A STUDY OF SOFTBALL PLAYER SWING SPEED*

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A field study was conducted to measure the effect of a bat's weight and mass moment of inertia (MOI) on the swing speed. The study involved 16 amateur slow-pitch softball players of two skill levels and two groups of bats. One bat group had a constant MOI, but varying weight, while the other group had constant weight, but varying MOI. Players were assigned to either the constant MOI or constant weight group of bats and asked to swing at pitched softballs, using each of the five bats in that group ten times. Bat motion was recorded using high speed video for each swing. The results from the batters were combined by normalizing each swing speed to the respective batter's average. The swing speed of the constant MOI bats was observed to be nearly independent of the bat weight, while the swing speed of the constant weight bats showed a strong dependence on MOI. The dependence of swing speed on bat weight and MOI was similar for the two player skill levels considered. The bat's center of rotation during the instant of impact with the ball was found to roughly correspond to the location of the center of the batter's wrists. The results of this study will be used to develop test methods to correlate bat performance.

1. Introduction

In order to properly characterize the hitting performance of a baseball or softball bat, it is necessary to have some understanding of how fast the bat can be swung. For example, if two bats perform identically in a laboratory test at a fixed relative ball-bat speed, the bat that can be swung faster will likely perform better in the field. Indeed, that is the current state of affairs with the National Collegiate Athletic Association, which has regulated that hollow aluminum baseball bats perform essentially identically to wood bats in fixed-speed laboratory tests. Nevertheless, it is generally perceived that aluminum bats

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outperform wood bats in the field *because* the aluminum bats can be swung faster. Unfortunately, it is very difficult to model the swing of a bat in order to predict how swing speed is affected by the inertial properties of the bat, such as its mass or mass moment of inertia (MOI). Moreover, there have been very few systematic studies of bat speed in the scientific literature, reflecting the fact that bat speed is difficult to measure and can depend on conditions not easily controlled or even quantified. Despite these difficulties, previous studies [1-4] have shown a *qualitative* dependence of bat speed on inertial properties. Unfortunately, because of the difficulty in doing such measurements and due to the selection of bats used in these studies, the dependencies are usually not quantified nor are the effects of mass and MOI separately determined. The lack of such quantitative results provided the prime motivation for the current study, the results of which will improve the way laboratory bat performance measures account for a bat's mass properties.

2. Field Study

The current study considered the effects that weight and MOI have on the swing speed of a softball bat. To this end, 20 aluminum bats of the same model, each 34 inches in length, were weighted to study the effect of weight and MOI independently. Ten bats had the same weight but different MOI, while the remaining 10 bats had the same MOI but different weight. The weight and MOI were increased in five increments, as shown in Figure 1, where MOI is referenced to a point 6 inches from the knob to the barrel end of the bat.

The study was conducted on an open field during daylight hours at the 2002 USA Softball Men's National Championship Series Tournament in Montgomery Alabama. Eight level A and six level D male right-handed players, known to be good hitters, were invited to participate in the study before tournament play began. Each player was assigned to the group of constant weight or constant MOI bats and asked to swing all five bats in that group in random order. To reduce fatigue effects, the batters worked in pairs, alternating after swinging each bat ten times. Each batter was allowed a few practice swings before hitting with a new bat.

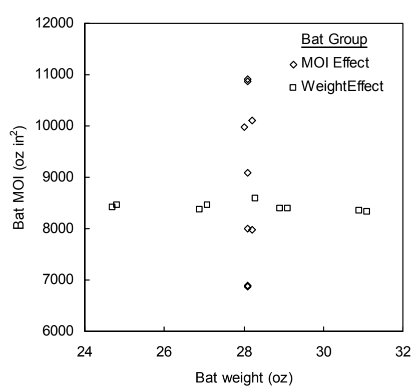

Figure 1. Weight and MOI of the 20 bats

The bat speed was measured using a high-speed video system as depicted in Figure 2. A high-speed video camera was placed on a truss directly over the batter. The camera recorded the player motion at 1000 frames per second using a shutter speed of 1/4000 second and a resolution of 1024 by 512. The camera was mounted 150 inches above the ground and had a horizontal field of view of 142 by 71 inches. Two additional video cameras were placed behind the batter to provide a redundant record of the vertical tip location of the bat as well as the orientation of the bat with respect to the horizontal plane. The video cameras were calibrated with scales that were placed horizontally on the ground and vertically next to home plate. To accommodate automatic video tracking from the overhead camera, each bat had markers placed at 12, 22, and 32 inches from the knob at four locations circumferentially around the bat. A redundant measure of bat speed was provided using reflective tape on the bat and a light trap that was placed next to home plate. Four radar guns (one behind home plate and three in the outfield) were used as secondary measures of the batted ball speed.

3. Data Reduction

The high-speed video data were reduced using commercial video editing software (Image Express Motiontrack) which provided the location and velocity of the ball and each marker on the bat as a function of time with respect to the fixed calibration scales. The bat-ball impact typically occurred 40 inches above the ground and up to 36 inches in front of the plate. The corrected locations for each marker were found by solving the following simultaneously equations for the corrected locations.

$$x_c^i = x_v^i\left(\frac{H - z_c^i}{H}\right) \tag{1}$$

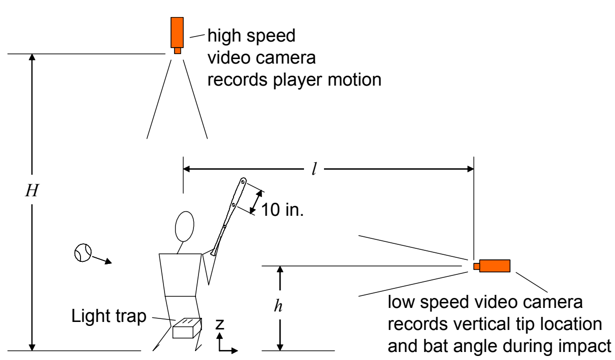

Figure 2. Schematic of video system used to determine the bat speed.

$$y_c^i = y_v^i \left(\frac{H - z_c^i}{H} \right) \tag{2}$$

$$z_c^i = (z_v - h)\left(\frac{x_c^i - x_s + l}{l} \right) - d^i \sin(\theta) + h \tag{3}$$

where x, y, and z denote the coordinates of the marker, the subscript c or v denotes the corrected or video location, respectively, the superscript i denotes the marker number, H and l are as depicted in Figure 2, and θ is the out-of-plane bat angle found from the low speed video camera. With the corrected marker locations, the velocity components, v, of each marker were corrected and expressed with respect to the bat in the radial, r, and tangential, t, directions according to

$$v_t^i = \left[v_x^i \cos(\alpha_{avg}) - v_y^i \sin(\alpha_{avg}) \right] \left(\frac{H - z_c^i}{H} \right) \tag{4}$$

$$v_r^i = \left[v_x^i \sin(\alpha_{avg}) + v_y^i \cos(\alpha_{avg}) \right] \left(\frac{H - z_c^i}{H} \right) \tag{5}$$

where α_{avg} is the average in-plane orientation of the bat, obtained from the angle between the markers, as

$$\alpha_{ij} = -Tan^{-1}\left(\frac{x_c^i - x_c^j}{y_c^i - y_c^j} \right) \tag{6}$$

The coordinates of the bat's center of rotation, with respect to the knob end of the bat, were found from

$$a^i = \left(\frac{-v_c^i}{v^{i+1}{}_c - v_c^i} \right) 10 + (34 - d^i) \tag{7}$$

$$t^i = \left(\frac{v_r^i}{v_c^i} \right) \left(34 - d^i - a_{avg} \right) \tag{8}$$

where a is the distance from the knob of the bat along its long axis, t is the transverse distance from this axis, and 34 and 10 represent the bat length and marker spacing, respectively. The distance along the bat from the ball to the outer most marker, d_b, was found from

$$d_b = h_b \sin \alpha_b \tag{9}$$

where

$$h_b = \sqrt{(x_b - x_c^i)^2 + (y_b - y_c^i)^2} \tag{10}$$

$$\alpha_b = Tan^{-1}\left(\frac{y_c^i - y_c^b}{x_c^i - x_c^b} \right) + \theta \tag{11}$$

4. Verification

After the data were reduced, they were checked to ensure their accuracy. The average marker spacing from the high speed video was within 0.03 inches of the nominal 10 inch spacing. The marker spacing during 15% of the swings was more than 0.5 inches from this value. This erroneous measurement exceeds the resolution of the camera (0.14 inches) and was attributed to non-level swings, impact occurring outside the field of view, or changing lighting conditions as the test progressed. The vertical location was adjusted for these swings to bring the marker spacing within 0.25 inches of the nominal value. With this correction, 70% of the swings had a marker spacing within 0.25 inches of the nominal value.

The distance from the pitcher to home plate (50 ft) and limits on the pitched ball arc (6 to 12 ft) allow an ideal pitch speed to be found using projectile motion. For a ball that begins its trajectory at 2 ft from the ground, the in-plane component of the pitch speed is between 22 and 34 mph. The average pitch speed from the high speed video was found to be 23 mph.

The swing speed from the high speed video was found to be, on average, 18% higher than that found using the stationary light trap. The unfavorable lighting conditions only allowed a comparison of 30% of the swings with the light trap. (The large amount of ambient light reduced the ability of the light trap to observe the reflective tape on the bat.) The ball-bat impact normally occurred in front of the plate, sometimes as much as three feet, resulting in a lower measured bat speed from the light trap.

On average the high speed video reported a batted ball speed that was 8% higher than that found using radar guns. The discrepancy was attributed to the one-dimensional speed measurement obtained from the radar gun, in comparison to the two-dimensional high speed video. Batted ball speeds are more difficult to measure accurately with a radar gun than pitch speed due to the uncertainty regarding the hit ball direction.

5. Results and Discussion

The speed for each swing was normalized to the average speed of the respective player. This allowed comparison between players independent of their skill level. The normalized swing speed of the bats with constant MOI is presented in Figure 3. The swing speed appears nearly independent of bat mass. The normalized swing speed of the bats with constant mass, presented in Figure 4, shows a strong dependence on bat MOI, where it scaled according to

$$\omega'/\omega = \left(I/I'\right)^n \tag{12}$$

where n=¼, and I=9000 oz in^2. The dependence of bat MOI on swing speed varied among the players ($0.08<n<0.37$), but no consistent correlation of *n* with player skill level was observed.

The average swing speed (at 6 inches from the end of the bat) of the A and D level batters was found to be 89 and 81 mph, respectively. These speeds are higher than have been observed in baseball [3]. The higher speeds may be attributed to the increased batter preparation and response time associated with a slower pitch. The instantaneous center of rotation of the bat during impact with the ball was found to lie near the center of the batter's wrists. The average location from this study was found to be 2.6 inches from the knob (toward the batter) and 2.7 inches behind the bat (toward the catcher). As might be expected, there was substantial scatter in the center of rotation of the swings. The majority appeared evenly distributed within a 4 inch radius of this location.

6. Summary

A field study was conducted to determine the effect of bat mass and MOI on the swing speed of softball bats. A two-dimensional high speed video system was used to measure swing speed, pitch speed, hit ball speed, and bat center of rotation. The system appears to have captured the desired parameters of the bat and ball motion. The bat speed was shown to have an observable dependence on bat MOI, while the effect of bat mass was not apparent. Results of this work will be used to improve test methods to determine bat performance.

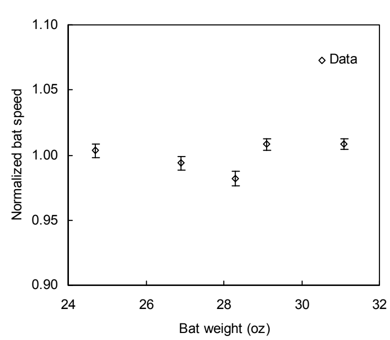

Figure 3. Normalized bat swing speed (6 inches from the tip) as a function of bat mass for bats with constant MOI.

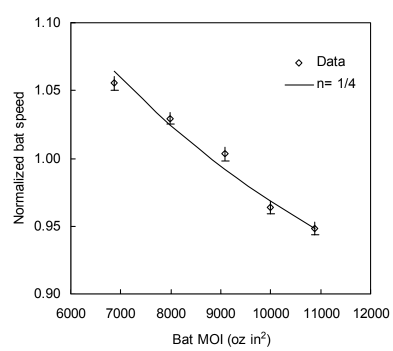

Figure 4. Normalized swing speed as a (6 inches from the tip) function of bat MOI for bats with constant mass.

7. References

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