The Physics of an Efficient Baseball Swing Improving Power and Consistency at Contact

By Dan Galaz at Galaz Baseball Technologies © 2020

Introduction

There are many methodologies used for teaching hitters how to swing a bat. Those who teach them have good intentions and are confident that their system is the best way. They even use the words like power, kinetic energy (*KE*), kinetic chain, sequencing, torque, etc.

Without question, understanding physics laws is essential in applying to any athletic movement, whether throwing an object or swinging an object to hit another object. Physics should always be in a hitting instructor's toolbox when working with hitters. You can stand in any hitting session while a hitting instructor teaches and hear the physics concepts mentioned above. I have observed that the baseball swing (BS) physics is misapplied, misinterpreted, or both.

Some hitting instructors teach what they were taught growing up and use phrases like:

- Squash the bug
- Stay inside the ball
- Stay over your legs
- Stay back on the ball
- Swing level
- Get your back elbow up
- Punch the ball with your top hand
- Your top hand is your power hand, and your bottom hand is your speed hand

They all have meaning to those who use these phrases, but there is no physics explanation for them, and if there is, it is incorrect. Two of the phases above have a physical description covered later in this literature.

To be thorough when teaching the BS more effectively, **physics laws**, the **mathematics** it takes to prove the physics laws are correctly interpreted and applied, and the **geometry** of the swing go hand in hand.

The purpose of this paper is to bring to light the true aspects of correctly interpreting and applying the physical principles to hitting. This is done by several illustrations as the physics supports the movements.

The motion observed in the BS isn't what is actually happening unless the physics is understood together with high-speed motion capture. Unfortunately, it is difficult to calculate the kinematics and kinetics of the hitting motion correctly due to the complexity of the plethora of movement occurring in 3D simultaneously. Even computer programs cannot precisely determine what researchers seek out to improve performance. The best that can be done is to model the body using stick figures and imagine how the forces and torque sequentially transmit through the kinetic chain. Then hypothesize the results using inverse dynamics, a standard structural quantitative analysis used by biomechanists.

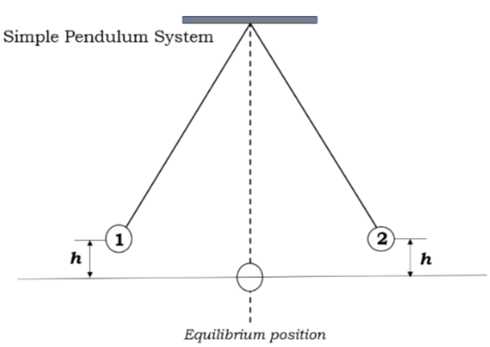
Qualitative analysis was the standard back in the day before the advent of the computer. Although still being used, but required a good eye for sound movement patterns to prescribe movement changes to improve performance. Not to mention having an understanding of how the body moves due to muscle contraction and relaxation.

In this material, there are four physics concepts and geometry used to describe the BS. These are the principles of the **conservation of angular momentum (CoAM)**, **angular impulse-momentum (AIM)**, **inertial centrifugal force** effect **(ICF)**, and **resonant frequency (RF)** theory. These laws are applied conceptually since the mathematics may be difficult. However, each of them has different insight into a more efficient swing. More specifically, producing more power and consistency at contact as the **center of**

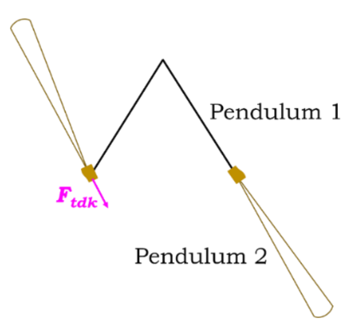
percussion (CP) or **sweet spot** of the bat stays in the hitting zone longer. Some of the variables are identical in what they represent in each of these principles. Therefore, their definitions are repeated in each section. Since repetition is a big part of learning, not only will the definitions be repeated, but so will the explanations.

The Theoretical Model of the BS

It must be prototypical after a physical theoretical model (TM) that resembles the swing to demonstrate an efficient swing adequately. That is the simple pendulum system (SPS), as shown below.



The SPS moves without a driving force (DF) since its movement only relies on gravity to return the mass from position **1** to the equilibrium position (EP) and continuing to position **2** (***h*** on both sides are equal). The TM assumptions are that the strings are massless, and there is no air resistance, which suggests that once the pendulum is released from some height ***h***, the mass swings from position **1** to position **2** without end. The BS does have a tangential DF F_{tdk} at the knob of the bat and is a double pendulum system (DPS) illustrated below.



To model the swing like a pendulum, one could superimpose the hitter over a pendulum system and see that the string attached at the top would be the hitter's axis of rotation, as shown above. Throughout this material, the TM of a SPS is used to analyze the swing using different physics principles of how a pendulum moves since there is a resemblance of action.

It should be hitting instructors' goal to teach their hitters to hit for power and consistency, from foul pole to foul pole. This paper gives an understanding of physics and geometry to clarify that concept.

The Physics of the Baseball Swing

The Conservation of Angular Momentum of the Baseball Swing

The CoAM, as it applies to the BS, helps give a better understanding of what is really happening throughout the swing. As mentioned early, motion observed in the BS isn't what is actually happening unless the physics is understood together with high-speed motion capture. The best one can do without understanding the physics of the swing is to analyze it qualitatively, which requires a good eye for sound movement patterns from muscle contraction and relaxation. However, some physics knowledge is needed to examine the BS qualitatively and quantitatively.

The definition of the principle of CoAM states that the system's total angular momentum stays in a constant state in magnitude and direction if the system is not subjected to any external forces or torques.

The CoAM is the rotational analog of linear conservation of momentum. It simply says that the system's **initial angular momentum** equals the **final angular momentum**, or angular momentum stays constant throughout the BS, written below.

$$I_i\omega_i = I_f\omega_f$$

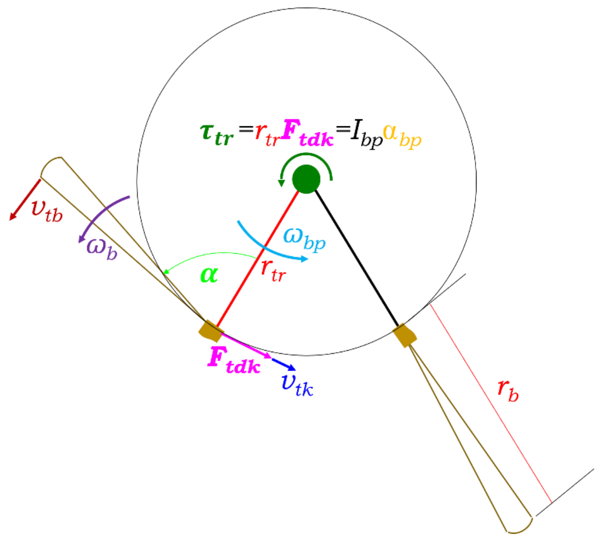
Where,

- I is the MOI of the rotating body resisting rotation and equivalent to the mass's inertia resisting linear motion in the conservation of linear momentum version.

- ω is the angular velocity of the rotating body and is the equivalent to linear velocity, as shown below.

$$m_i v_i = m_f v_f$$

The image below is the BS illustrated as a DPS with all the kinetics and kinematics variables and constants to calculate desired values.



Where,

- τ_{tr} is the torque produced at the trunk.
- r_{tr} is the radius from the center of the trunk to the bat.
- r_b is the length of the bat.
- F_{tdk} is the tangential DF at the knob of the bat produced by the torque at the trunk.
- v_{tk} is the **tangential velocity** at the knob of the bat.
- v_{tb} is the **tangential velocity** at the end of the bat.
- I_{bp} is the **moment of inertia (MOI)** of rotating body parts and is equivalent to Newton's 2nd law mass.
- α_{bp} is the **angular acceleration** of rotating body parts and is the equivalent to the linear acceleration in Newton's 2nd law.
- ω_{bp} is the **angular velocity** of the body parts.
- ω_b is the **angular velocity** of the bat

- α is the **lag angle** between the front arm and the bat and is essential to increasing bat speed covered later.

The DF F_{tdk} is the bottom hand pulling on the knob of the bat as the bat trails the bottom hand. The DF F_{tdk} is produced by a torque at the hitter's axis of rotation. The equation below is the rotational analog of Newton's 2nd law.

$$\tau_{tr} = I\alpha \leftrightarrow F = ma$$

And can is also written as:

$$\tau_{tr} = r_{tr} F_{tdk}$$

As the torque τ_{tr} is applied, the smaller the LA α is, the higher values ω_b and v_{tb} for more bat speed. Many are under the impression that snapping the wrists or positive wrist action (PWA) in the forward direction helps increase bat speed. Hypothetically speaking, it would mean that if the LA α is getting larger too early, the bat's speed would be slower through the hitting zone.

Hitters have always been taught to be forceful or have PWA with the top hand. Again, if this move is made too early, it causes the lag LA α to increase too early, decreasing the bat speed bat's tangential velocity v_{tb}. In order to maintain a smaller LA α of the bat, the torque of the trunk τ_{tr} must be applied longer for more angular acceleration α_{bp} (not to be confused with the LA α) while not allowing the top hand to start PWA. When the top hand gets involved too early, the hitter concentrates more on the PWA, and the trunk slows down. Therefore, with the understanding that a lower MOI allows for faster swing speeds, it should be a good reason why the LA α must be as small as possible and maintained longer.

For the angular momentum to be conserved throughout the entire BS, the product on the left of the equation is always equal to the product on the right. As the BS begins, the initial MOI I_i of the hitter's body parts resists rotation. As the rotation gets to the bat, the final MOI I_f of the bat resists rotation from the loaded bat position through the entire swing. Similarly, the initial angular velocity ω_i (ω_{bp}) of the body parts must diminish as the final angular velocity ω_f ($\boldsymbol{\omega_b}$) of the bat increases to keep the equation balanced. Since the mass of the body parts of the hitter is large, so is its MOI. Contrarily since the mass on the bat is much smaller, so is its MOI. Therefore, if we are to maximize the bat's velocity in the hitting zone, the equation looks, as shown below. Notice that the font size of the text of the variables shows that the magnitudes have significance. It exemplifies that MOI on the left side of the equation is larger than the left, and the angular velocity on the left side of the equation is smaller than the right.

$$I_{bp}\omega_{bp} = I_b\omega_b$$

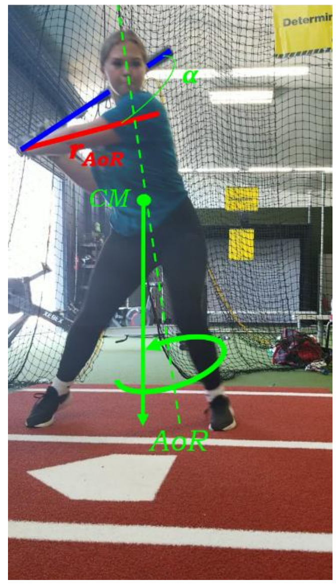
The MOI I_{bp} of the rotating body parts of the hitter is large, so ω_{bp} is very small, and the MOI I_b of the bat is small; therefore, ω_b must become very large, balancing out the equation. Although the angular velocity ω_b of the bat is important to know and understand, the tangential velocity v_{tb} is what the baseball industry relates to more. To determine the values of v_{tb}, the CoAM equation must be rewritten so that v_{tb} is visible. To do this, the CoAM equation must be rewritten in terms of v_{tb}. Since $\omega_b = v_{tb}/r_b$ and $\omega_{bp} = v_{tk}/r_{tr}$, it can be substituted into the CoAM equation, as shown below.

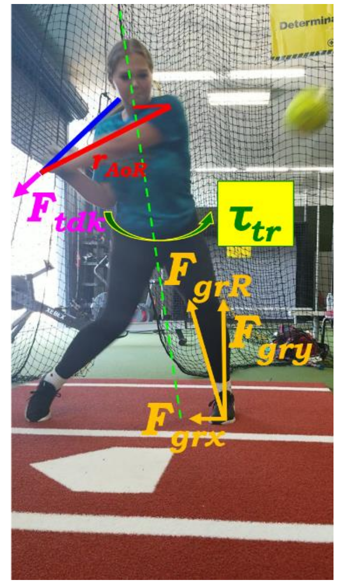
$$\frac{I_{bp}v_{tk}}{r_{tr}} = \frac{I_b v_{tb}}{r_b}$$

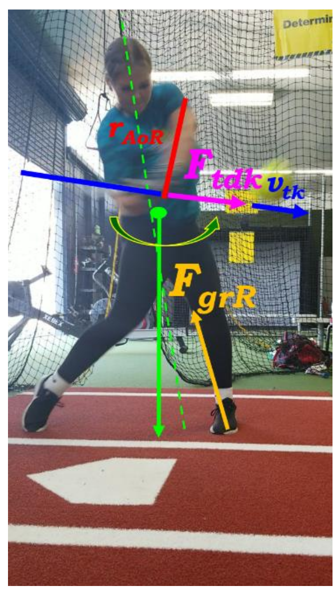
Solving for v_{tb},

$$v_{tb} = \frac{I_{bp}r_b v_{tk}}{I_b r_{tr}}$$

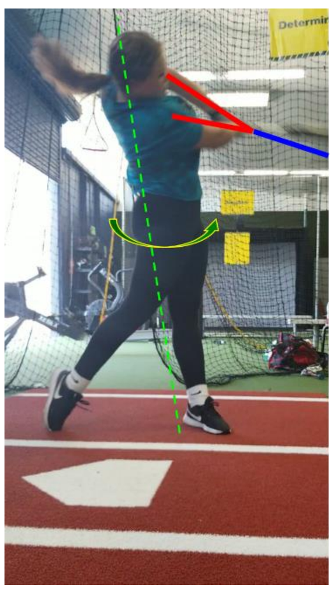
The next series of seven images demonstrates the principle of CoAM. Every image is colorfully illustrated to show kinetic sequencing and is self-explanatory regarding their description using the terminology covered in the CoAM section. Also, as mentioned earlier, geometry plays an essential role in the analysis of the swing.





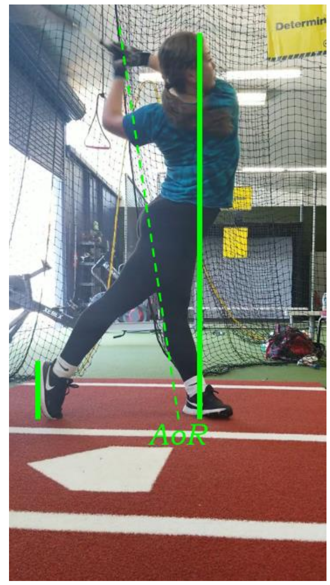


In the 1st image above, the hitter has her body and bat loaded before the swing begins. It shows the axis of rotation (AoR), the radius r_{AoR} from the AoR to the arc of the bat path where her front arm is fully braced and is a must to produce maximum bat speed. It also shows the bat lag angle α, which is an essential aspect of increasing bat speed. As mentioned earlier, the smaller α is, the faster the bat speed. Therefore, the center of mass (CM) must be as close to the center of her stance as to get the full effect driving her front foot into the ground. In the 2nd and 3rd images above, the hitter starts generating torque τ_{tr} by extending her leg as she drives her foot into the ground, and the ground reacts with a resultant force F_{grR} with both x and y components F_{grx} and F_{gry}. Notice how her *CM* stays close to the *AoR* just before and after contact in the 3rd and 4th images, ensuring maximum torque τ_{tr}. Also, the 2nd image shows the tangential DF F_{tdk} the front arm exerts on the knob of the bat as the bat passively continues to load to maintain a small LA α. In other words, avoid PWA. The following two images show the continuation of the swing as the front arm force F_{tdk} keeps pulling on the knob of the bat and α increases.



As the torque τ_{tr} continues through the hitting zone, the hitter extends her arms, making the letter 'Y' with the bat. This move is essential to increasing bat speed. Arms bent into the body decrease r_{AoR}, decreasing bat speed (tangential velocity v_{tb}). In the following image, the hitter finishes with her upper body off the *AoR*. The swing's momentum is the reason for this kind of finish and should be adopted to completely transfer the momentum of the bat to the ball.

Contrary to this is how the majority of hitters hang back on their back leg. Understandably, they are trying to increase launch angle. The natural swing plane (SP) of the bat automatically creates the correct launch angle. Hanging back on the back foot doesn't allow for the proper usage of the front leg. There is a misunderstanding of which leg is the power leg. The front leg is the power leg – **not the back leg**.



To clarify why the front leg is the power leg, a good understanding of how a pendulum works together with a linear driving force F_{grR} is applied to produce a torque τ_{tr} at the hip and trunk. The greater F_{grR}, the greater τ_{tr}, producing a larger value of v_{tb}. When it comes to swinging a bat, it is essential to know that linear forces help create more efficient rotational movements.

Another way of describing the CoAM of the BS is as the previous link's angular momentum goes to zero, increasing the following link's angular momentum until the bat's angular momentum is at its maximum. Since the bat's MOI I_b is much smaller than the larger part of the entire swing, it ultimately gives a larger angular ω_b and tangential velocity v_{tb}.

Contrary to the swing above, hitting instructors teach to increase swing launch angle by tilting the shoulders back. Angling the shoulders back is counterproductive, which assumes that the back leg is the power leg. Some or most of the energy created in the lower half of the body dissipates at the core. Many hitters have mastered hitting this way and sustained most of the oomph they have produced from the ground up, but the goal is to ultimately harness all the power created from the legs up through contact.

The following five images of a hitter angling his shoulders back to give him more launch angle. In the first two images, notice how the hitter is tilted back, and the lower body stalls, which causes his arms to stall. The arms from the 1st image to the 2nd are virtually the same, with no elongation of the arms. This suggests that there is insufficient lower force production since the front knee has not started to extend. Also, the *CM* has not moved, which does not allow for maximum torque production at the hips and trunk.

In the following two images, the *CM* has not moved, and the arms are not where they need to be represented by the red and blue lines forming the letter “Y”. Again, the lack of force produced from the ground has not allowed the arms to extend entirely, cutting the swing off losing leverage from the *AoR*. In the first two images, the top hand is starting to roll over the top hand, and in 1st at the top of the page, the top hand has fully rolled over the bottom hand due to the hitter hanging back on his back foot and PWA.

In the image below, the *CM* has remained in the exact location, and the diagonal green line is tilted back, suggesting poor momentum transfer from the ground to contact. Hence, poor bat speed. In athletics, improved power, distance, velocity is the goal. Therefore, if *CM* doesn’t move in most athletics, it indicates poor athletic movement.

The physics and geometry disprove that this swing type doesn’t produce more power due to the shoulders tilting back. Again, what provides power to the swing is the proper usage of the front leg shown on pages 4 and 5 and with the natural SP of the swing. Leaning the shoulders back only creates more problems for the hitter down the road. Not only that, the physics for hitting for power doesn’t support that ideology, and physics never lies.

The Angular Impulse-Momentum Relationship of the Batting Swing

The AIM relationship gives insight into how the duration of the swing increases or decreases the tangential velocity v_{tb} of the bat. The AIM relationship is the equivalent to the linear impulse-momentum relationship and is derived from Newton's 2nd law $\boldsymbol{F} = m\boldsymbol{a}$, as shown below.

Impulse = Change in Linear Momentum

$$\boldsymbol{F}\Delta t = \Delta m\boldsymbol{v}$$

Angular Impulse = Change in Angular Momentum

$$\boldsymbol{\tau}\Delta t = \Delta I\omega$$

Where,

- $\boldsymbol{\tau}$ is the torque applied to an object
- Δt is the duration of time the torque is applied to the object
- I is the MOI of an object resisting rotation on which the angular impulse is applied
- ω is the angular velocity of the object
- $\boldsymbol{\tau}\Delta t$ is the angular impulse
- $\Delta I\omega$ is the change in angular momentum of an object

The AIM principle is derived using calculus shown below.

$$\boldsymbol{\tau} = I\alpha \;\&\; \alpha = \frac{d\omega}{dt}$$

Substituting $\frac{d\omega}{dt}$ for α into Newtons 2$^{\text{nd}}$ law becomes:

$$\boldsymbol{\tau} = \frac{Id\omega}{dt} \rightarrow \boldsymbol{\tau}dt = Id\omega$$

If we integrate both sides of the equation, we get:

$$\boldsymbol{\tau}\int_{t_1}^{t_2} dt = I\int_{\omega_1}^{\omega_2} d\omega$$

After integrating both sides becomes:

$$\omega(t_1 - t_2) = I(\omega_1 - \omega_2)$$

and further reduces to:

$$\boldsymbol{\tau}\Delta t = \Delta I\omega$$

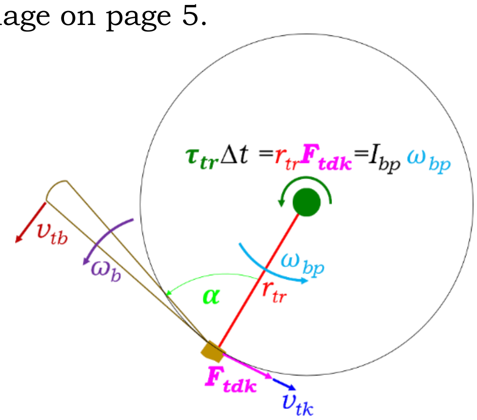
$$\tau t = I\omega$$

To make the **tangential velocity** v_{tb} appear in the equation and since $\omega = v_{tb}/r_{tr}$, transforms the angular impulse equation in terms of v_{tb}, the equation becomes:

$$v_{tb} = \frac{\boldsymbol{\tau}_{tr} t r_{tr}}{I_{bp}}$$

The significance of the variables on the right side of the **tangential velocity** v_{tb} gives us insight into increasing bat speed. The torque $\boldsymbol{\tau}_{tr}$ is a result of the drive of the leg into the ground. So, the more intense the drive, the larger the torque $\boldsymbol{\tau}_{tr}$. The radius r_{tr} from the trunk to the bat should be maintained. In other words, the front arm should have no flexion. If the front elbow flexes reduces the radius r_{tr}, which decreases bat speed. Not to mention, it would pull the CP out of the hitting zone prematurely. The MOI I_{bp} of the body parts resisting rotation could be challenging to overcome, especially if the movements are done incorrectly. All the variables covered above do have implications depending on their magnitude, but the value of t in this equation has more of a determining factor for increasing bat speed, along with a smaller LA $\boldsymbol{\alpha}$, and proper front leg usage. Substituting values for the unknowns demonstrates that higher values of t produce higher values of v_{tb}. The hitter can decide if she is going to apply the torque **tangential velocity** v_{tb} *0.44s* or *0.33s*. Therefore, the AIM principle's premise is the duration Δt the torque $\boldsymbol{\tau}_{tr}$ is exerted on a body. In this case, the longer $\boldsymbol{\tau}_{tr}$ is exerted on the bat, the faster the bat speed. Since the resultant force $\boldsymbol{F}_{grR}$ is only applied until the front leg is fully extended, the torque $\boldsymbol{\tau}_{tr}$ can be exerted as long as the hitter decides to continue to rotate.

For example, once the hitter in images on pages 4 and 5 starts her transverse rotation with the hips and trunk, she has the option to continue rotating until she gets to the position in the last image on page 5 or stop anytime after she starts her rotation. Most hitters don't get to this position since they want to concentrate more on the PWA. As mentioned earlier, when the top hand gets involved too early, the hitter focuses more on the PWA, and the trunk slows down. Therefore, if the hitter focuses on finishing her rotation, the front arm or bottom hand keeps pulling with a tangential force $\boldsymbol{F}_{tdk}$ through the hitting zone, increasing the value of v_{tb}. It's more important to continue the rotation than to try timing the PWA. The best way to do the former is for the hitter to start the swing as she drives her front leg into the ground while isometrically contracting the muscles above the hips and trunk. In other words, once the hitter has fully loaded concentrically as the trunk, front arm, the right shoulder externally rotates, as shown in the 1st image on page 4, she then drives her front leg into the ground. The angular impulse $\boldsymbol{\tau}_{tr}\Delta t$ of the trunk, as shown in the 1st image on page 8, the hitter rotates until she finishes, as in the last image on page 5.

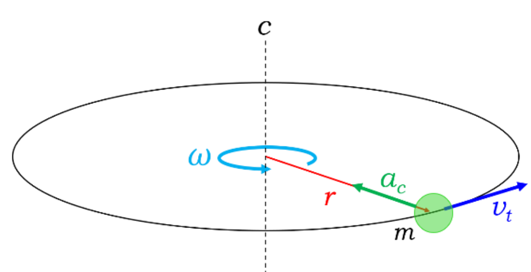


As mentioned earlier, As the torque $\boldsymbol{\tau}_{tr}$ is applied, the smaller the LA $\boldsymbol{\alpha}$, the higher values ω_b, and v_{tb} have (higher bat speed). Thus, hypothetically speaking, using the PWA would mean that if the LA $\boldsymbol{\alpha}$ is larger from the start, the bat's speed would be slower through the hitting zone. In addition, it would lend to the fact that if the hitter begins the PWA, the LA $\boldsymbol{\alpha}$ starts to become larger too early, reducing the ability to maximize bat speed through the hitting zone.

Putting it all together to increase bat speed starts when the bat is fully loaded with a decreased LA $\boldsymbol{\alpha}$, as shown in the 1st image on page 4, which aids in increasing bat speed. Next, the hitter drives her front foot into the ground with a resultant force $\boldsymbol{F}_{grR}$, which starts the swing. As the leg begins to straighten, starting a chain reaction causes the hips and trunk to rotate transversely with a rotational impulse $\boldsymbol{\tau}_{tr}\Delta t$, shown in images 1, 2, and 3 on page 4.

The Inertial Centrifugal Force (ICF) of the Baseball Swing

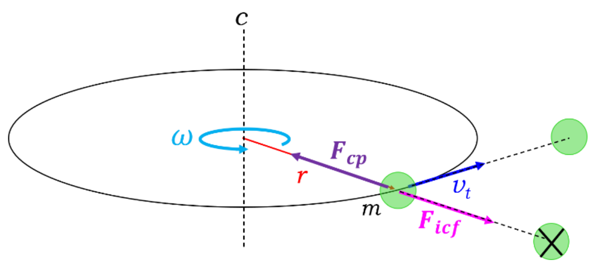
The concept of **centrifugal force** has been in controversy among those that teach physics for a good reason. Some call it a "**fictitious force**." Its counterpart is the **centripetal force** and is considered a real force and is equal and opposite in direction and magnitude due to the inertia of the object's mass. **Centripetal** and **centrifugal force** is described using the concept of **uniform circular motion (UCM)**. UCM is defined as the motion of an object of mass m moving in a circle at a constant velocity. As the object moves in a circle, it constantly changes direction and moves tangent to the circle. Since the object always changes direction as it moves in a circle, it accelerates due to the object changing direction. That acceleration, called the **centripetal acceleration** a_c, is directed inward, as shown in the 1st image on page 9.



To increase the tangential velocity v_t, what are the kinematics and kinetics we control to do so? Starting at the center of the circle out:

- increase the angular velocity ω
- increase the radius r
- reduce the mass m

To truly understand the forces involved in the swing, the two forces' definitions clarify how they affect the swing. **Centrifugal force** means **center fleeing force**, and **centripetal force** means **center seeking force** depicted in the image below.

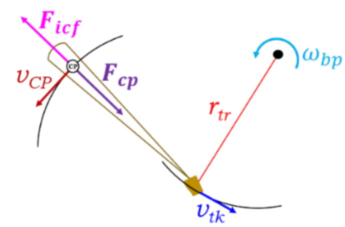


The equation for the centripetal force F_{cp} is:

$$F_{cp} = \frac{mv_t^2}{r} = mr\omega^2 = F_{icf}$$

As the disk rotates at some angular velocity ω and the mass m is at the end of a string of length r from the center c, the mass moves along the arc with a tangential velocity v_t. As a result, the mass m experiences an ICF F_{icf} directed outward (inertial since the mass is experiencing an inertial effect outward), as shown in the image above, and is counteracted by a centripetal force F_{cp} directed inward, and are equal and opposite in magnitude and direction.

If a person were rotating the mass and string, they would feel that if they released the string, the mass would release straight outward away from the center c, as shown above. On the contrary, the mass actually would release in the same direction as the tangential velocity v_t, due to Newton's 1st law. The person feels the mass would release straight because of the mass's inertia due to Newton's 3rd law. Hence, centrifugal force is fictitious since it is not going outward, but tangent to the circular disk and is the inertia's reaction to the centripetal force. So what does it have to do with BS? In the following image, as the hitter starts rotating about the center of rotation at angular velocity ω_{bp}, the bat's CP starts to swing out away from the hitter at a CP velocity v_{CP}. Similar to how the mass's inertia reacts to the ICF F_{icf}, as shown in the image across the page and as shown below.



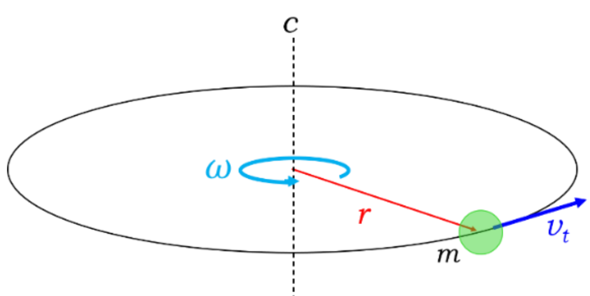
Those involved teaching how to increase bat speed or, more specifically, increasing the speed of the CP of the bat, there must be an understanding of what part of the physics of the swing can be manipulated to prescribe proper movements to maximize the speed of the CP.

Simplifying Complex Physics to an Easier to Understand Form

Complex physics is used by those who want to find a solution to a complex problem. Still, one can simplify what is being described in a difficult problem to understand it conceptually.

Since the BS is a DPS, it would take advanced physics to calculate bat speed. So, to correctly solve the physics of a DPS, one would need to use **Lagrangian** physics, which considers the difference between kinetic and potential energies and is written in position and velocity form. In contrast, **Hamiltonian** physics considers the system's total energy written in momentum and position form. These two methods are covered in calculus 3, to some degree, but heavily covered in advanced physics in graduate school. Therefore, they are way beyond the level of this material, which makes a point of this section that complex physics may be simplified if you understand fundamental physics. So, due to the complexity of these advanced physics procedures, the mathematics is not included in this material since it is long, complicated, and tedious.

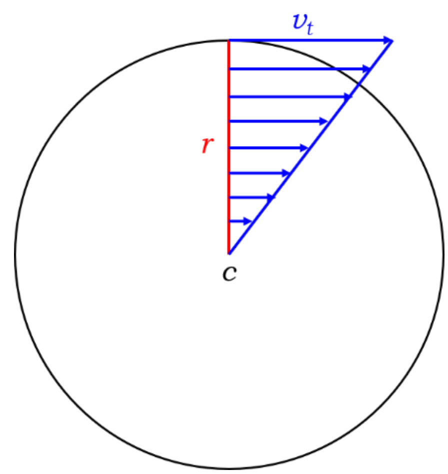
Although there are instruments that give bat speed readouts, that doesn't provide insight into what helps increase bat speed. For instance, if a device gives a bat speed readout, a hitting instructor can prescribe a movement they may think increases bat speed as a trial and error. Whereas, if one understands the physics of each movement in the swing, there is no try and error necessary. For example, suppose we use the UCM theory. In that case, as shown below, one can interpret how to increase bat speed by understanding what would increase the object's tangential velocity v_t moving on a circle.



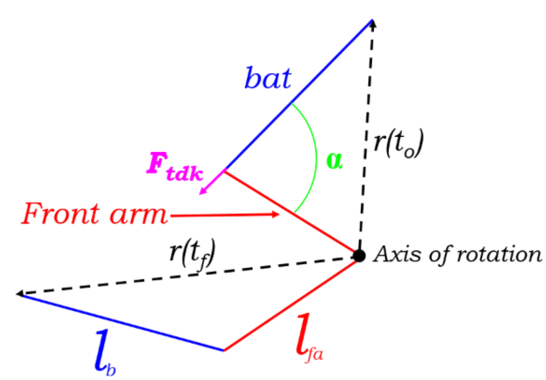
By observation, there are three options to increasing the object's tangential velocity v_t:

- Increase the angular velocity ω
- Increase the radius r
- Reduce the mass m of the object (the bat)

To increase ω, one would have to increase the strength and power of the hitter and improve the sequencing of the whole swing. To increase r, the length from the *AoR* c to the mass m must increase. Lastly, reducing the mass of the bat goes without saying.
As mentioned earlier, the swing is a DPS, and due to the complexity of the physics, it would not be easy to understand how to increase bat speed. This is where one can simplify complex physics theory to an easier-to-understand form.
To premise the notion of simplifying complex physics to a more straightforward method starts with increasing the radius of circular motion increases the tangential velocity of the object as it moves around the circle, which is a hitter's goal. The image below illustrates how v_t increases with an increase in radius.



As the radius increases, so does the MOI (the resistance of an object to rotate increases). If the MOI is too high, it doesn't allow for higher swing speeds. Consequently, there must be an application of a technique that enables the radius r to start small with a low MOI. A low MOI at the beginning of the swing begins by keeping the lag angle α as small and as long as possible, as shown in the image below.



Also, in the same image, the radius starts at $r(t_o)$ and as $r(t_f)$ increases with time, making the radius a function of time. As the tangential force F_{tdk} is applied at the knob of the bat initially, the lag angle α and initial radius $r(t_o)$ are at their smallest, and both increase as $\boldsymbol{F_{tdk}}$ is continually applied. As $\boldsymbol{F_{tdk}}$ is applied until contact, the bat's barrel experiences an inertial centrifugal force $\boldsymbol{F_{icf}}$ covered in an earlier section, causing the bat's barrel to continue to speed up until contact. In an actual swing, the final radius $r(t_f)$ never reaches a length of l_b + l_{fa}, but is at an optimal length before contact while the barrel continually accelerates through the ball.

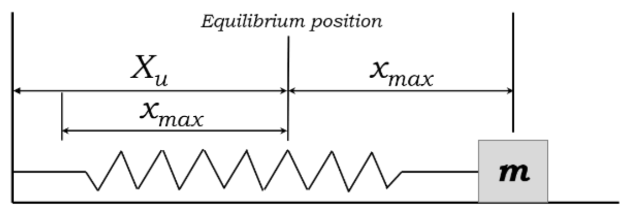
For this concept to be optimized, there must not be any PWA mentioned earlier in this material. The reason is, if the radius $r(t)$ increases too fast, it increases the MOI of the swing, therefore not allowing for maximum bat speeds. In other words, since the MOI is increased too early, it increases the barrel's resistance to swing out through the hitting zone at an optimum speed.

The Resonant Frequency of the Batting swing

Everything globally has its unique **natural frequency (NF)** of movement or vibration called the **resonant frequency (RF)**. NF is equal to RF as long as there is no dampening in a system; therefore, RF and NF are interchangeable. RF is when a system can store and easily transfer from one energy form to another. Such as **potential energy (*PE*)** (stored energy), also known as **elastic energy**, which converts to **kinetic energy (*KE*)** (energy of motion) in an oscillating system due to the **conservation of energy** principle, where a system oscillates at its natural or unforced resonance.

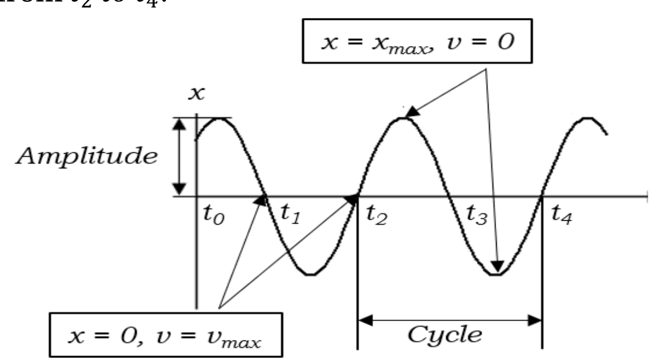
The Model of Resonant Frequency

An RF movement is rhythmic and temporal and behaves like a clock or a **harmonic oscillator (HO)**.[1,2] Shown in the following image is a spring and mass system that oscillates with minimal effort. The system performs **simple harmonic motion (SHM)**, consisting of a spring attached to a mass on one end and a wall on the other, assuming no air resistance damping the mass's movement on a frictionless surface. X_u is the spring's unstretched length, and the mass sits at the equilibrium position (EP) undisturbed and is at rest. If the mass is pushed or pulled from its EP, the spring exerts a restoring force to bring the mass back to equilibrium with **rhythm** and **tempo**. However, whether the mass is pushed or pulled, the system is forced into a *PE* state when released and converts to *KE*.[3] Theoretically; the mass oscillates back and forth from one side of the EP to the other at equal distances x_{mass} endlessly due to no air resistance and frictionless surface, not dampening the mass's movement.

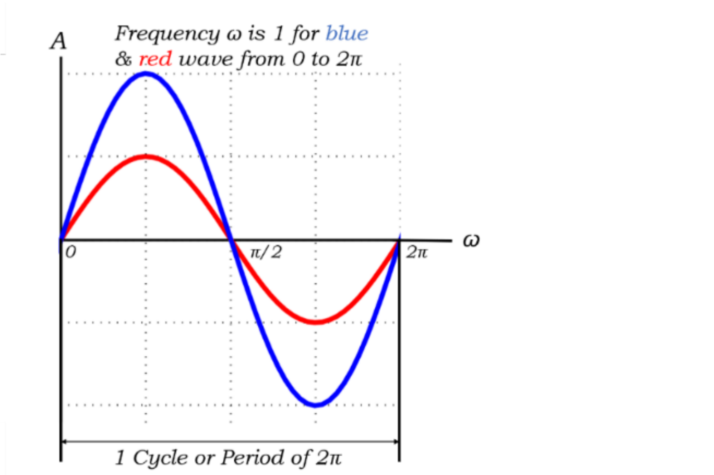


Harmonic Ocsillator

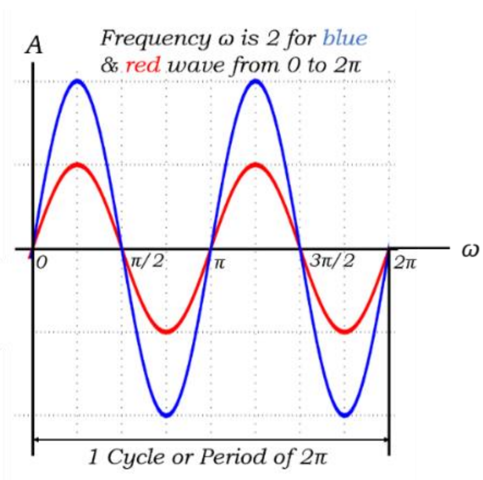
The displacement (amplitude) versus time is a sinusoidal graph below representing the HO above as the mass moves back and forth on either side of the EP.[4] The graph describes the position of the mass as time goes from time t_0 to t_4 where $v = 0$ at x_{max} and v_{max} at $x = 0$. The frequency of the wave is within 1 cycle from t_2 *to* t_4.



If the frequency is more than 1, say the frequency is 2, then there would be two waves within 1 cycle or period of 2π, whether it be the blue function or the red, as shown in the following image. Also shown in the following sinusoidal amplitude (A) vs. radians graph with two waves with different amplitudes; the blue wave is larger, representing more energy. So both waves have a frequency of 1 showing one wave in 1 cycle or a period of 2π, and *ω* is a radian frequency (rad/sec).



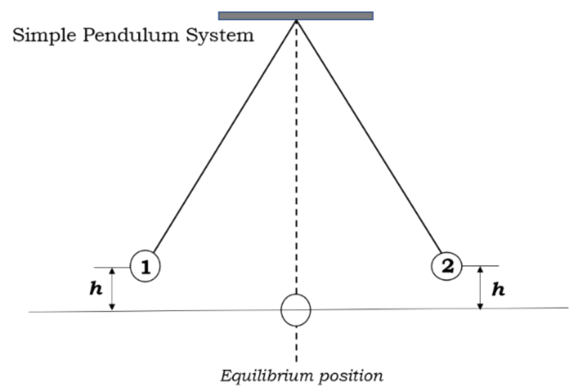
Below is the same graph as above with double the frequency showing two waves in 1 cycle or a period of 2π.



The question is, **"how do we find the RF of a system?"** When the system moves with the least amount of effort or with the least energy. When a system moves outside of its RF, more energy must be generated to keep it moving. Therefore, the more energy spent, the less efficient the system is. A better representation of how a hitter should move is a **simple pendulum system (SPS)**. Although a hitter is a **double pendulum system (DPS)**, the concept still applies. A thorough understanding of RF's theory could revolutionize how hitters are taught to move more efficiently to increase bat speed and consistency at contact.

A Simple Pendulum System Modeled as a Harmonic Oscillator

The figure below is an SPS used to demonstrate a HO system moving at RF. To describe how an SPS mimics an HO, we must identify the SPS's analog construction to a HO. For example, a mass attached to some ceiling support assumes that the cord is massless and has no air resistance on the mass. In this case, the restoring force is gravity endeavoring to bring the mass to its EP experiencing SHM. As the mass undergoes SHM, it goes back and forth from position **1** to position **2**, converting from *PE* at position **1** to maximum *KE* at the EP. From the EP to position **2**, the system converts from *KE* back to *PE* from the EP to position **2**. The same process happens from position **2** to position **1**, completing the cycle.



The word '**harmonic**' pretty much says it all derived from the word '**harmony**,' which means the mass oscillates from position **1** to position **2** and back to position **1** with minimal energy and effortlessly in the theoretical model. In other words, the energy within the system keeps the pendulum moving due to the **conservation of energy** principle written below.

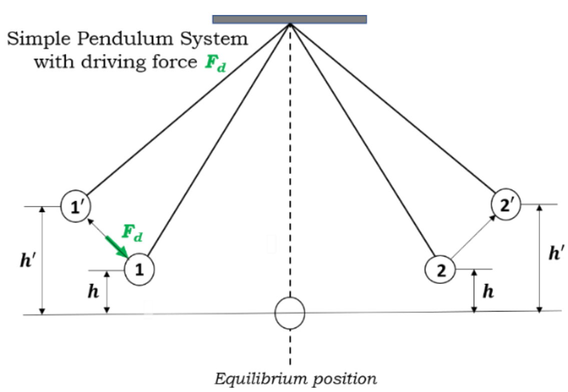
$$PE = KE \rightarrow mgh = \frac{1}{2}mv^2$$

Where,

- m is the mass of the ball

- g is the gravity constant
- h is the height of the mass to the bottom of the arc at the EP
- v is the max velocity of the ball passing through the EP

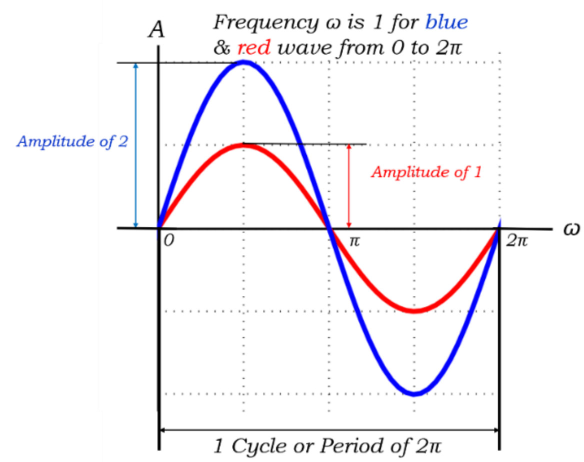
During the hitting motion (PM), the driving force (***F_d***) should be introduced to the system at the precise time to increase the amplitude of the hitter's RF through the hitting zone, therefore improving the system's energy production to increase maximum output while conserving energy. If we observe the displacement versus time graph on page 2, the graph has an absolute amplitude. To increase the system's energy production, we must increase the amplitude. Introducing ***F_d*** at the perfect time to not disrupt the system's RFs, increasing the system's amplitude illustrated by the red wave rising to the blue wave shown in the two images on page 8; it increases the *PE* and *KE.* If ***F_d*** is introduced at position **1** as it returns to position **1**, the mass starts its way back to position **2**, not interrupting the system's natural frequency (RF), as shown in the first image below.[5]



As mentioned earlier, the ***F_d's*** timing should not interfere with the SPS's RF to increase the system's energy, enhancing the output. When introducing the ***F_d*** to the system increases its *PE* from position **1** to position **1'** (**1** prime) and position **2** to position **2'** due to increasing ***h*** to ***h'*** (***h*** prime), increasing its *PE*, therefore, increasing its *KE* due to the conservation of energy principle. Where ***h'*** is directly proportional to the square of the velocity, the higher ***h'***, the greater the velocity v'^2 when the mass passes the EP. So, the new formula for the conservation of energy of the system is:

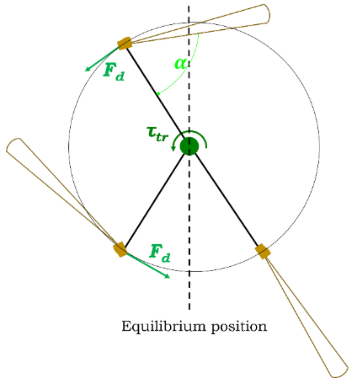
$$PE' = KE' \rightarrow mgh' = \frac{1}{2}mv'^2$$

Even though the energy of the system has increased, the RF remains the same. As the amplitude increases from ***1*** to ***2***, as shown below, the wave still crosses the ω axis at 0, π, and 2π. Therefore, maintaining the RF of the system. The importance of preserving the RF while increasing the output requires less energy; hence, **effortless motion**, demonstrated by hitters that maintain their RF. The red function represents the *PE* at the height ***h*** of the SPS with no ***F_d***, as shown in the last image on page 9, and the blue function describes the PE' at the height ***h'*** of the SPS with the ***F_d*** introduced in the same image. Increasing the PE' of the system increases the KE', increasing the velocity, in this case, bat speed.

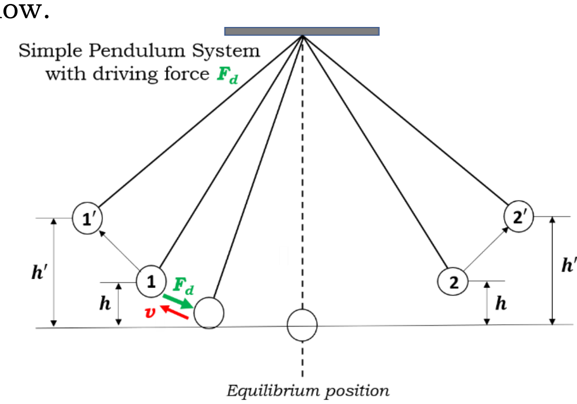


Although the hitting motion is a double pendulum system (DPS), the single pendulum model serves its purpose of describing the hitting motion HM. The physics of both are similar, although the mathematics of the DPS is very rigorous.

Below is the swing modeled as a DPS with a driving force $\boldsymbol{F_d}$.



The first pendulum in the above image hinges at the trunk center, and the second at the hands. A driven force $\boldsymbol{F_d}$ should be exerted at the right time, so the swing's RF is maintained while increasing the system's amplitude and increasing the system's energy simultaneously. To accomplish this, the hitter must move into the bat-loaded position smoothly and rhythmically, similar to how a pendulum swings back and forth. The forward swing must not start forward immediately after the bat load has been completed since the front leg has not fully planted. Starting the swing too early would interfere with the hitter's swing's RF. Also, starting the swing too early would be as if the $\boldsymbol{F_d}$ is applied before the pendulum reached ***h*** or ***h′***, which is still moving toward ***h*** or ***h′***. At this point, the hitter is fighting the bat's inertia, which is still moving with some velocity $\boldsymbol{v}$ toward heights ***h*** or ***h′*** and positions **1** or **1′** in a collision course with $\boldsymbol{F_d}$, as shown below.



The Geometry of the Baseball Swing

It is without question that the laws of physics and geometry go hand in hand. It would be challenging to solve physics problems without a geometrical sketch or a free body diagram illustrating what is happening to come to some mathematical solution while applying physics – demonstrated throughout this material. Although there were not any calculations, all the physics was theoretical.

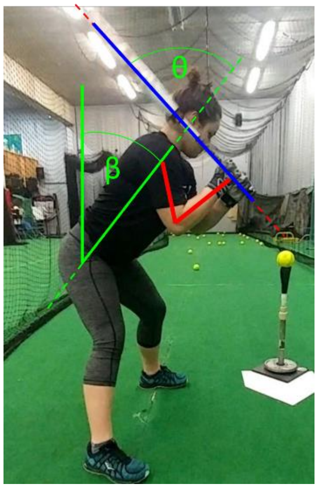
Hitting for power and consistency from foul pole to foul pole has to do with how long the CP of the bat stays in the hitting zone. A good understanding of the geometry of the swing brings insight into those very facts.

Putting physics and geometry together starts with **'the eight pillars for hitting for power and consistency.'**

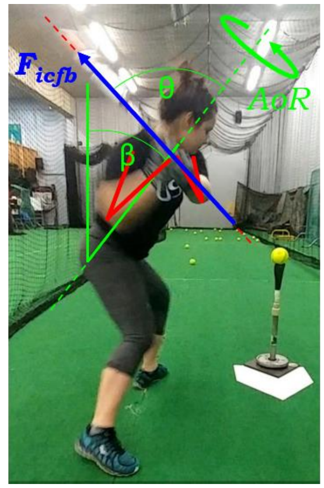
1. Load the bat with the proper LA α
2. Maintain the smallest LA α from the start of the swing through the hitting zone
3. Maintain spine angle SA β
4. Maintain SP from the start of the swing to the finish
5. The front leg is the power leg due to the geometry position (not the back leg)
6. Pull the knob of the bat throughout the entire swing to the finish (no PWA or wrist-slap)
7. Release the back foot
8. Look inside and adjust outside

In the 1st image on page 15, the hitter starts with her stance evenly distributed between both feet just before she loads the bat, where her arms are relaxed as they hang down, illustrated with red lines. Having her arms hang down allows the bat to fall into the SP more naturally. It also relieves tension in the shoulders instead of how most hitters start with the back elbow very high, gripping the top hand too tight, which forces the bat to fall into the SP later in the swing and cause casting of the barrel of the bat. The red dotted and green dotted lines represent the relationship between the bat's SP and the *AoR* angle θ of the body throughout the entire swing, respectively.

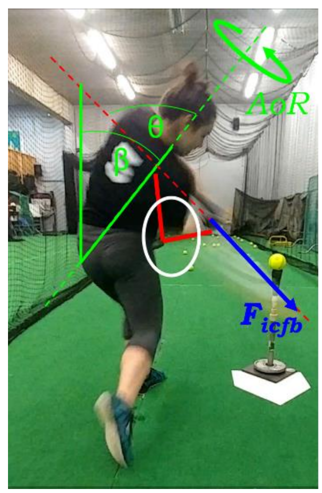
Illustrated throughout the entire swing is the hitter's SA β that must be maintained through contact, allowing the bat to stay in the hitting zone longer. In the 2^{nd} image below, the hitter loads the bat to a proper LA *α* between the bat and the front arm in red. As mentioned earlier, the smaller the LA *α*, the more bat speed is produced.



In the following four images, the hitter starts her swing as she starts to drive the front foot into the ground pulling the knob of the bat to the ball, and the bat begins to lay into its SP, as she maintains a small LA *α*. It is vital to understand what causes the bat to start to pull out of its SP – it's the bat's ICF F_{icfb}, as shown in the last four images. Pulling the knob of the bat to the ball as she pushes her front foot into the ground keeps the MOI as low as possible throughout the swing allowing higher bat speeds. The PWA movement causes a higher MOI of the swing reducing bat speeds. A PWA movement also forces the bat out of the SP. The hitter's hands and bat must remain on the dotted red line where the barrel of the bat throughout the swing until it finishes where it started at the load. If this is accomplished, the hitter will be able to elevate balls at the knees and below. Pitchers are told to keep the ball down, but this is a weapon, so to speak, that helps hitters expand the zone on hittable balls where pitchers try to use low balls as part of their tactics on winning the battle.

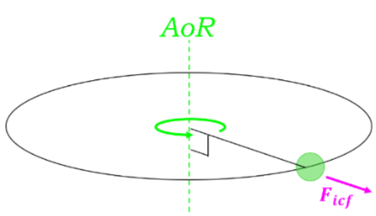


In the 2^{nd} image above and the following three images, the white oval shape show how the right elbow connects to the right side. This right-side connection occurs when the hitter drives her front foot into the ground and pulls the knob of the bat toward the ball, again avoiding PWA.

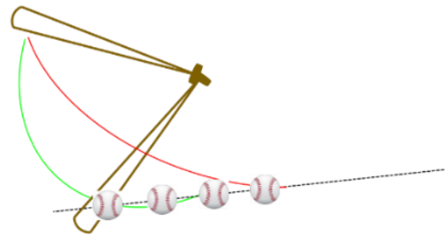


It is also essential that the back foot releases as she drives her front leg into the ground, as shown in the last five images if the hitter is to hit the ball to the opposite field more efficiently. Also, in images three to six, the blue arrow representing the bat and the ICF F_{icfb} of the bat are experiencing as the hitter transversely rotates about her *AoR*. An important note concerning the relationship between the SP represented by the dotted red line and the dotted green line of the *AoR*, the angle θ should be 90^0 because of the ICF F_{icfb}. Thus, the hitter finishes with the bat pretty just off the red dotted line, maintaining her SP, which is 90^0 off her SA represented by the green dotted line, as shown in the image below.

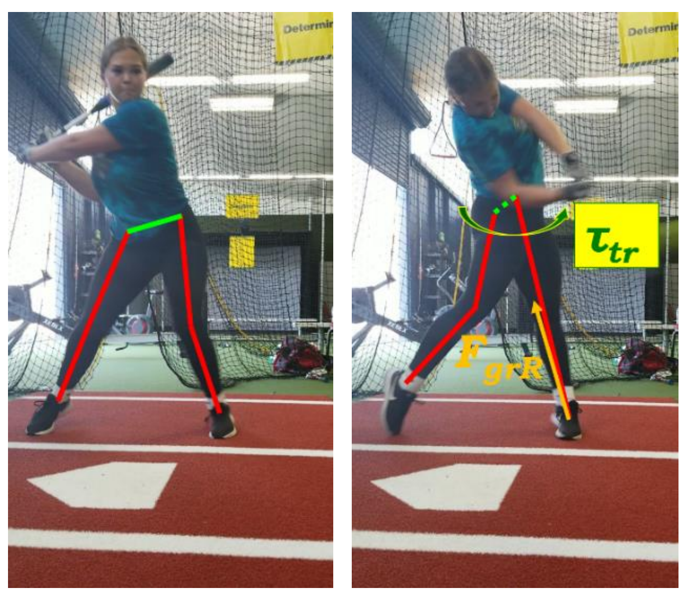
To further clarify why the angle θ is close to 90^0, it should make sense that if a rotating body is spinning about its *AoR*, whatever is attached to the *AoR* swings out at 90^0, as the green ball experience an ICF $\boldsymbol{F_{icf}}$, as shown below.



For this reason, the PWA forces the bat off the SP since a forceful snap of the top hand would pull the bat off flatter to the left side of the hitter. As a result, the bat would finish below the number considerably below the red dotted line. Therefore, the bat should finish even or above the red dotted line. If the bat's SP is genuinely understood, one would need to understand the geometry of how the bat is tracing through the strike as the bat remains in its SP. With this insight, one can ascertain that the SP gives the ball loft as it leaves the bat and not where the hitters tilt their shoulders up to increase the launch angle. As the pitcher releases the ball from the mound, the ball's downward trajectory toward home plate is around 3^0 to 6^0 below horizontal. Therefore, the proper SP would allow the bat to meet the ball upward along the 3^0 to 6^0 trajectory from the pitcher's hand. This would enable infinite points of intersection where the bat can meet the ball instead of how hitters are taught to swing down through the ball with a PWA, which only allows one point of intersection represented by the red path, as shown below.

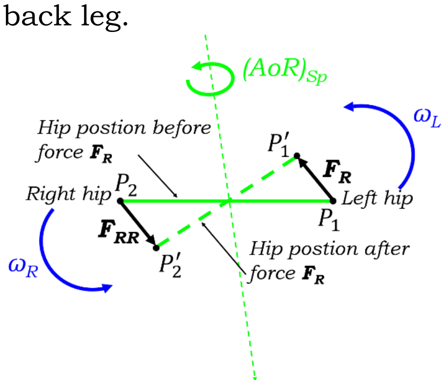


Since the red path to the ball is downward, it makes sense why hitters are taught to angle back to give the ball loft, which is unnecessary since the upward path of the bat illustrated by the green arc provides the ball with loft. Furthermore, angling back doesn't allow the hitter to unload the full potential of energy the hitter can unleash on the ball since they hang back on their back leg. Not the mention what was covered earlier – **the front leg is the power generator, not the back leg!** If the rear leg were the power leg, it would be fully extended because that is how power is created from the ground and up the kinetic chain. The stick figures superimposed over the hitter are illustrated in the two images below.



In the 1st image of the last two images on page 16, the hitter is in the loaded position. The front leg is bent until the hitter is ready to drive the front foot into the ground, and the hips are facing the camera, represented by the green line. The back leg supports the hitter's body and should not be used to push the hitter forward (the back leg should be almost entirely extended, keeping the hitter's weight over the front leg), which is what the status quo teaches. The 2nd image demonstrates the front leg driving the front foot into the ground with a resultant ground force $\boldsymbol{F_{grR}}$. As the front foot is driven into the ground, a chain reaction occurs. First, the front hip is driven away from home plate, shown by a dotted green line. This action creates a torque $\boldsymbol{\tau_{tr}}$ that rotates the upper body, which in turn accelerates the knob of the bat toward the pitcher and ultimately the barrel of the bat, more specifically, the CP.

Applying the fundamentals of machine dynamics theory for hip mechanics with the assistance of a free body diagram demonstrates how the front leg's drive into the ground confirms that the front leg is the power leg and not the back leg.



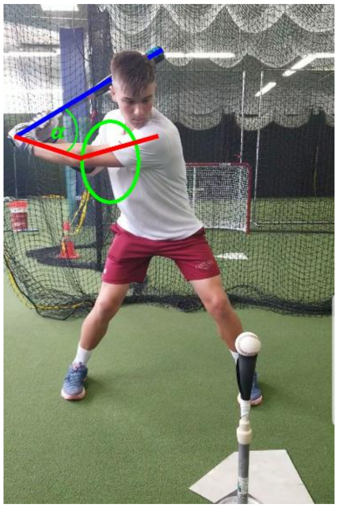
A solid green line represents the hip at the point $\boldsymbol{P}_1$ and $\boldsymbol{P}_2$ as the starting position. As the resultant force $\boldsymbol{F_R}$ is exerted on the left hip due to the front leg pushing into the ground, the green line rotates about the spines axis of rotation $(AoR)_{sp}$ illustrated by the dotted green line as the point $\boldsymbol{P}_1$ moves to point $\boldsymbol{P}_1'$ causing an angular rotation ω_L of the left hip. Also, point $\boldsymbol{P}_2$ moves to point $\boldsymbol{P}_2'$ due to the reaction force $\boldsymbol{F_{RR}}$ causing an angular rotation ω_R of the right hip, and ω_L equals ω_R. The hip mechanics demonstrated in the diagram above show that the BS starts with a linear force and not a body's rotational force. The rotational forces of the BS are due to the front leg's linear force into the ground and the ground reacting with an equal and opposite force (Newton's 3rd law), initiating the swing and the muscles in the hips and trunk engaging afterward.

In this method, hitters must land on the front leg to about 60% to 50% of their weight to maximize bat speed. Contrary to the consensus methodology, hitters put 60% of their weight on the back leg and 40% on the front. The latter negates the full potential of correctly generating the ground reaction forces and transmitting them efficiently through the hitting kinetic chain. The 60-40 method is susceptible to hanging back on their back leg and swinging with their shoulders pulling off the ball. Not to mention not being able to use the front leg effectively. Also, the 60-40 method implies that the back leg is the drive leg. Driving with the back leg doesn't effectively produce the torque to get the hips to rotate powerfully. If a hitter drives with the back leg, it creates a linear movement toward the pitcher. The 60-40 method works to some extent because the hitters land with a slightly bent front leg, allowing for some drive of the front leg into the ground producing some torque at the hips. However, there are some hitters who put more weight on the front leg allowing them to create more torque at the hips.

What happens with the back leg? As mentioned earlier, the back leg must release off the ground for several reasons. 1st, it allows for maximum torque at the hips. 2nd, it enables for hitting for power from foul pole to foul pole. 3rd, it provides for a better path to the ball. Finally, it allows to better adjust from the inside pitch to the outside pitch.

Swinging with Power

The true essence of swinging for power is connecting the lower and upper body, contrary to what is taught everywhere. That is driving the front leg into the ground with a resultant force F_{grR} and pulling the knob of the bat with a tangential force F_{tk} to the ball simultaneously with an almost totally brace front arm illustrated with red lines, presented below, becoming one movement.

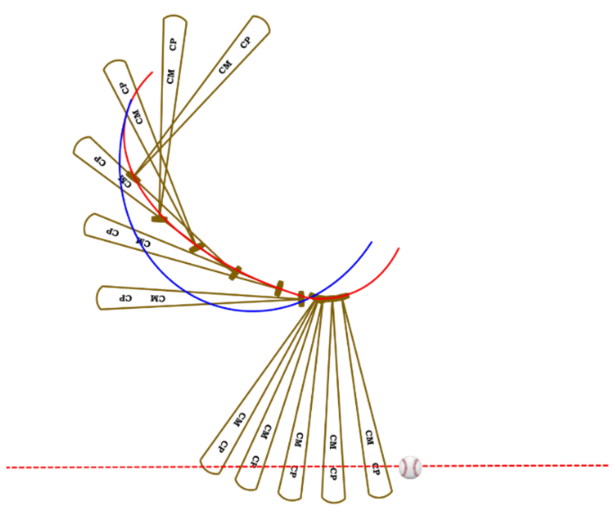


It also includes the right elbow working cooperatively with the push-pull by connecting to the right side illustrated with a green oval, as shown in the two images above and the next two below. As the front leg pushes into the ground, it allows for a more natural transverse hip and trunk rotation and a back foot release shown in the following four images. As mentioned earlier, the back foot's release is a must for hitters to hit for power to the opposite field. If the back foot stays anchored back where it started, it forces the hitter to pull strictly.

Combining the right elbow's movement to the hitter's right side as he drives his front leg into the ground and pulls the knob of the bat to the ball improves his ability to transfer the power from the ground up more efficiently. In addition, the right elbow attaching to the hitter's right side ensures the LA α remains a small as possible, which improves bat speed, as mentioned earlier, and allows the lower and upper body to stay connected throughout the entire swing. If the right elbow doesn't connect with the right side of the swing requires a PWA.

If the swing is done correctly through contact, the arms and the bat form the letter 'Y' represented by the red and blue lines as shown in the 1st image above. Also, the hitter's weight transfers smoothly to the front side as his back foot finishes heel-over-toe, illustrated with the vertical green lines, as shown in the 2nd image above.

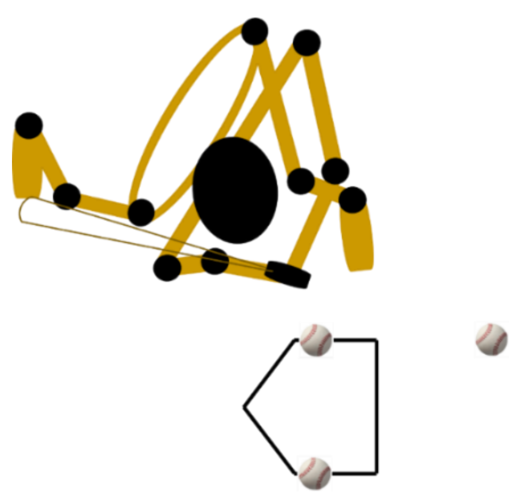
Another reason the right elbow must connect to the hitter's right side is that it allows hitters to hit the ball to the opposite field more efficiently and with power, as illustrated with the green ovals in the images of the hitter in images one through four. The hitter must also continue pulling the knob of the bat through the ball and not produce any PWA through contact. The physics that supports this movement comes from two physics principles. The first principle is the CoAM, demonstrated in many physics books of a skater spinning at some angular velocity ***ω*** with her arms away from her body. As she brings her arms closer to her body, her angular velocity ***ω*** increases. The second concept comes from understanding MOI. Since MOI means resistance to spin or rotate, if her arms are away from the body, it makes it hard to spin as fast she can. Therefore, if a hitter's arms fly away from the body too early, swinging a bat is difficult since it would feel heavier. Contrarily, if the arms stay close to the body, it reduces the MOI, making the swing easier while increasing bat speed. Also, If hitters get their back arm connected to the side of their body as they pull the knob to the ball, it keeps the bat close to the body as it shortens the path the CP takes to the ball as it decreases the MOI of the swing increasing swing speeds. The image below shows how shortening the path to the ball illustrated by the red arc by keeping the back arm close to the body would also lengthen the CP's time in the hitting zone. The blue arc is the path most hitters take produced by a PWA, a longer path and shortens the time the CP (the CP spans about 5 to 6 inches from its center) stays in the hitting zone. This illustration also confirms that changing the geometry of the swing can improve the output of the swing.



Another reason the back arm should stay close to the body is that the bat's CP is better directed to the ball. The bottom or lead hand pulls the knob of the bat toward the ball with a force **F_{tk}**. As the hitter's arms and bat start to fully extend, the CP is directed through the ball's plane of trajectory. Since the CP is in the same line as CM, the CP has to replace the knob of the bat as the CP is led through the ball's plane of trajectory toward home plate, again because of the ICF.

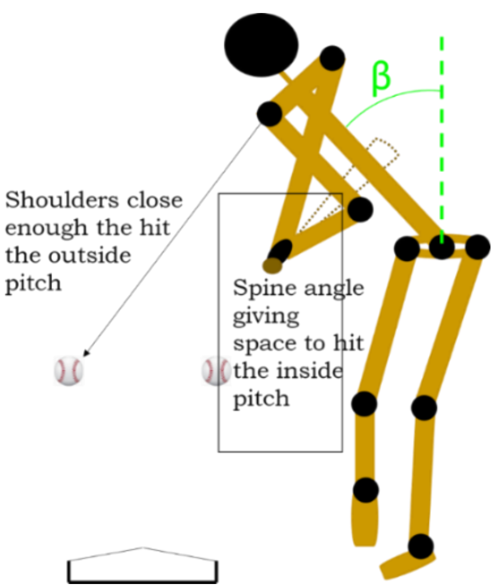
Without question, Combining the right elbow's movement to the hitter's side as he drives his front leg into the ground and the lead hand pulls the knob of the bat to the ball is the most efficient way to produce power from the ground through the hitting zone. This movement works together with maintaining the SA and SP. Emphatically, this single combination of movements produces more bat speed from the ground through the hitting zone than any other technique. This action is the **biomechanical** movement called the **push-pull principle**. As the front foot **pushes** down on the ground, the lead hand **pulls** on the knob until the CP finishes through the hitting zone. **This technique allows the CP to be short to the ball and long through the ball, keeping the CP in the hitting zone longer.**

Another important note to be clarified is what is taught, even at the major league level. Hitters are instructed to go for the outside fastball and adjust to the inside fastball, which is physically impossible. The image below shows, let's say is a 95 mph fastball on the outside and inside part of the plate.



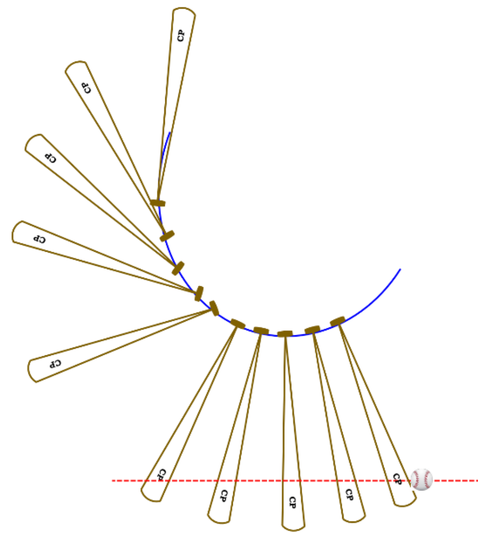
It should make sense that it's physically impossible to go for an outside fastball and adjust inside when hitting an outside pitch requires the hitter to let the ball travel. Since the inside fastball would be at the same location depth-wise as the outside fastball, as shown in the previous image. The hitter would not have a chance to adjust to the inside fastball. For the hitter to get to the inside fastball, he would have to hit the ball further in front of the plate, as shown in the same image. Therefore, the hitter should look inside and adjust outside.

Another reason why hitters should maintain their SA β is to create space to hit the inside pitch and put the shoulders in a great position so the arms can reach the outside pitch, as shown in the image below.

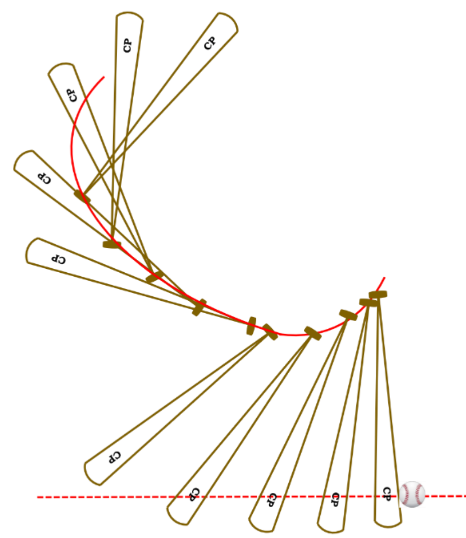


<u>The clarification of Why PWA Should Be Avoided</u>

PWA is the casting of the barrel, whether it is done early or later in the swing. The less experienced hitters tend to cast earlier in the swing than the more experienced hitters and occur when the top hand is too dominant. It usually happens when the hitter hits from their dominant arm side. The following image is the arc in blue the knob takes for hitters that are top hand dominant. Notice how the CP is in the path of the ball back in the hitting zone and out front of the hitting zone. This type of hitter would have to bring his hands closer to his chest to ensure he hits the ball at the CP, which would reduce bat speed since it decreases the radius r_{tr} from trunk's *AOR* to the knob of the bat ultimately to the CP.



In the image below shows the path of a hitter who is bottom hand dominant.



Usually but not always, this type of hitter swings on their non-dominant side and tend to grip tighter with their bottom hand pulling more on the knob of the bat, making them bottom hand dominant. Observe how the CP stays in the path of the ball longer when the bottom hand pulls on the knob of the bat.

Regardless of which hand is the predominant hand, hitters should make the bottom hand the dominant hand during the swing to help increase bat speed and more consistent contact.

Conclusion

Self-made instructors in baseball make claims in their teaching methods that don't coincide with physics laws. Not everyone would take the time to study physics before teaching hitting or pitching for a good reason. Physics is probably the most challenging and time-consuming class anyone could take, but if anyone is going to teach anything that requires motion, they need to take the time to understand why and how things move the most efficient way. Many may think they understand the physics of what they teach, causing interpretation and application.

"In Russia, no one is allowed to work with their top athletes and dancers without a degree that requires physics or a major in engineering." ***Anna Karamuzin***

Throughout this material, several physical principles, with the help of geometry, were presented to describe the BS to give the richness of how physics is applied to improve efficiency and how to use physics to improve performance. Below are some examples of what hitting instructors should be interested in:

1. Where is the power of the swing created?
2. How do you create bat speed?
3. How do you maintain the power production throughout the swing?
4. What is the optimum angle the bat should have before it goes through the hitting zone?
5. What keeps the CP of the bat in the hitting zone the longest?
6. How do you hit for power to the opposite field?
7. How should you hit the inside and outside pitches?

Other mechanical principles and geometry may be applied to the BS, again due to the richness of physics. Applying physics does not require rigorous calculations but a conceptual understanding. As one gets familiar with the equations representing each principle and what the variables and constants represent, one eventually envision what is physically happening throughout the entire swing.

A good understanding of the methodology covered in this material gives insight to anyone who wants to improve their knowledge of taking the CP short to the ball and long through the hitting zone while increasing bat speed, as mentioned earlier. Doing so allows the hitter to be proficient in hitting the ball from foul pole to foul pole with consistency and power.

This knowledge can also be an excellent tool for scouting opposing hitters since this system develops hitters to hit from foul pole to foul pole. Therefore, opposing teams would have to play hitters straight away. So, yes, opposing pitchers like Greg Maddux could make hitters hit the ball where he wanted them to go. Still, there are not many pitchers like Greg now at days that could sustain command on both sides of the plate with all his pitches to strategically force a hitter to hit the ball in the desired direction. Greg Maddux is probably the best control pitcher of all time, without a doubt. What made him great was not that he could command both sides of the plate but that he could pick out hitters' tendencies and attack those weaknesses.

There is a plethora of predispositions hitter exhibit that may be a weakness. For example, hitters that hang back on their back leg tend to pull the ball, roll over, or flare the pitch to the opposite field. Therefore, pitchers should live on the outside part of the plate on a strictly pull hitter. Yes, great pull hitters can adjust to pitches on the outer part of the plate, but they also have to look away from their strength – middle and in. Now their strength can become their weakness.

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