HITTING A BASEBALL…IT'S ALL IN THE PHYSICS

It has been said that our entire life is ruled by physics. This sounds pretty logical when you realize that physics, in its most specific sense, is "a science of matter and motion". It appears that "physics" just about covers everything. But we will leave that debate to the scientists and concentrate on one specific area that definitely depends on physics: hitting a baseball with a bat.

The following interview was conducted at Hillerich & Bradsby Company's Louisville, Kentucky headquarters, where the world famous Louisville Slugger bat is made. The original interview was with George Manning, Vice President of Technical Services for H&B. Before retirement Mr. Manning, an accomplished mechanical engineer was in charge of research and development and quality control for the sporting goods manufacturer. Prior to joining H&B, Mr. Manning was with the Battelle Memorial Institute and the True Temper Corporation, where he served in both research and management capacities.

While at Battelle and True Temper, the largest manufacturer of golf shafts in the world, he developed and coordinated tests on the famous "True Temper Swing Machine". Manning's machine also known as "Iron Byron" has become the industry standard for performance evaluation.

Along with his golf expertise, Manning is now heavily involved in baseball and softball. He insists that baseball and softball, like golf, is a proving example of the result of the interaction between matter and motion, i.e., physics.

An understanding of the basic physical phenomena when hitting a ball with a bat may be tremendously significant in developing hitting skills. So get ready for some basic high school physics and some interesting facts you probably never knew about the very "simple" action of hitting a thrown ball with a bat.

Interviewer: Let's start with the basics. What actually happens when a thrown ball meets a swinging bat?

Manning: Very basically, an impact occurs; and the scientific fact that is involved in this impact is the "conversation of momentum". At that time of impact we have to be concerned with the mass of the bat, the velocity of the bat, the mass of the ball, and the velocity of the ball. We also have to be concerned with what is called the "coefficient of restitution" (which is a fancy phrase for velocities of objects before and after they make contact) between the bat and the ball.

Interviewer: Does the ball really "flatten" at impact?

Manning: Yes, it flattens, but it only stays on the bat for a couple of centimeters of travel of the bat. So they would only be in contact together over that very short period of time. Now, if a batter "high forces" the ball, the average forces would probably result in a home run. Such high forces would be in excess of 3,000 pounds against the bat when the ball is in contact.

Interviewer: At that point where the ball is in contact with the bat, does the bat flatten?

Manning: A solid wood bat does change its shape slightly, but very little in comparison to the ball. Some of the new metal bats change shape and flatten considerably in comparison to the ball. And if we have the proper characteristics, they both come back to their original shape. Obviously, if an aluminum bat is not heat treated properly, for example, it flattens and does not come back to its original shape. This will absorb energy, and you end up not hitting the ball as far. That's why proper manufacturing methods are so vitally important.

Interviewer: What factors influence how far a ball travels when hit with a bat?

Manning: The factors are the speed of the bat, the speed of the ball, the mass of the ball, the location of the hit of the ball and the bat, the angle of the hit, the weather conditions, the coefficient of restitution between the bat and the ball, the ball's surface condition, the direction of the bat at impact, the direction of the ball at impact, the spin on the ball, etc. There are probably a dozen other things that are also going to

determine how far a ball will be hit. So, you can see how many different factors can have an effect on a batted ball. It's a lot more involved than most people think. For example, let me expand on something I brought up earlier. The coefficient of restitution that I mentioned is the relationship of the ratio of the velocities before things contact to the ratio after they contact. For example, if you are dropping a ball against the floor, the coefficient of restitution is determined by the height from which you drop the ball and how far back up it comes. The higher you hold the ball, the higher the ball will bounce. You can look at the coefficient of restitution on a number scale. Assume that the number 1 is the maximum capability that you could possibly achieve. If you drop the ball from head height, and it bounces back up to that exact same height, then you have achieved the maximum capability, which is 1. There would be no losses of energy in the ball at all. You might call it the "perfect rebound", which is the coefficient of 1. However, it never really comes up to 1! A most usual coefficient would be somewhere around 0.5. But even if you could achieve the perfect rebound of 1, it would never come higher than the height from which you dropped it, assuming it was a free-fall drop. If you had putty and dropped it on the ground, it would just stop as a glob on the ground, and you would have a coefficient of restitution that would be 0. If you had something perfectly elastic, it would be 1. So there are the two extremes. Now, if you put any additional energy whatsoever on that ball, then you have changed the whole picture. If you throw the ball against the ground instead of just dropping it, it will bounce higher. Likewise, a ball can come off the bat faster than it comes onto the bat because you are putting energy in from the bat itself. You added something to it. It is no longer a plain old "rebound".

Interviewer: What would the middle range be?

Manning: The middle would be 0.5. Basically, the coefficient of restitution is a measure of the velocity that occurred in the impact. It's like the internal energy. If you don't use any of it up, you don't lose anything in the coefficient of restitution.

Interviewer: Could there be different reasons for low or high coefficient? For example, if the ball is wet, wound tightly, wound loosely, etc.?

Manning: That's correct. And remember that the coefficient of restitution is affected by both the ball and material that it is striking. So if you had a very soft ball and used something that would absorb the energy in the bat, you end up with a very low coefficient of restitution. So anything that absorbs energy will result in that ball coming off the bat slower.

Interviewer: What is the "sweet spot" or the center of percussion on a baseball bat?

Manning: The center of percussion is a single point on a bat. That is the point where you want to strike the ball because it gives you the most energy exchange into the ball. If you hit anyplace else on the bat, you are actually "wasting" energy by absorbing too much of it. This cuts down on distance, and you also wind up with a sensation known as "stinging" of the hands. It is interesting to note that the center of percussion of the bat can be affected by how the bat is used. If I just have a bat standing in the corner, the center of percussion of that bat is different at that point than it would be if a man picked it up to swing it. Any time you hold the bat with your hands in a slightly different location on the bat, you have changed the center of percussion. So, keep in mind that the center of percussion does change (or move) depending on the way you hold the bat. So you have to decide how you are going to hold it before you can decide where the sweet spot is.

Interviewer: In other words, a person who chokes up on the bat and a person who holds it right down on the knob may have different sweet spots, even though they are using the exact same bat?

Manning: That's right. Now, they wouldn't be very far apart, but they would be different. Also, a sweet spot is a spot. It is not an area. One of the things that we tend to want to do is to make the effects of hitting off that spot less meaningful, so that it turns out being an effective area. Since hitting on the exact center of percussion every time is extremely difficult, we try to manufacture bats that are "more forgiving" when hit slightly off the sweet spot. We feel this is a great aid to the average hitter. The really good hitters hit on the sweet spot more consistently than bad hitters. And that's one of the reasons we have bad hitters.

Interviewer: Can a person tell when he has hit the ball on the sweet spot?

Manning: Theoretically, you should feel little or no reaction with your hands. There will be a slowing down of the bat from the energy exchange, but when you hit the ball on the ideal spot, you feel like saying, "I didn't even feel like I hit it!"

Interviewer: What happens to the ball and the bat if you hit the ball in either direction off the sweet spot?

Manning: Basically, if you hit the bat on the sweet spot, the bat would move straight back. But, if you hit it to the right of the sweet spot, that barrel end wants to come around in that direction. This, in effect, is what causes a loss of the exchange of energy because the effect of the velocity of the bat transferred to the ball is much less. In other words, you are once again wasting energy.

Interviewer: Now, what about the direction of the ball?

Manning: If you hit the ball on the sweet spot, it's going to go straight off the bat. I guess that's one good reason center field is considered the "power alley". You could still hit the sweet spot, but be a little ahead of the ball, and hit it to left field (if you are a right handed batter). Likewise, you can hit it on the sweet spot, but swing a little late, and you will probably hit to right field. The direction the bat is traveling at the time it hits the ball is going to have a big effect on how you are going to hit it. Even though you hit the ball on the sweet spot, you can still hit it in the air, on a line, into the ground, etc., depending on the path of the bat.

Interviewer: Then a ball hit on the sweet spot is not always a line drive?

Manning: No, it's not. It is a straight line resultant of the direction that the bat is traveling and the direction that the ball is traveling when they meet. For instance, if you had a pitcher who has a climbing fast ball (assuming that the trajectory of the ball is up and your bat trajectory is down), you could drive that thing right into the ground and hit it right smack on the sweet spot. So now we begin to see that a good level swing is probably the best trait to begin to develop. If you have a good level swing and you hit the ball in the sweet spot, you are certainly going to be in line with the direction the ball is coming from more closely. Now please keep in mind that we are really talking about baseball in this particular instance. Slow pitch softball would be a different matter since the ball and bat usually do not travel in straight lines. But the line of action of the ball and the line of action of the bat should be in direct opposition to each other. If this is the case, you are going to get the most effect in hitting the ball the farthest of the fastest. And this comes as a result of hard practice and instinctive reactions.

Interviewer: Can you move a sweet spot?

Manning: Well, as we have mentioned earlier, you can theoretically move a sweet spot. Since it is the center of percussion of a bat, the batter can move it depending on how he holds the bat. But the bat manufacturer can also move the sweet spot depending on how he designs the bat. This opens up a whole new world of possibilities in the future design of bats. If you are a singles hitter, you may well want a truly different bat than a home run hitter would want. And we might want to design a different bat for those two types of hitters.

Interviewer: Theoretically, let's say that the sweet spot (for the purpose of this question) is located exactly six inches from the end of the barrel. Now, if I choke up on that bat, is the sweet spot going to move out closer to the barrel of the bat or move towards me?

Manning: The sweet spot of the bat won't change locations on the bat much, but in relation to your hands as you choke up, it will get closer.

Interviewer: Is the batter, in essence, shortening the bat?

Manning: Yes, the batter is indeed shortening the bat. But the effect on the sweet spot is not the same as using a shorter bat. You might say that the player at the plate, whether he wants to or not, is changing the performance of his bat by the way he holds it. He is also changing the swing weight of the bat, which is the bat inertia. If he chokes up with the same weight bat, it is much easier to get the bat up to speed.

Interviewer: Is a person who chokes up on a bat less likely to be a power hitter?

Manning: Yes, potentially.

Interviewer: And doesn't hit it as far?

Manning: As a general statement, that is correct. One of the things that certainly would qualify it would be if a batter is using a very, very heavy bat and that is one of the reasons for choking up. A Batter may well generate just as much power by choking the bat up as would occur by taking a shorter bat that's lighter weight and holding it on the end.

Interviewer: So what we are talking about is bat swing speed?

Manning: Yes, and this is terribly important. It's really more important to get bat speed than it is to get bat mass.

Interviewer: Can we enlarge a sweet spot?

Manning: You can't enlarge a sweet spot because by definition it is a point. You can reduce the falloff of performance as you move away from the sweet spot. Golf clubs have done this, and you can do it effectively in a baseball or softball bat. In fact, that's what we have done with the aluminum bat, and it is one of the reasons it performs differently than a wood bat. You haven't made the sweet spot bigger, but you have made the effect of hitting off the sweet spot less punishing. In other words, you have not necessarily enlarged the sweet spot, but you have made the effect of hitting one inch off the sweet spot a lot less significant. We can do this more easily with an aluminum bat than we can with a wood bat.

Interviewer: In a previous question, we touched upon mass and velocity. Will a heavier bat hit a ball farther than a light bat?

Manning: The answer is yes, <u>if</u> it is swung at the same velocity as the light bat and they are both hit on the center of percussion. However, most people can't swing a heavier bat as fast. There is a limitation as to what each batter's energy input capability is. Probably, the range of weights is not terribly broad. I don't know of anybody who has done this with baseball bats or softball bats, but it has been done with golf.

Golf clubs have been taken and intentionally made very light and intentionally made very heavy. We have a good golfer swing through light beams to measure the club and velocity. We do discover that you can get to a point with light clubs where they just don't go any faster. You can also get so heavy that they really slow down, but between a fairly wide range the slow down in velocity and the increase in mass is almost compensation, so that the end result of your hit is pretty close to being the same.

Now one of the things that's different in golf than in baseball is that a golfer is hitting a stationery ball. He can wait for his swing with that heavy club. But you just can't wait for the ball with a heavy bat, so I suspect it is more sensitive in baseball, but we can say almost certainly that a heavier bat would be more difficult to swing. The formula I discussed earlier shows that because the mass of the bat is so much greater than the mass of the ball, the velocity is a much more significant factor than the mass of the bat. So you really want a lighter bat that you can swing faster, because an increase in velocity is a bigger factor in how far you will hit the ball than an increase in the mass. Actually, the more you increase the velocity, you actually increase the effect of the mass. An object that weighs 30 ounces and swung at 50 miles per hour is going to be more potent than if it is swung at 40 miles per hour.

Interviewer: So most people who get a big healthy piece of timber or aluminum should be trying to strive for more bat speed. Is that right?

Manning: That's right. The one question that I think might not exist though, and certainly the factors are still correct, would be in slow pitch softball. The ball is so slow in relationship to everything else that you really have time to apply a large energy input. You are not nearly as affected by the changes in the directions of the ball. It isn't going to make wild curves, breaks, and this sort of thing. You can probably handle a heavier bat and still get good velocity out of it. You can stand back and wait for the ball and build up a lot of energy to put into the heavier bat, and probably obtain the same velocity that you could with a lighter bat in baseball. So a heavier bat could be an advantage in slow pitch softball.

Interviewer: But the big key is that normally you cannot obtain the velocity with a larger bat?

Manning: That's right. At least with the bat control that is necessary.

Interviewer: If you are an extremely strong player, it is still very unlikely that you can swing a 42 ounce bat as fast as you can swing a 33 ounce bat.

Manning: I don't think there is any question about that, but you might be able to swing a 36 ounce bat nearly as fast as you can swing a 33 ounce bat. Or you may be able to swing a 42 ounce bat faster than anyone else can swing a 33 ounce bat.

Interviewer: How important is "wrist snap" at the moment of impact? Does that increase bat speed?

Manning: Yes, in baseball, golf, or any kind of activity where you are trying to get maximum velocity, but have a limitation in how much time and how much energy you can put into it, the advantage of a wrist snap is paramount. You can keep the mass tucked in close to the center that you are rotating around until the last instant. Say, for instance, you are swinging a simple broom. If you hold it by the handle and swing it way out, it is terribly difficult. But, if you turn the bristles around toward you and swing the handle, it becomes very easy. This is an example of the fact that the closer you keep the mass to the center of rotation, the easier it is to accelerate the speed. So, the reason a golfer does it, and the reason a baseball player wants to use wrist snap is to get a lot of energy stored into his body and available for exchange into the bat while it's tucked in close. Remember, it takes a lot less energy to get up to a faster speed this way. Then, when he wants to flick it out, he wants to do it at the last second and get the mass away from the center of rotation. One of the things you have done in the course of getting your body movement is that you have stored a lot of energy in your body, and you get to exchange that energy through your wrists into the bat. So you have stored the energy for release in a way that is extremely efficient.

Interviewer: Let's look at a basic question that is a center of controversy in both baseball and softball. Does an aluminum bat hit a ball farther than a wood bat?

Manning: Some data says yes. There are many reasons, not the least of which is that the construction is different. It is easier to make a lightweight aluminum bat than it is a lightweight solid wood bat. Larger barrels have seen shown to hit the ball farther than smaller barrels . . again, it's easier to make a certain weight specification with aluminum to a full barrel diameter than it is with wood. Off the sweet spot hits will go better with aluminum than with wood, so an aluminum bat is more "forgiving" to a hitter. Recently, college and high schools have reduced the maximum diameter and increased the weights of permissible bats. They also, have put limits on exit speed. Their desire has been to make the aluminum bats more woodlike. Their performance data suggests that this has been achieved.

Interviewer: Then you are saying that we may be able to get more bat speed out of an aluminum bat that weighs exactly the same in overall weight as an equivalent wood bat?

Manning: Yes, because the swing weight of an equal weight aluminum bat (resistance to acceleration) will generally be less. You would expect that accompanying these characteristics would be a change in the location of the center of percussion. College and high schools have recently applied a minimum bat inertia to make the aluminum perform more like wood. It may well be that one of the reasons a lot of

people can hit farther with aluminum is that the point on the bat they have been hitting has not been the center of percussion with a wood bat, and they can get closer to hitting the center of percussion when they go to an aluminum bat. You simply have more area to work with in aluminum bats without losing as much of the exchange of energy between the bat and the ball. The trampoline effect of aluminum bats results in less energy loss at impact and greater velocity off of the bat. Greater velocity means more hits and more home runs.

Interviewer: *Some people will say, if there are more hits, more home runs . . . greater offense there has to be more injuries to players.*

Manning: There is no data that supports that statement.

Interviewer: *The trend in bat weights was until recently lighter and lighter.*

Manning: Recently, the Rules Bodies have put limits on how light a bat can be for college or high school use. This was to reduce performance.

Interviewer: *If you could "construct" a good solid base hit, what would it look like?*

Manning: Well, at least theoretically, if you want the maximum distance, that ball is going to have to leave that bat at a 45º angle. That's the maximum carry path. The maximum velocity attainable is affected by the angle of the ball and the path of the bat. In many instances, you would sacrifice too much velocity to try and hit a 45º angle. There would be a lot of conditions that wouldn't allow you to hit it at 45º and get maximum velocity. In slow pitch softball, that's pretty easy to do. But it's much more difficult in baseball. For a solid base hit you want to have the bat and ball moving in the same plane and contacting the bat on the sweet spot.

Interviewer: *How significant is ball speed? Is the old adage, "the harder they come in, the harder they go out", a valid* statement?

Manning: Absolutely. In fact, one of the things I have calculated with our bat machine, which utilizes a stationery ball, is how much faster we have to swing to get the effect of a pitched ball. If you would take the 90 mile per hour fast ball as being the standard of a Major Leaguer, we have to hit 50% faster with the bat on our machine in order to get the same distance as we would if that ball were coming in at 90 miles per hour.

Interviewer: *So, if the pitcher throws a slow curve that's say, 45 miles per hour, you are going to have to swing the bat faster to hit the same distance you would with a ball that's coming in at 90 miles per hour?*

Manning: That's right, you have to supply most of the energy on a curve ball. The thing that determines how far the ball is going to travel is the initial velocity when it comes off the bat and the angle at which it comes off, with other factors such as the weather conditions. So, if a fast ball is really fired into the batter, it is going to come back faster than if it was served up nice and easy. Granted, it is harder to hit a fast ball, but when you hit it where you are supposed to, it will go farther.

Interviewer: *What should a hitter strive to do when at the plate?*

Manning: He should strive for maximum velocity and control. You want to get the maximum speed that you can and still hit the ball on the sweet spot.

Interviewer: *But what if I want to place the ball? Do physics come into play here?*

Manning: Yes, but we probably are not looking for maximum distance by a long shot, but are more interested in controlling and being able to pick the spot where we are going to hit it. So we might well want to use a different type of bat. In other words, we may be dealing with a different shape of bat, a different center

of percussion, etc. I may want to have that center of percussion and much of the weight in more towards the handle if I want to "control" the ball.

Interviewer: *Is there any way that a coach can determine if his players are achieving a maximum swing speed with a certain weight bat? Does it take a lot of money and special equipment?*

Manning: Well, you have to have some special equipment, but I don't think we are talking about a lot of money. There have been a number of devices made for golf that have been the promotional type of gimmick where you come in and just swing your club through light sensors. They let you try different clubs and you get to pick the one that you get the maximum velocity out of. I think the same kind of thing could be done with bats . . . where you could swing them and determine which bat you get the maximum velocity out of. I suspect that is what most players have done anyway by trial and error.

Interviewer: *Would it behoove a college or high school coach to discuss the actual hitting of a baseball with a physics professor?*

Manning: I think it might really be worthwhile for a coach to do this. Primarily because there are some things that you need to understand so that you can at least try to push people in the right direction. If a coach understands some of the basics of physics, he might not be coaching the same as some of the coaches seem to be. One of the things that I think would be <u>best</u> to understand is that the effect of hitting on the center of percussion is so much more significant than a small change in bat velocity. The guys going up there swinging from their heels probably could get much longer hits by swinging more in control. I think that's pretty common sense, but I sure see people, even in the Major Leagues, look as if they are swinging totally out of control, especially in the late innings when a home run will make the difference. Everyone seems to suddenly decide they are going to go up there and kill it, and when they are <u>trying</u> to kill it, they really spoil everything.

Interviewer: *How can a coach find the sweet spot or center of percussion on the bat, and how could he utilize such knowledge in helping his hitters?*

Manning: Well, you can get a pretty good estimate of it. You can grab a bat at the knob and hold it fairly loosely, and then tap it with another bat. The point where you get a totally different sound and no vibration in your fingers is generally very close to the sweet spot of the bat. Then you could mark it with a piece of tape or something, and you could stress that "this is where this bat wants to be struck". This might be one training aid in helping players hit closer to the center of percussion.

Interviewer: *Is the balance point of a bat important?*

Manning: Yes, the reason that the balance point is important is that the center of percussion is affected by the way the material is distributed in the bat, and the center of balance represents <u>one</u> factor in how that material is distributed. But I must stress that this is not as important as the center of percussion.

Interviewer: *Is the trend toward lighter bats today a sure fire answer to distance?*

Manning: I surely believe it is in the right direction. I think all things being equal, it's the most likely to yield benefits. It should contribute to the bat speed, and bat speed is most important in determining how far you hit the ball. Control, however, is also important. Too light or too heavy make this control more difficult.

Interviewer: *What should an individual look for in the bat he uses?*

Manning: Well, the only qualification I'd make is what does he want in performance? If he is looking for distance, I think we have defined pretty well what he should look for. I think that is being recognized. I'd look for the biggest barrel, lightest weight bat I could swing and feel comfortable with that satisfies the Rules at his or her level of play.

Interviewer: What physical attributes should a player develop to improve his hitting?

Manning: Well, your sight, muscle coordination, and depth perception are all terribly important to a player. He does need to have some strength, and he has to have a good sense of timing.

Interviewer: I have often heard it said that most sports revolve around "timing".

Manning: Yes, and I'm not sure just how you teach that.

Interviewer: There was a lot of discussion during the recent World Series about the seemingly large number of wood bats that were broken during play. What caused this?

Manning: One very significant reason for apparent increase in breakage is the bat that batters are stepping up to the plate with the lightest bat they can use. And the wood properties are such that when you go to light bats, they get weaker. In some instances where you get jammed, the bat is going to break. When you get to a World Series where you have the power, the capability, and the tremendous bat swing speed all putting tremendous force on light wood, you are going to have more breakage.

Interviewer: So there is the possibility that these players might be sacrificing durability for performance?

Manning: That's right, but I think I would do what they do. If they hit that ball right on the sweet spot, it probably wouldn't break. But if they hit it where they are not supposed to, it stands a strong chance of breaking. But the lightweight bat will give them greater distance if they get their swing speed up tremendously. Therefore, it's probably worth the risk as far as they are concerned.

Interviewer: What do you see in the way of future bat developments?

Manning: One of the things we are doing and talking about here at H&B is a more scientific approach to bat design. I think we are all involved in the reduction of the overall weight of the bat, making the bat more effective, and being aware and responsive to the Rules making bodies of the different games. Some of them have gone on record that they do not want the bats to perform better than present day top-of-the-line aluminum bats.

Interviewer: Do you see experimentation with different types of materials in the future?

Manning: There are going to be changes in materials. I think it is inevitable that material developments will play an important part in the future of baseball and softball bats. Even if there are performance limits, there will be economic, durability, and safety considerations.

Interviewer: Do you consider the safety of players when bats are designed?

Manning: We continually monitor all injury data compiled at all levels of play. Further, we only manufacture and sell bats that meet Rules Bodies restrictions. Let me make sure that everyone is aware that the injury data we see shows that baseball is the safest of all competitive sports at the college, high school, and youth levels and has shown <u>no</u> increases in injury levels over the last 15 years.