Swing Weights of Baseball and Softball Bats

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Baseball and softball bats are sold according to length in inches and weight in ounces.[1] Much to the consternation of players buying new bats, however, not all bats that weigh the same swing the same. The reason for this has to do with moment of inertia of the bat about a pivot point on the handle, or what the sporting goods industry refers to as *swing weight*.[2-3] A number of recent field studies[4-7] have confirmed that the speed with which a player can swing a baseball or softball bat depends more on the bat's moment of inertia than on its mass. In this paper we investigate the moment of inertia (swing weight) of a variety of baseball and softball bats.

Figure 1 shows the knob sticker of an older softball bat advertising the actual weight as being 23 oz while its *swing weight* is 28 oz. Indeed, when swung this bat appears to have more inertia than several heavier 30-oz softball bats in our collection. However, labeling the swing weight as 28 oz is rather nebulous since this bat demonstrates that weight does not equate to inertia during the swing. What does a 28-oz bat swing like?

Our bat collection also includes two 34-in, 30-oz slow-pitch softball bats, one a graphite bat and the other an end-loaded aluminum bat. As shown in Fig. 2 the balance points (centers of mass) for these two bats differ by almost five inches. As a result, their moments of inertia, about a pivot point in the handle, are very different. Even though they weigh the same, these two bats do not at all appear to have the same inertial properties when swung.

Measuring at bat's moment of inertia

Baseball and softball bat manufacturers and governing associations define swing weight by treating the bat as a physical pendulum and measuring the moment of inertia about a pivot point six inches from the knob end of the handle.[8] The period of oscillation of a physical pendulum is given by

$$T = 2\pi\sqrt{\frac{I}{mgd}}, \qquad (1)$$

where I is the moment of inertia about the pivot point, m is the mass of the bat, g is the acceleration due to gravity, and d is the distance from the pivot point to the center of mass. The center of mass (bat manufacturers call it the *balance point*) is measured from the knob end of the handle and is officially measured[8] using two scales and a stand that supports the bat at two locations, six inches and 24 inches from the knob, as shown in Fig. 3. The sum of the two scale readings is the total mass, while the balance point is determined from the two scale readings:

$$c.m. = \sqrt{\frac{6W_6 + 24W_{24}}{W_6 + W_{24}}}, \qquad (2)$$

though it could also be determined as the point where the bat balances on a small circular tube.

Knowing the mass, the distance from the pivot point to the center of mass, and the period of oscillation, the moment of inertia about the pivot point is easily determined from Eq. (1). Figure 4 shows the simple apparatus we use in our laboratory to measure the moment of inertia. The bat is gripped at the 6-in point in a knife-edge pivot apparatus and the period is measured with a CPO Time II photogate timing system.[9] The pivot assembly is easily calibrated by measuring the moment of inertia of a steel or aluminum cylindrical rod and comparing measured and theoretical values to determine the moment of inertia of the pivot assembly itself. Our pivot assembly has a moment of inertia of 150 oz·in^2.

Fig. 1. The knob of a 1997 Dudley Fusion slow-pitch softball bat listing both the swing weight and the actual weight.

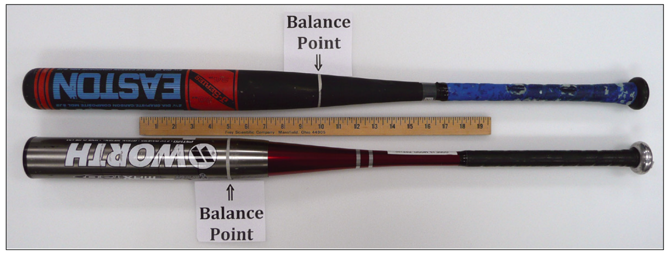

Fig. 2. Two slow-pitch softball bats of the same length and weight, but very different balance points (centers of mass).

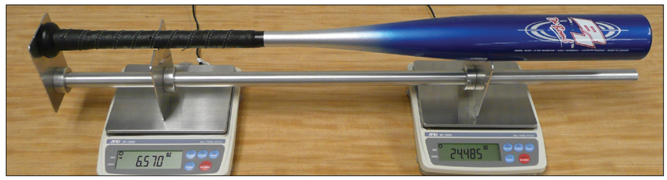

Fig. 3. Apparatus for measuring the weight and balance point of a softball or baseball bat.

Table I. A sampling of several 34-in slow-pitch softball bats comparing combinations of weight, balance point, and moment of inertia about the 6-in point on the handle.

Softball Bat	Length (in)	Weight (oz)	BP (in)	MOI_6 ($oz\cdot in^2$)
S1	34	30.2	23.3	12143
S2	34	30.0	22.3	11007
S3	34	30.1	19.4	9154
S4	34	30.2	18.5	8436
S5	34	25.2	22.7	9487
S6	34	28.3	21.0	9461
S7	34	27.9	19.5	8193
S8	34	25.8	20.9	8195
S9	34	31.7	22.4	11268

Table II. A sampling of 34-in wood baseball bats and 33-in aluminum or composite bats comparing combinations of weight, balance point, and moment of inertia about the 6-in point on the handle.

Baseball Bat	Length (in)	Weight (oz)	BP (in)	MOI_6 ($oz\cdot in^2$)
B1	34	31.2	22.8	11239
B2	34	36.5	22.4	12283
B3	34	37.3	20.3	11836
B4	34	31.9	21.2	10127
B5	33	31.4	19.9	9325
B6	33	31.0	20.4	9590
B7	33	30.5	19.3	8664

Fig. 4. Apparatus for measuring the period of oscillation for a softball bat pivoted about a point 6-in from the end of the handle.

Fig. 5. Wood, aluminum, and composite adult baseball bats with different profiles, corresponding to data in Table II.

Moments of inertia for a variety of bats

Table I shows measurements of bat weight, balance point, and moment of inertia about the 6-in point on the handle for a variety of commercially available aluminum and composite slow-pitch softball bats, all with the same lengths and similar diameter profiles. The first four bats in the table, S1-S4, have nearly the same weight (30 oz), but with different balance points the moments of inertia vary considerably. The bats with larger moments of inertia are end-loaded models and are noticeably harder to swing. Bat pairs S5-S6 and S7-S8 have different masses and balance points, but the same moments of inertia. As a result, the bats within each pair swing about the same. It should be possible to design two bats with the same mass and moment of inertia but different balance points. Unfortunately, we were unable to find such a pair in our collection of more than 100 softball bats.

Bat S9 is a wood softball bat, which is somewhat of a rarity since almost all softball players exclusively use aluminum or composite bats. However, it does provide a comparison of moment of inertia for wood and non-wood bats. Table I clearly shows that there are some non-wood slow-pitch softball bats with equal or greater moments of inertia than a wood bat of the same length.

Table II lists measurements for several adult baseball bats of various shapes and materials as shown in Fig. 5. Bat B1 is an MLB-quality 34-in ash bat, and its moment of inertia is pretty typical for adult wood baseball bats of this length. Bat B2 is a replica of a "bottle bat" used by Heinie Groh, who played third base for the Cincinnati Reds from 1913-1921. This replica is made from ash, and is probably at least 6 oz lighter than the hickory stick Groh used. Bat B3 has a 3-in knob, moving the grip position toward the barrel and bringing the balance point closer to the hands. Bats like this are sometimes used to help players develop better wrist control and swing mechan-

Fig. 6. 30-in youth baseball bats, corresponding to data in Table III.

Table III. A sampling of several 30-in wood and aluminum youth baseball bats comparing combinations of weight, balance point, and MOI about the 6-in point on the handle.

Youth Bat	Length (in)	Weight (oz)	BP (in)	MOI_6 ($oz•in^2$)
Y1	30	19.7	19.8	5029
Y2	30	22.7	19.9	5800
Y3	30	25.2	19.9	6425
Y4	30	27.2	18.3	6139
Y5	30	17.1	19.4	4420
Y6	30	22.1	19.7	5675

ics. Bat B4 is a laminated bamboo wood barrel attached to an aluminum handle. Bats B5 and B6 are 33-in aluminum and composite bats, respectively. Bat B7 is an aluminum bat with a vibration-reducing mass-spring mechanism in the knob. The concentration of weight in the knob moves the balance point toward the handle and lowers the moment of inertia.

Unfortunately our bat collection doesn't include a 33-in wood baseball bat or a 34-in aluminum bat to make a direct comparison between wood and non-wood baseball bats of the same length. However, the spread in weights and moments of inertia for bats of the same length is not as great for baseball bats as it is for softball bats. The NCAA requires that baseball bats exceed a minimum moment of inertia and that the weight in ounces cannot be more than three digits less than the length in inches. There is no such restriction for softball bats or youth baseball bats.

Figure 6 shows several 30-in youth baseball bats, used for play in Little League, with the corresponding inertia data in Table III. Bats Y1-Y3 are the same make and model wood bats, with identical profiles and balance points. However, the densities of the wood, and thus the overall bat weights, are very different giving rise to noticeable differences in their moments of inertia. This provides a nice contrast to softball bats S1-S4 from Table I, for which the differences in moments of inertia were due to differences in balance point, not differences in weight.

Youth bat Y4 is an older aluminum bat that weighs more than wood bat Y3, but because the aluminum bat is hollow, its center of mass is closer to the handle and the moment of inertia is actually smaller. There are currently no restrictions on weight for youth bats, and bat Y5 represents one of the lightest 30-in youth bats currently available. Bat Y6 is a large-diameter (2.75 in instead of 2.5 in) version of bat Y5. Such large barrel "senior league" bats are used by 13- to 15-year-olds, and the larger barrel size means greater mass and greater moment of inertia.

Table IV. A significant amount of mass may be added to the knob of a bat with only a slight change in the moment of inertia about the 6-in point on the handle.

Extra mass added to knob (oz)	Total bat mass (oz)	CM (in)	MOI_6 ($oz•in^2$)
0.0	26.1	19.9	8118
3.2	29.3	17.5	8145
8.0	34.1	15.0	8445

End loading and knob loading a bat

Recent research has suggested that most players could benefit from using an end-loaded bat, provided that they can still maintain close to the same swing speed.[10] A growing problem in slow-pitch softball is the illegal doctoring of bats in an attempt to improve performance. One popular method of doctoring a bat is to end load the bat by adding mass to the barrel end, which increases the moment of inertia. Provided that players can swing end-loaded bats with the same speed, increasing the moment of inertia can increase the batted-ball speed.[11]

The opposite approach is used by some coaches to teach young players how to swing the bat with maximum wrist rotation.[12] Table IV shows that a large amount of mass may be added to the knob of a bat without significantly altering the bat's moment of inertia about the 6-in point on the handle. This surprising result indicates that the shift in balance point offsets the increase in total mass.

Suggestions for further exploration

1. Measure the mass, balance point, and moment of inertia for a variety of baseball and/or softball bats. Use lead tape, or something similar, to add mass at the barrel end and/or at the knob and measure how the balance point and the moment of inertia change. Grip a bat at the handle and notice how it feels while holding it horizontally (which is sensitive to balance point) and while rotating it rapidly (which is sensitive to moment of inertia).
2. Explore the trend shown in Table IV. Compare how the knob-loaded bat feels to an unmodified bat when rapidly rotating it with the wrists.
3. Start with two identical bats (or uniform rods) and determine where to add mass to each bat so as to produce two bats with the same weight and moment of inertia, but different balance points.

References

1. While SI metric units are preferable for a physics article, the entire baseball and softball community (players, manufacturers, and associations) make exclusive use of inches for length and ounces for weight, and thus these units are used throughout this article. For discussion on the appropriateness of using units other than SI, see R. Romer, "Units—SI only, or multicultural diversity," *Am. J. Phys.* **67**, 13–16 (Jan. 1999).
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10. A. T. Bahill, "The ideal moment of inertia for a baseball or softball bat," *IEEE Trans. Syst. Man Cybernetics – Part A: Syst. Hum.* **34**(2), 197–204 (2004).
11. C. Cruz, *Characterizing Softball Bat Modifications and Their Resulting Performance Effects*, master's thesis, Washington State University (2005).
12. See, for example, the discussion of hitting mechanics at www.procut.com, which advocates the use of a heavy weight attached to the knob to help players learn how to develop a more powerful swing and a quick wrist action.

Additional Reading

For more information about the physics of baseball and softball bats, visit the author's website: www.kettering.edu/~drussell/bats.html.

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