we can get

$$V^2 = \frac{Mr^2\left(V+V_2\right)^2}{I} - 2\omega_1 r\left(V+V_2\right) + V_2^2 \tag{4}$$

By computing Equation (4), we can get the relationship between V_2 and r. The result is as follows:

$$V_2 = \frac{\left(\omega r - \frac{VMr^2}{I}\right) \pm \sqrt{\left(\omega r - \frac{VMr^2}{I}\right) - \left(1+\frac{Mr^2}{I}\right)\left(\frac{Mr^2V^2}{I} - V^2 - 2\omega rV\right)}}{\left(1+\frac{Mr^2}{I}\right)} . \tag{5}$$

In the collision process, it satisfies the condition $I\omega \gg MVl$. So it's easy to get the conclusion that $\frac{Mr^2}{I} \ll \frac{\omega r^2}{Vl} < \frac{\omega l}{V}$.

In general, the relative speed of ball to the bat is equal to speed of the barrel end of bat, thus we can acquire that $\frac{\omega l}{V} \approx 1$.

Therefore, it's apparent that

$$V_2 \approx \omega r + \sqrt{\omega^2 r^2 + V^2 + 2\omega rV} . \tag{6}$$

Consequently, $V_2 = 2\omega r + V$. As we know [3],

$$V_2 = e_A V_{ball} + \left(1+e_A\right)V_{bat} , \tag{7}$$

in which $V_{bat} = \omega r$, and $V_{ball} = V$. e_A denotes the collision coefficient and it satisfies $-1 \le e_A \le 1$. By connecting Equations (6) and (7), we get the conclusion that Equation (6) is a special condition in which $e_A = 1$.

Our conclusion is that further a point on the bat is apart from the pivot point, the larger the batted-ball speed is.

3.2 STEP TWO OF SOLUTION

Whenever an object is struck, it vibrates in response. At one point, which is called "the node", the waves always cancel each other out, and the batter won't feel any stinging or shaking in his or her hands. Since little of the bat's energy is lost to vibration when this spot is hit, more can go to the ball. Our purpose in this model is to find the special node where the loss of energy is the least. Here we apply the experimental result of Daniel A. Russell PH.D [4].

Figure 1 shows the first two bending modes of a freely supported baseball bat. The handle end of the bat is at the right, and the barrel end is at the left. The numbers on the axis represent inches (this data is for a 30 inch Little League wood baseball bat). The amplitude of the vibration is greatly exaggerated for clarity. When excited by an impact force, such as a baseball striking the bat, all of these modes, (as well as some additional higher frequency modes) are excited and the bat vibrates.

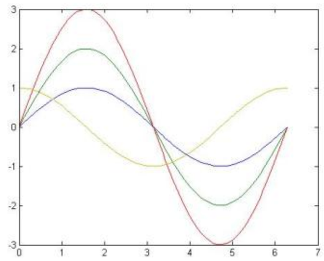

FIGURE 1 Mode shapes for 30-inch Little League wood bat

The fundamental bending mode has two nodes, or positions of zero displacement). One is about 6-1/2 inches from the barrel end close to the sweet spot of the bat. The other at about 24 inches from the barrel end (6 inches from the handle) at approximately the location of a right-handed hitter's right hand.

The second bending mode has three nodes, about 4.5 inches from the barrel end, a second near the middle of the bat, and the third at about the location of a right-handed hitter's left hand.

In our model, we prefer to follow the conclusion used by Rod Cross who defines the sweet zone as the region located between the nodes of the first and second modes of vibration (between about 4-7 inches from the barrel end of a 30-inch Little League bat). Since the vibrational motion of the bat is very small in this region, an impact in this region will result in very little vibration of the bat (no stinging a player's hands) and a very solid hit will result with maximum energy being given to the ball (Figure 2).

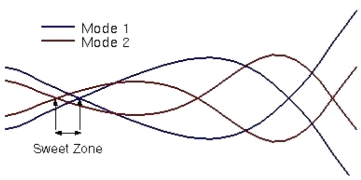

FIGURE 2 The sweet zone got from this model

An impact to the outside (towards the barrel end) or inside (towards the handle) of this zone will result in a much more significant vibration of the bat, often felt as a painful sting. And the ball will not travel as far because some of the energy is now being stored (or dissipated) in the bat's vibration.

3.3 STEP THREE OF SOLUTION

What makes the COP special is that an impact at the COP will result in zero net force at the pivot point. Impacts closer to the handle will result in a translational force at the pivot. Impacts closer to the barrel end will result attempt make the bat rotate about its centre-of-mass, causing a force in the opposite direction at the pivot point. However, for impacts at the COP these two opposite forces are balanced, resulting in a zero net force. The COP would seem to be a likely candidate for the sweet spot since an impact at that location would result in zero force at the batter's hands (the top hand is right about 6-inches from the knob). However, the COP is not a fixed point on the bat, but depends on the location of the pivot point. All current methods of testing baseball and softball bat performance use the 6-inch point as the pivot point, and thus as the reference for locating the COP.

3.3.1 The normal method

As definition in textbooks [5], a solid object which oscillates about a fixed pivot point is called a physical pendulum. When displaced from its equilibrium position the force of gravity will attempt to return the object o its equilibrium position, while its inertia will cause it to overshoot. As a result of this interplay between restoring force and inertia the object twill swing back and forth, repeating its cyclic motion in a constant amount of time. This time, called the period, depends on the mass of the twill swing back and forth, repeating its cyclic motion in a constant amount of time. This time, called the period, depends on the mass of the object M_1, the location of the centre-of-mass relative to the pivot point d, the rotational inertia of the object about its pivot point I, and the gravitational field strength g according to Equation (1).

$$T = 2\pi\sqrt{\frac{I}{M_1 g d}}\,. \tag{8}$$

Instead of being distributed throughout the entire object, let the mass of the physical pendulum M_1 be concentrated at a single point located at a distance L from the pivot point. As we all know from textbooks, the period of single pendulum is

$$T = 2\pi\sqrt{\frac{l}{g}}\,. \tag{9}$$

This point mass swinging from the end of a string is now a "simple" pendulum, and its period would be the same as that of the original physical pendulum. According to Equations (1) and (2), we can get

$$L = \frac{I}{M_1 d}\,. \tag{10}$$

3.3.2 The advanced method

As we all know, if impact happens in the position of CM (Centre of Mass), the batter's hands will feel force after bat's translational motion. If a batter's hands don't feel force, then torque caused by hitting a ball balances the translational force. As the next step, we will introduce our advanced method to get the equation from which the location of COP can be computed.

Here, we assume the average force during a collision process is f , and the translational acceleration of bat is

$$a = \frac{f}{M_1}.$$

In this method, we assume the direction of a point at the left side. When consider rotation of bat, we regard the CM as the axis point. Then the moment of inertia of bat after impact is $I_1 = I - M_1 d^2$, and I denotes the moment of inertia of bat before impact. According to the theorem of angular momentum, we can get $f \cdot \Delta r = I_1 \alpha$ (a denotes the angular acceleration and Δr denotes distance between hit point and CM). At this moment, the acceleration of pivot point is $a_1 = d\alpha$, and the direction of a_1 points at the right side.

If one can't feel force, then $a = a_1$, that is

$$\frac{f}{M_1} = \frac{fr_1}{I_1} \cdot d . \tag{11}$$

As a consequence, we can get

$$r_1 = \frac{1}{M_1 d}\left(I - M_1 d^2\right). \tag{12}$$

Therefore, the value of L is

$$L = r_1 + d = \frac{I}{M_1 d} . \tag{13}$$

From the above analysis and derivation, we also obtain the same value of L as the normal model. Advance is that the gained result is under the condition of regarding the acceleration about the pivot point as zero instead of considering the collision period, T .

3.3.3 Calculation of both methods

This location L is known as the "centre-of-oscillation", since it represents the length of an equivalent simple pendulum with the same total mass and that has the same period as the actually physical object. The exact location of this special point depends on the location of the pivot - a fact which will be very important to the application of this concept to a baseball bat, as we will see below.

Then the following problem is how to make sure the location of CM (Centre of Mass). As the next step, we'll confirm the location of CM.

In order to make sure CM, we apply an axis named x which is shown in Figure 3.

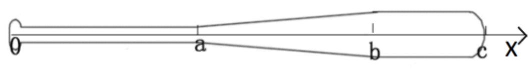

FIGURE 3 Bat in an axis named x

As we assume that the shape of bat is symmetrical and that the density (ρ) of bat is uniform, so we can make a conclusion empirically that the CM location is in the axis. Then we can acquire the position of CM (we apply the notation X_c to denote it) through the following Equation:

$$X_c = \frac{\sum m_i x_i}{M_1} = \frac{\int_0^{M_1} x dm}{M_1} . \tag{14}$$

In our model, dm can be simplified as

$$dm = \begin{cases} \rho\pi r_1^2 dx & 0 < x < a \\ \rho\pi r_x^2 dx & a \le x < b, r_x = r_1 + \frac{r_2 - r_1}{b-a}(x-a) \\ \rho\pi r_2^2 dx & b \le x \le c \end{cases} . \tag{15}$$

Here, we assume the phase from 0 position to a position is a cylinder, and its radius is r_1 ; the phase from a position to b position is r_x ; the phase from b to c is r_2 . Thus, we can confirm the position of CM, that is, we can acquire the value of d .

The next step is to make sure the value of I , and I can be expressed as: $I = \sum m_i r_i^2 = \int_0^{M_1} r_i^2 dm$ (r_i denotes radius of bat in a point with value in axis is i). Thus, we can compute the value of I .

After we have known the value of I , d and M_1 , the value of L is very apparent. Therefore, the position of COP is acquired.

3.3.4 Further talk about this model

As shown in our advanced method, we can get the conclusion that the composite force exerted to the pivot point can be expressed as

$$f_c = f\left(1 - M_1 \frac{\Delta r \cdot d}{I - M_1 d^2}\right). \tag{16}$$

We have to know acceptance range if we want to compute energy delivered to batter's hands. As the acceptance range of the pivot point caused by vibration in batter's hands is relatively small, the loss of energy is

$$E = f_c l_1 = f\left(1 - \frac{M_1 \Delta r d}{I - M_1 d^2}\right) l_1 . \tag{17}$$

In the previous equation, f is determined by the initial and final speed of ball and l_1 denotes moving distance of bat in a batter's hands. That's to say, it's related to the batting effect. Yet, because the discrepancy got from the batting effect is relatively small, we can assume the value of f is constant. Then, there is a significant linear correlation between E and Δr . That's to say; the farther a point on a bat is apart from the CM, the larger loss of energy. In our real life, batter's hands may exert larger forces, the true loss of energy may less than E. But if hands' force is not large, the effect of E can't be negligible.

3.4 PRELIMINARY CONCLUSION

By taking batted-ball speed, COP and vibration node into consideration, we can get the final kinetic energy of ball after impact. Then we have to find the location in which the ball can get the largest final kinetic energy. And this position is the sweet spot.

As shown in vibration model and COP model, we can get the conclusion that the loss of energy satisfies the same principle. Thus, we can assume the coefficient of loss of energy is $\eta\ (\eta > 1)$. As a whole, the final kinetic energy of ball is

$$E_1 = \frac{1}{2}MV_2^{\ 2} - f\left(1 - \frac{M_1\Delta rd}{I - M_1d^2}\right)l_1 \cdot \eta . \tag{18}$$

As shown in Equation (6), we get, $V_2 = 2r\omega + V$ $V_2 = 2r\omega + V$ in maximum batted-ball speed model and here we assume $V = r\omega$ as the hitting ball zone is small compared with the length of bat and it is far from the pivot point. So the variation of $r\omega$ is small.

Then we get $V_2 = \lambda r\omega$. We can also know from Fig. 2 that $\Delta r = r - d$. Then the above equation can be transferred into

$$E_1 = \frac{1}{2}M\lambda^2\omega^2 r^2 - r \cdot \frac{fl_1\eta M_1 d}{I - M_1d^2} + C . \tag{19}$$

In the above equation, C is a constant value. As we can see, E_1 is a parabola about r, and it has the smallest value in the point where r satisfies

$$r = \frac{fl_1\eta M_1 d}{\left(I - M_1d^2\right)\left(M\lambda^2\omega^2\right)} \cdot \tag{20}$$

As the value of f is large, if we substitute values of every parameter, we find that it's easy to get the conclusion that

$$\frac{f\eta M_1 dl_1}{\left(1 - M_1d^2\right)\left(M\lambda^2\omega^2\right)} > l . \tag{21}$$

As a result, as the coefficient of r^2 is positive, so when $r < \frac{fl\eta M_1 d}{\left(I - M_1d^2\right)\left(M\lambda^2\omega^2\right)}$ E_1 is smaller and smaller on the left side of parabola with the increment of r. As COP is the smallest one, thus the point in which the ball can get the largest kinetic energy is the COP point. That is also the sweet spot which is just not at the end of the bat, but on the fat part of a baseball bat.

4 The Corking problem

Some players believe that "corking" a bat enhances the sweet spot effect. The reason why they think so may be based on the theory that it's much easier to swing something when the weight is concentrated closer to one's hands than when it's concentrated far from one's hands which they get from experience. The goal of our next step is to prove whether corking enhances sweet effect or improve performance in a baseball match.

If we hollow out a cylinder in the head of the bat, fill it with cork or rubber, and replace a wood cap, then it's a corked bat.

4.1 THE PROCESS OF ANALYSIS

Here, we assume the density difference between bat and cork or rubber (whose density is less than bat) is $\Delta\rho$; the radius of filling material is r_3; the depth of filling material is h. By the same way, we assume the decreasing mass of bat is Δm. We also assume the initial mass of bat is M_1.

Then the CM position of bat can be indicated as

$$x_{c1} = \frac{\int_0^{M_1} xdm - \int_0^{\Delta m} xdm_1}{M_1 - \Delta\rho\pi r_3^{\ 2}h} . \tag{22}$$

In the above Equation, $dm_1 = \Delta\rho\pi r_3^{\ 2}dx$ and the mass of corking bat can be expressed as $M_1 - \Delta\rho\pi r_3^{\ 2}h$. With the same method, we can get the location of new CM which we use d_1 to indicate.

What's more, we can get new moment of inertia I_1 of bat about the pivot point with the same method. As a result, we can get the new position of COP with the Equation

$$L = \frac{I_1}{\left(M_1 - \Delta\rho\pi r_3^{\ 2}h\right)d_1} . \tag{23}$$

4.2 THE CALCULATION PROCESS

By calculation, we find that after corking a bat, the mass of bat is less; moment of inertia decreases; the position of CM is closer to the handle end of bat. Thus, when a batter swings a bat, the speed of bat is larger than before. However, the resistance force exerted by air (which is in proportion to the square of speed of bat) is larger at the same time.

We assume work done by the batter to the bat is uniform because work has done by a batter equal multiplying force by distance. Under both circumstances, no matter force or distance is uniform. Thus we can get

$$\tfrac{1}{2}I\omega_1^{\ 2} = \tfrac{1}{2}I_1\omega_3^{\ 2} , \tag{24}$$

in which ω_3 represents the angular velocity after corking a bat. We get the result that

$$r\omega_3 = \frac{I_1}{\left(M_1 - \Delta\rho\pi r_3^{\ 2}h\right)d_1} \cdot \omega_3 . \tag{25}$$

As we get from Equation (1)

$$\left(M_1 - \Delta\rho\pi r_3^{\ 2}h\right)d_1 = M_1 d - \Delta\rho\pi r_3^{\ 2} \cdot \frac{l^2 - (l-h)^2}{2} . \tag{26}$$

Equation (2) indicates that $\omega_3 = \sqrt{\frac{I}{I_1}} \cdot \omega_1$, so when $\left(M_1 - \Delta\rho\pi r_3^{\ 2}h\right)d_1$ reduce, ω_3 increases respectively. So the value of $r\omega_3$ doesn't change very much.

We also assume that the node with the zero displacement which is gained in the vibration model and COP is the same one. Then loss of energy caused by vibration and offset will be negligible when the hit point is the sweet point. Loss of energy caused by inelastic collision is uniform for the reason that though the speed of bat is larger, the increment can be negligible.

As shown in the maximum batted-ball speed model, energy got by the ball is concerned with value of $r\omega_3$, and the value of ω_3 can be gained through Equation (2). And $r = L$, in which L has been known before. By computing, we find that after corking a bat, the final speed of ball doesn't change dramatically. The graph is as follows.

Relative to the normal bat, the corked bat had a cavity in the barrel end of diameter 0.875" and depth 9.25". The computation assumes that the ball-bat COR is the same for each bat, as shown from experiment, and assumes a particular relationship between the bat swing speed and the moment of inertia of the bat. The computation shows that the corked bat is not superior to the normal bat in batted-ball speed.

Conclusion: By computing, we can get the conclusion that after corking a bat, the sweet spot effect doesn't improve. As we know, the efficiency of the bat in transferring energy to the ball is in part depends on the weight of the part of the bat near the impact point of the ball. For a given bat speed, a heavier bat will produce a higher hit ball speed than a lighter one. By reducing the weight of bat which can be done by corking a bat in the barrel end produces a less effective collision [6].

4.3 REASONS FOR PROHIBITING "CORKING"

Firstly, by drilling out the centre of a wood bat and replacing it with cork, the mass of bat is lighter. More importantly, the location of the centre-of-mass of the bat would shift slightly towards the handle end of the bat. This means that the moment of inertia of the bat would decrease and it would be easier to swing, which increases the better control of the bat.

Secondly, according to Newton's second law, under the condition of constant force applied to the ball when impact happens, the mass of bat is lower, and then the acceleration of bat will increase, only to lead in shortening the time of swing, thus allowing the batter to react to the pitch more quickly. So corking a bat in a baseball game will reduce greatly the technique and specialty of the professional players.

5 Analyses of different materials

The above models we have built is based on the baseball bat made of wood, which has well solved the previous two problems. To the final issue, we have to take other material (usually aluminium) into account in order to verify our model and analyse the effect of different materials on the model. Given the amount of controversy over the metal versus wood bat issue, there have been surprisingly few scientific studies comparing the performance of wood and metal baseball bats. There is one paper from 1977, when aluminium bats were just beginning to assert their prominence, which concluded that the batted ball speed of an aluminium baseball bat was about 3.85 mph faster than a wood baseball bat [7]. A second phase of the study attempted to explain the increase in performance of the aluminium bat by comparing the size of the "sweet spot" for the two bats by locating the COP. The study found that the aluminium bat appeared to have a larger COP than the wood bat. In contrast to the 1977 study, a 1989 study concluded that metal bats did not outperform wood bats [8]. Then, now what confuses us is whether the material of bat is a matter.

In our opinion, if the constructed material of bat is different, the bat performance factors making a difference on the bat are also greatly different. We will analyse and confirm our view from the following three aspects.

5.1 PERFORMANCE OF ALUMINIUM BATS

We get statistics published by the NCAA for Division I college baseball starting from the year 1970 through this year. The raw data includes yearly results for batting averages, home runs per game, runs scored per game, strikeouts per 9 innings, pitcher earned-run-averages, stolen bases and fielding percentages [9]. Here we only concern batting averages, home runs per game.

We get performance of aluminium bats from 1970 to 2006 by citing the experimental results of Daniel A. Russell PH.D. Figure 4 and Figure 5 show batting average and home runs per game. Note: there are three important data points to be paid attention to. First, 1974 was the year aluminium bats were introduced to NCAA college baseball, and metal bats have been used almost exclusively since that year. Secondly, in 1986 the NCAA imposed a lower limit on the weight of a bat. Finally in 1999, after the 1998 season – during which a number of scoring records were broken – the NCAA implemented a performance standard to limit the performance of aluminium and composite bats. Here we only make a main discussion from 1974 to 1986.

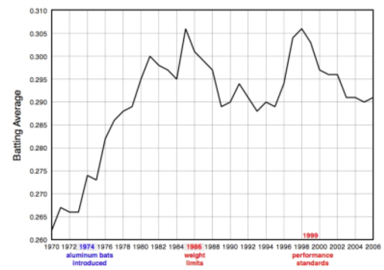

FIGURE 4 Batting average

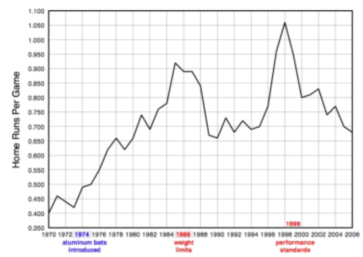

FIGURE 5 Home Runs per Game

The two plots at above which show the mean batting average and home runs per game for all NCAA Division I college baseball players as a function of year from 1970 through 2006 [10]. The two data have the same trends. Note that from 1970 through 1974 there appears to be an almost steady increase in both. After players using aluminium bats make solid contact with the ball more often than former players did with wood bats. During the same time period, batting averages were quickly increasing, so pitchers had increasing difficulty to strike batters out [11]. One thing is true: Aluminium bats typically have lower moment of inertia than wood ones and therefore may be swung more quickly. As a result, the hit-ball will have higher speed and fly faster and further.

From this we see aluminium bats outperform wood bats in games, in despite of performance standard to limit the performance of aluminium and composite bats.

5.2 REASONS FOR PROHIBITING METAL BATS

On the basis of previous analyses, we find the reasons why Major League Baseball prohibits metal bats. They are as follows:

Firstly, baseball rules require that the bats used in professional baseball be constructed of wood, whereas amateur players can use aluminium bats. Players agree that the aluminium bats drive the ball much faster; the balls come off the aluminium bat with more velocity. Overall, the use of aluminium bats could be expected to double the number of home runs hit during a season. And that would change the balance of the game too much, reducing the observability of professional baseball, so rules limit the professional players only use wood bats.

Secondly, the controversial issue at hand is the claim that aluminium bats are inherently more dangerous than wood bats; despite that it has the following advantages: lighter in weight, not prone to crack or break, higher batted ball speed.

Finally, according to the baseball regulations made by NCAA, the field safety determines to prohibit the use of aluminium bat. It is the greatest advantage that higher hit-ball speed puts pitchers and infielders at higher risk for injury that has led to calls for restrictions on bat performance.

Acknowledgments

This work is supported by soft-scientific project of Henan Province (No. 142400410425).

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