A Performance Comparison Between Two Cricket Bat Designs

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Executive Summary

In this study a set of four cricket bats provided by MCF were tested for a set of three mechanical properties. These properties are known to be related to the performance of the cricket bats in terms of pick up weight, feel, vibrations, and energy imparted to the cricket ball.

A set of three Mongoose cricket bats that are characterised by two significant features, namely, a short blade and a blade/handle join that does not protrude beyond the neck of the blade, were tested and compared to a bat of equivalent quality with a more traditional design (Woodworm) and manufactured by the same bat manufacturer.

The following tests were conducted: freely-suspended vibration analysis, bending stiffness and moment of inertia.

Mongoose Analysis:

It was found that the three Mongoose cricket bats performed in a highly consistent manner in all three tests.

Bending stiffness (StB): the Mongoose bats had a consistent StB along the length of the blade. The blade/handle interface bending stiffness was less than for the blade in isolation.

Vibrations: The second, third and fourth vibrational modes that correspond to bending of the bat were highly consistent between bats. These modes were highly consistent both along the length of the bats and across the width of the bats. The sweet spots of the bats were consistent.

Moment of Inertia (MoI): The MoI varied by up to 12% between bats.

Comparison with Traditional Bat:

The Woodworm bat had a variable StB along the length of the bat and had a lower overall StB than the Mongoose. The Woodworm also had very consistent vibrational modes that were only slightly different from the Mongoose. These were consistent along the length and width of the bat. The MoI of the traditional bat was significantly less than that of the Mongoose bats.

Performance Implications:

The relatively stiff blade of the Mongoose will allow more of the energy of the bat swing to be imparted to the ball. For the same weight of bat, the Mongoose will be harder to ‘pick up’, but for the same pick up height will impart greater energy to the ball due to the greater moment of inertia; this results in a collision of greater energy. Vibrations imparted to the batsman are likely to be equivalent between all bats.

1. Introduction

This report describsd a set of experiments conducted by Theofano Eftaxiopoulou of Imperial College London in order to assess the performance properties of two types of cricket bat. This forms part of a larger study in which multiple bat types will be assessed. The aim of this study is to compare performance characteristics of the Mongoose and Woodworm cricket bats.

The cricket bat exhibits important elastic properties, since it is not completely rigid, during swing and impact (Noble, 1998). Studies suggest that the vibrational behaviour of a bat approximates that of a uniform beam (Noble, 1998; Brooks et al, 2006; Jaramillo et al, 2003). Noble (1998) represented the baseball bat as a uniformed rod, clamped at the point of contact with the hands and defined for various amplitudes of vibrational modes, the approximate length and node locations. Nodal point positions are quite important when assessing bat performance since vibrational modes are not excited when the ball strikes the bat at nodes of given modes (Noble, 1998).

The boundary conditions have a significant effect on the bat's vibrational response and it is important for the bat to impact excitation when it is under boundary conditions analogous of those used in real games (Brooks et al, 2006). Brooks et al, (2006) determined the frequencies and mode shapes for the first four modes of vibrations for three different boundary conditions; the 'freely suspended', the 'clamped handle' and the 'hand held' condition. The 'freely suspended' condition uses strings to support the bat in two positions at the end of the handle and at the end of the blade so that the bat is free to vibrate (Brooks et al, 2006; Jaramillo et al, 2003). The results of the modal analysis showed that during impact the vibrational response of a 'freely suspended' bat corresponds to that of a 'hand held' bat (Noble, 1998; Brooks et al, 2006). Noble (1998), defined that for a 'freely suspended' rod the number of nodes for each successively higher mode increases by one at each step. In the same study the node locations and the frequency of the fundamental and first harmonic modes were measured for baseball bats. Finally, modal testing was also employed by Gutaj (2004) who excited a 'freely suspended' bat in order to determine its elastic properties.

Experimental modal analysis has enabled researchers to define each bat's 'sweet spot' as the region of low vibrational energy absorption, by changing the blade's profile the 'sweet spot' can move (Brooks et al, 2006). Studies have also demonstrated the importance of stiffness and mass distribution to the bat's vibrational properties (Shaw, 2004; Brooks et al, 2006; Jaramillo et al, 2003; Smith, 2001). The higher elastic modes have been found to play significant part in restoring 50% of the loss in ball velocity, a degradation usually associated with the bat's stiffness (Noble, 1998).

Therefore, in this study, both bat stiffness (bending stiffness) and freely suspended vibration analysis will be conducted.

The Moment of Inertia (MoI) of a cricket bat is a measure of it's resistance to being swung. As such, this is a direct measure of the 'pick up' weight of a bat. This is equivalent to the 'swing weight' of a tennis racket (Brody, 1986). In addition, a racket or bat with a greater MoI imparts greater energy to the ball for the same angular velocity and thus will strike the ball further.There are two ways of increasing the MoI of a bat. The first is to increase the mass of a bat. The second is the redistribute the mass of the bat further away from the rotational axis. In the light of the different designs of bat available that have significantly redistributed mass by reducing blade hitting area it was decided to quantify the MoI of the different bats available according to the method of Brody (1986).

2. Materials and Methods

2.1 Bending Stiffness

The cricket bats were placed over two supports specifically designed for this type of testing. All the bats were loaded up to 4 kN with a constant rate of 5 mm/sec.

All the bats were tested at four/five different points and for each point the test was repeated ten times.

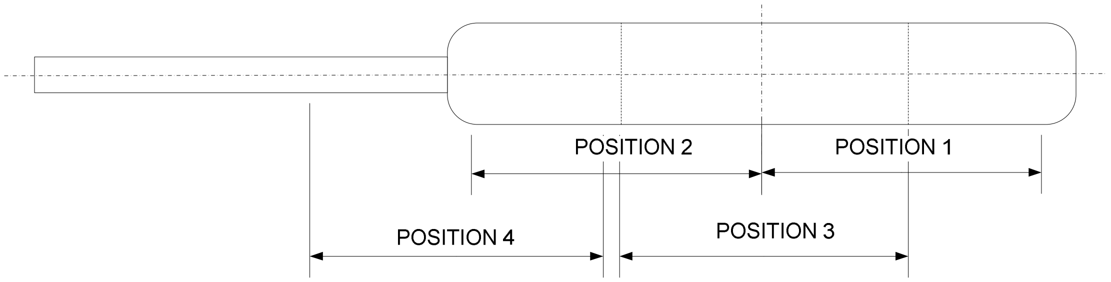


Figure 1: The 4 positions tested for the Mongoose bats

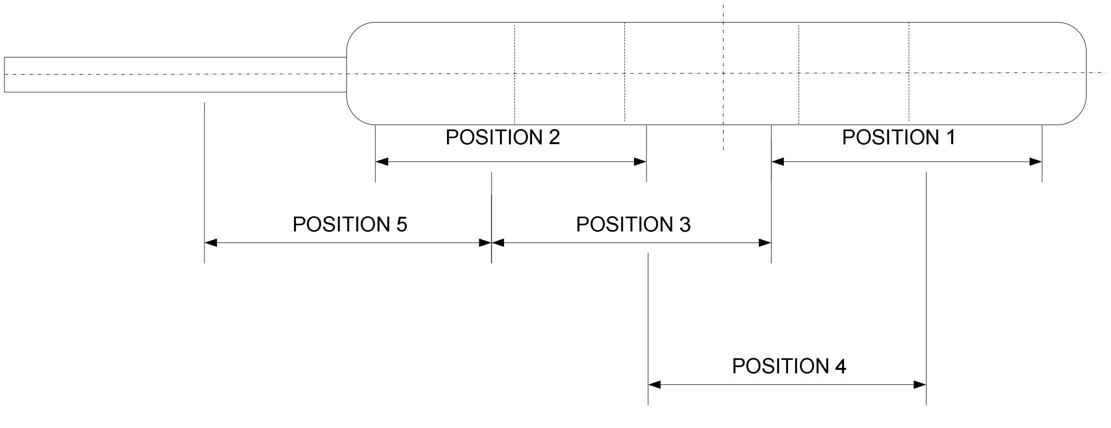


Figure 2: The 5 positions tested for the comparator bat

Bending stiffness was calculated as below. The test configuration is shown is Figure 3.

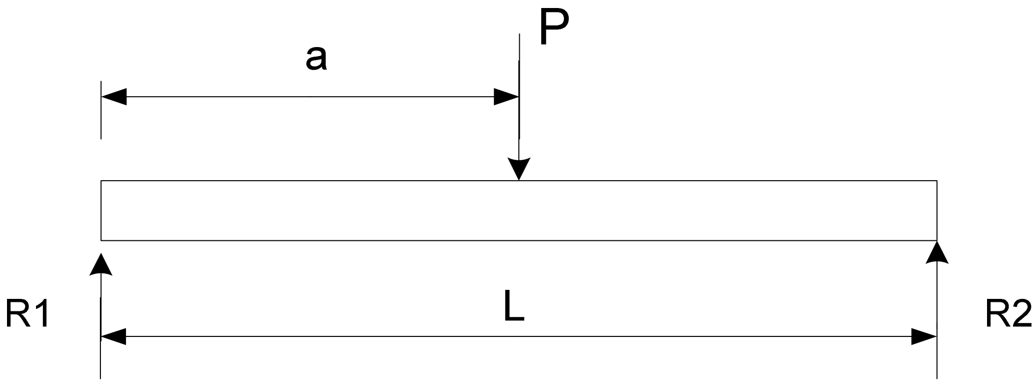


Figure 3: Load always mid-span

Bending Stiffness: $a = L/2 \Rightarrow E \cdot I = \dfrac{P \cdot L^3}{48 \cdot W}$

(L = 176 mm in all cases)

Bending stiffness was calculated from the slope of the curve between 2100 and 3800 kN (example curve in Figure 4).

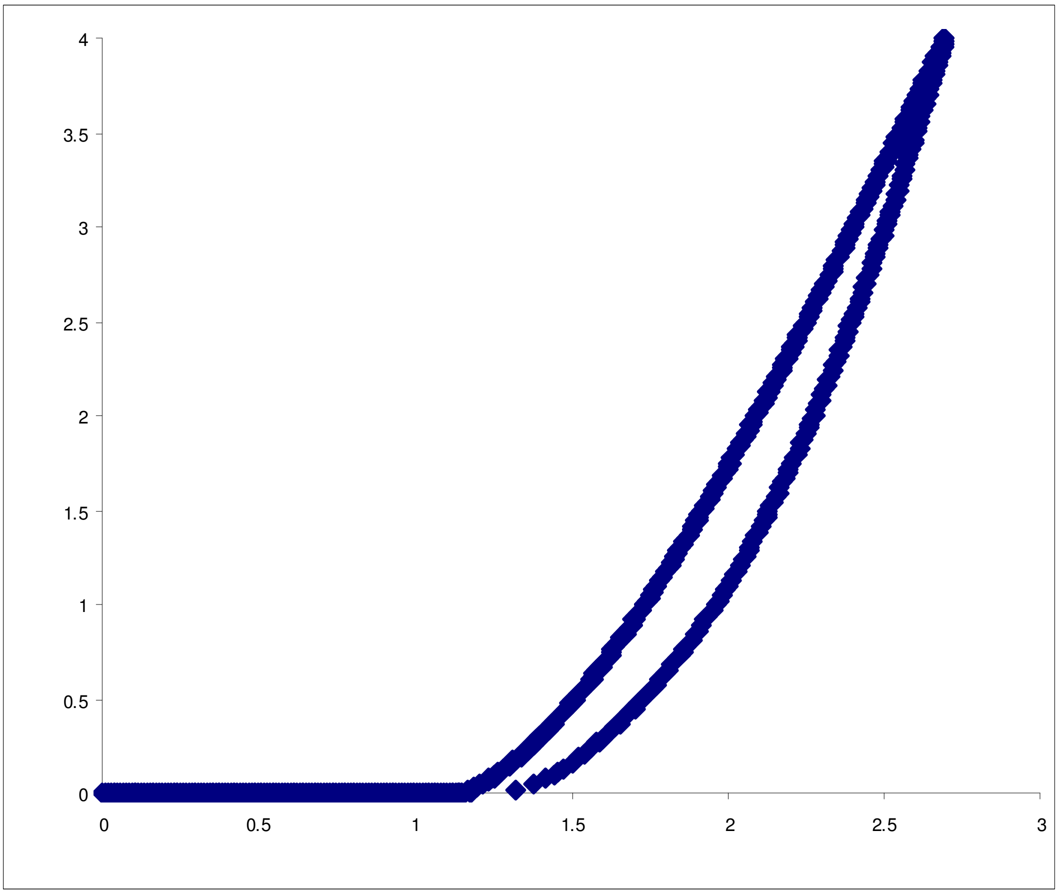


Figure 4: Typical bending stiffness experiment result (load in kN against deflection in mm)

2.2 Vibration Analysis

The cricket bats were excited with the impulse hammer technique. As shown in Figure 5 the experimental setup is based on the use of an impulse hammer to excite the bat over a range of frequencies and an accelerometer. The frequency range was set at 0–1200 Hz and the accelerometer was attached on the back of the blade near the toe region using a thin layer of wax (Brooks et al, 2006). This position was chosen as it did not correspond to any of the nodes of vibration (Brooks et al, 2006; Gutaj 2004). Each of the cricket bats tested had marked out a series of equally spaced impact points along the blade's hitting surface covering the length and width of the blade from toe to neck. During testing each of the points was impacted three times by the hammer and the average frequency response was quantified using appropriate software SignalCalc ACE (Dynamic signal analyzer) from Data Physics.

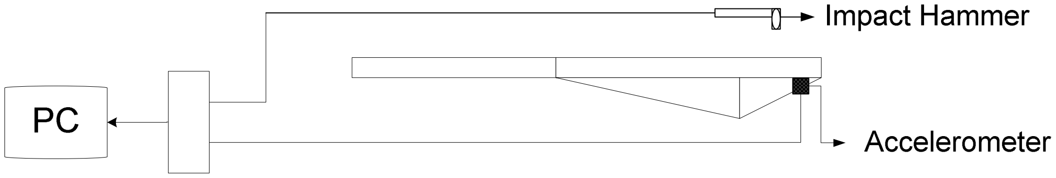


Figure 5: Experimental set-up

For this work the first three bending modes are included in the magnitude/energy calculations as higher modes are unlikely to be excited and lower modes may include noise. The Y axis on the Figure 6 below is:

$$\frac{\ddot{x}}{F} = \frac{mm/s^2}{N}$$

and the x-axis is the frequency response in Hz.

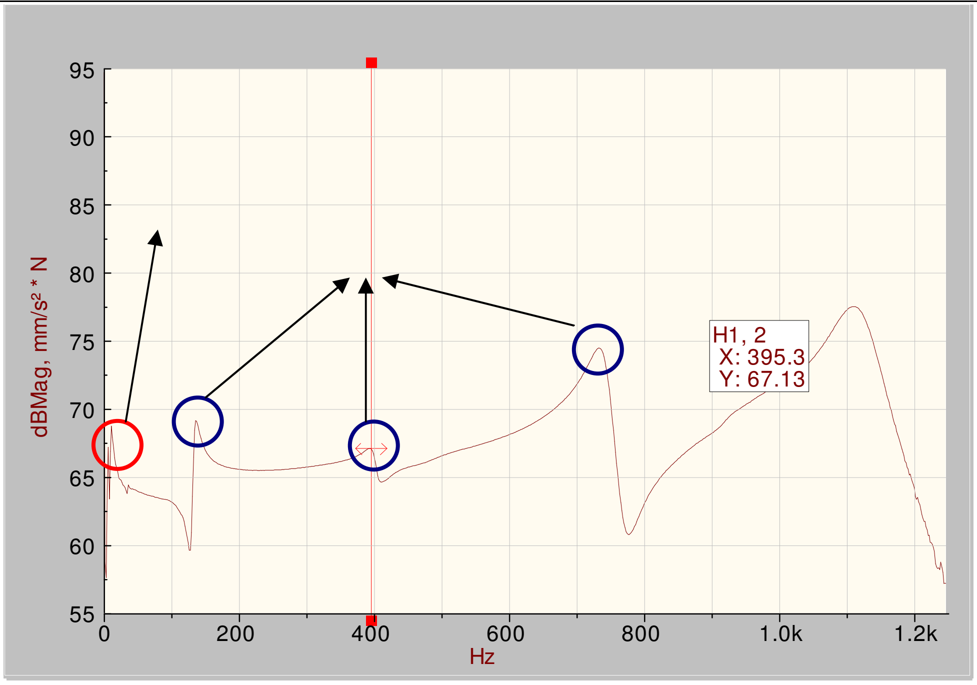


Figure 6: A typical FRF for one position on a Moongoose bat

2.3 Moment of Inertia

In this study, the moment of inertia about an axis through the handle of the bat was determined by turning the bat into a physical pendulum (Brody, 1985). The period of a physical pendulum is given by the formula:

$$T = 2 \cdot \pi \cdot \sqrt{\frac{I}{mgd}}$$

Where I is the moment of inertia of the bat, *m* is its mass and *d* is the distance between the pivot point and the centre of mass (CoM.).

A 6 mm hole was drilled through the handle of each bat and a rod was inserted through the hole to form an axis of rotation. A frame was manufactured out of mild steel to support the rod so as to allow for the bat to be held in a vertical position in order to swing freely. Each bat was displaced from the vertical position through varying angles ranging up to 10°, so that the small angle approximation:

$\sin a \cong a$ (for $a \leq 14^{\circ}$)

was valid, and then released. For each initial angle of displacement, 10 full cycles were recorded using an electronic timer and the mean period (the time required for a pendulum to oscillate through one complete cycle) was determined.

The mass of each bat was then measured to within 1 g.

The position of the CoM was determined by a balance experiment.

I was determined from the equation below:

$$I = T^{2} \cdot \frac{m \cdot g \cdot d}{4 \cdot \pi^{2}}$$

Due to the small variability in mass of bats, the moments of inertia were also normalised by scaling linearly to the lowest bat mass.

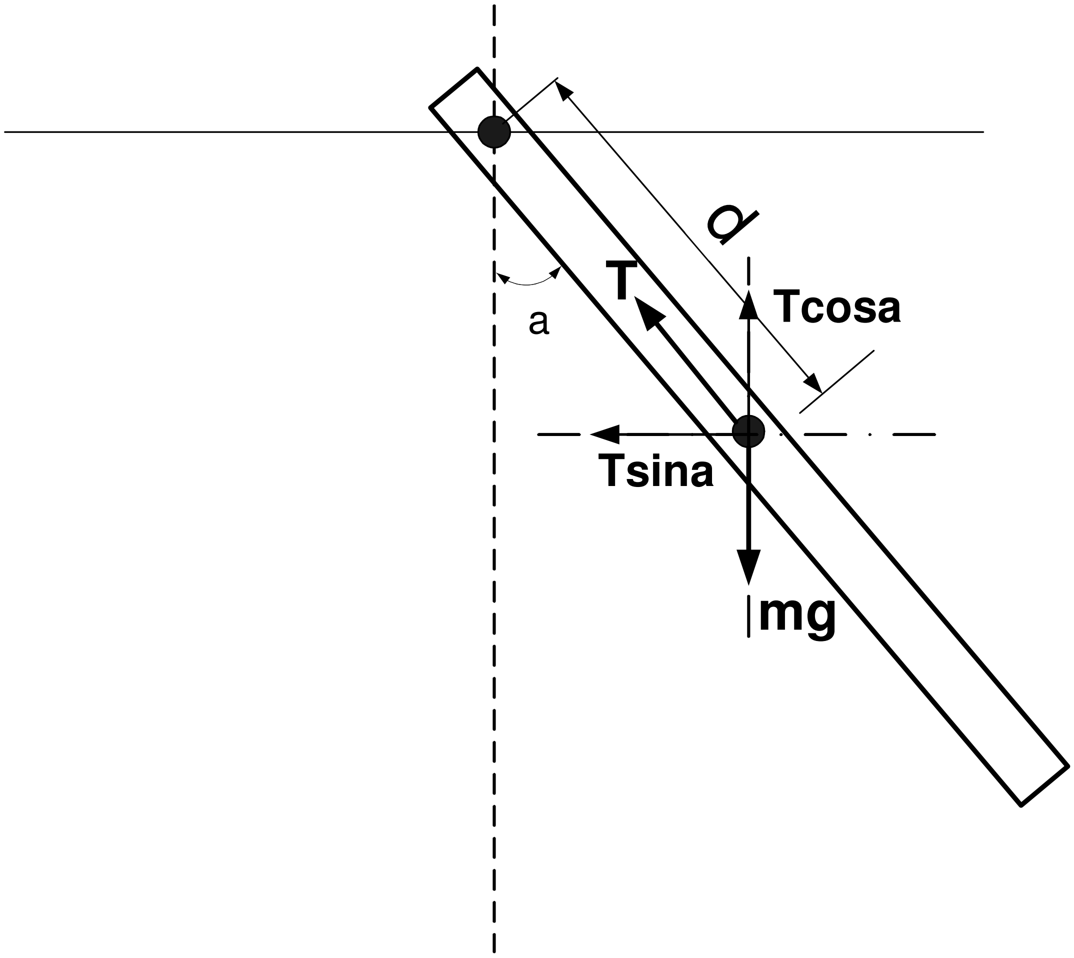


Figure 7: Pendulum arrangement for Moment of Inertia measurements

3. Results

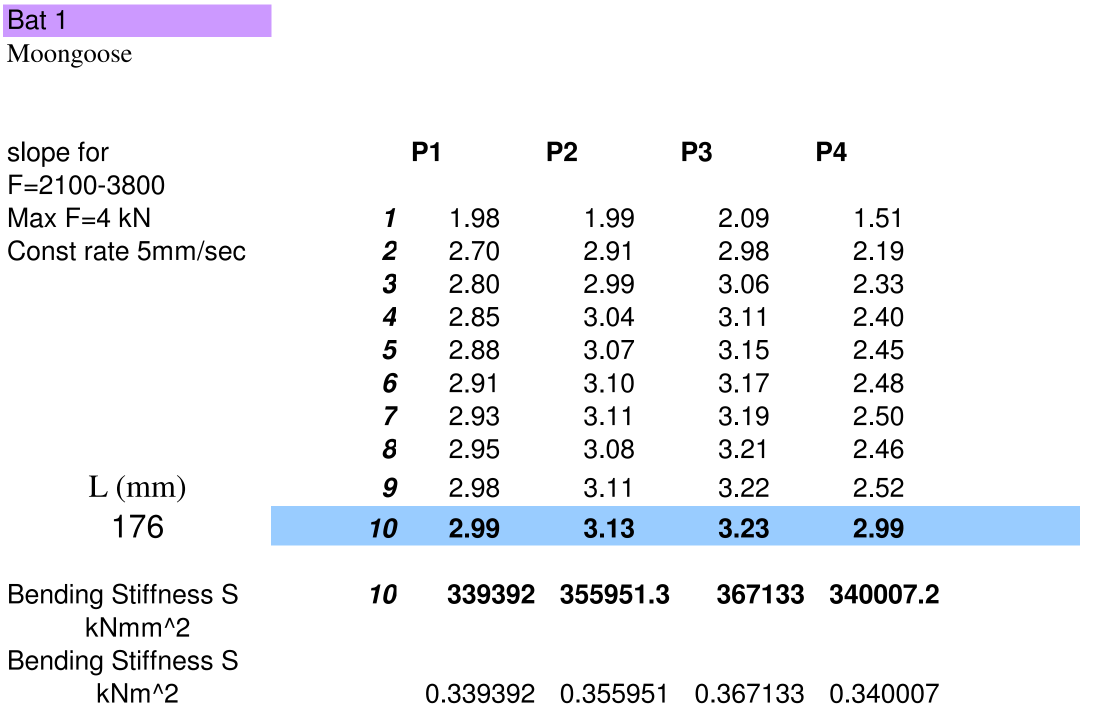
3.1 Bending Stiffness Experiment

Testing and analysis of four bats was completed; three Mongoose and one Woodworm. Complete results are presented below in Figure 8 - 11.

The Mongoose bending stiffnesses were 0.373 kNm^2 with a standard deviation of 0.017. This demonstrates that the bending stiffnesses were highly consistent within and between Mongoose bats.

The Woodworm bending stiffness was 0.297 (0.043) kNm^2. This is 20% lower stiffness than the average Mongoose with a higher variability than the Mongoose.

The bending stiffness of the Mongoose bat/handle interface was 0.320 (0.02) kNm^2 compared to 0.283 kNm^2 for the Woodworm.

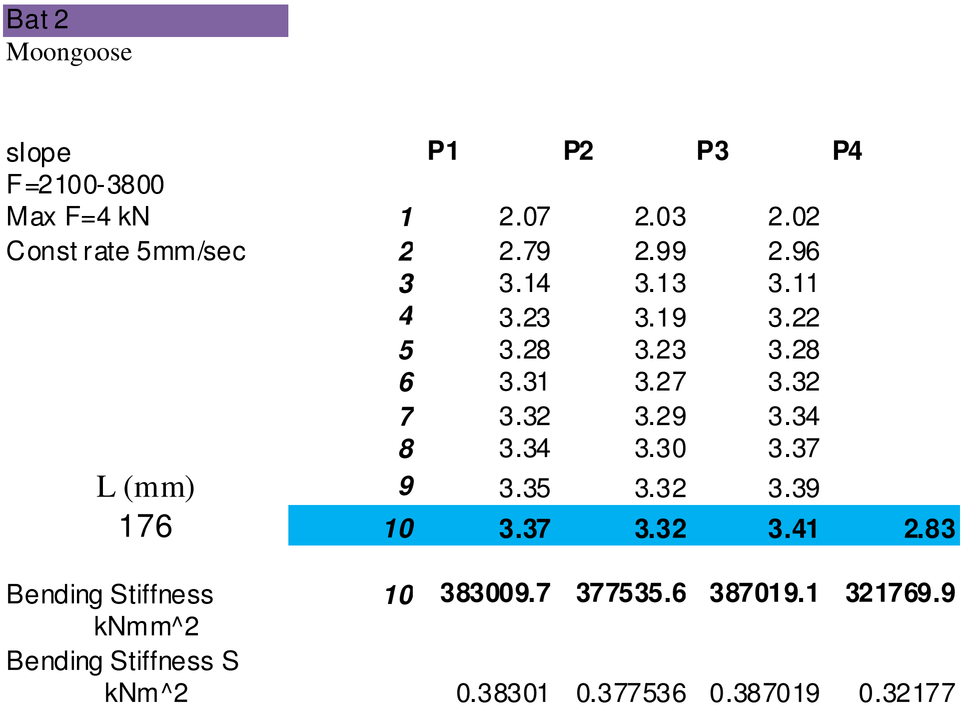


Bat 1

Moongoose

slope for		P1	P2	P3	P4
F=2100-3800					
Max F=4 kN	*1*	1.98	1.99	2.09	1.51
Const rate 5mm/sec	*2*	2.70	2.91	2.98	2.19
	3	2.80	2.99	3.06	2.33
	4	2.85	3.04	3.11	2.40
	5	2.88	3.07	3.15	2.45
	6	2.91	3.10	3.17	2.48
	7	2.93	3.11	3.19	2.50
	8	2.95	3.08	3.21	2.46
L (mm)	*9*	2.98	3.11	3.22	2.52
176	***10***	**2.99**	**3.13**	**3.23**	**2.99**
Bending Stiffness S kNmm^2	***10***	**339392**	**355951.3**	**367133**	**340007.2**
Bending Stiffness S kNm^2		0.339392	0.355951	0.367133	0.340007

Figure 8: Bending stiffness for Mongoose Bat 1

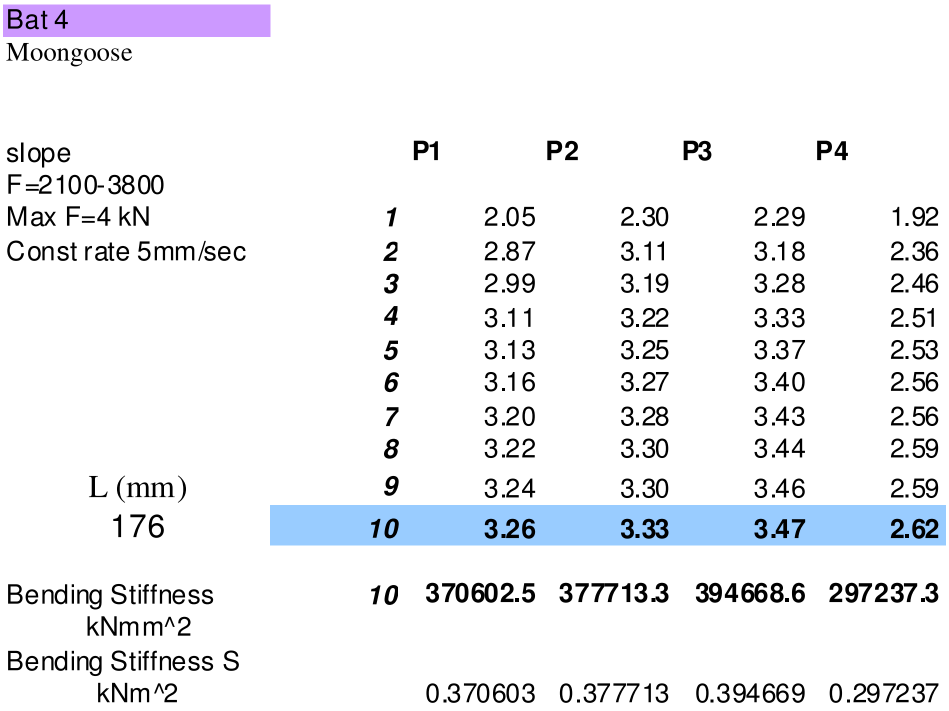


Bat 2

Moongoose

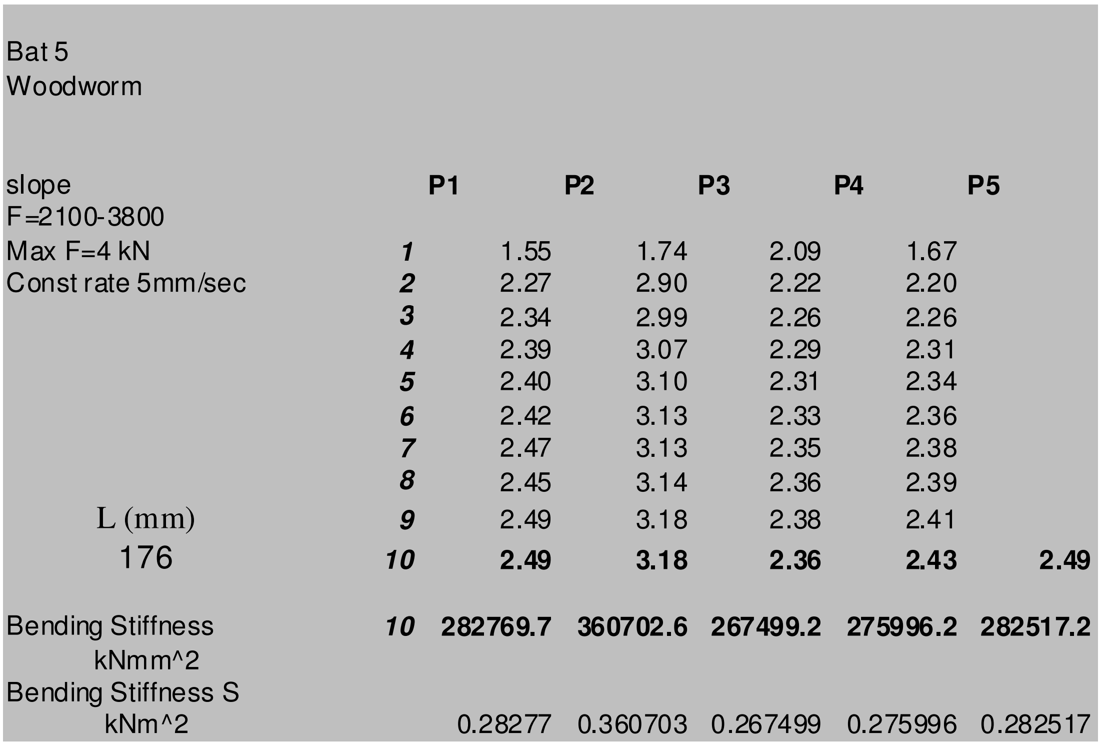
slope		P1	P2	P3	P4
F=2100-3800					
Max F=4 kN	*1*	2.07	2.03	2.02	
Const rate 5mm/sec	*2*	2.79	2.99	2.96	
	3	3.14	3.13	3.11	
	4	3.23	3.19	3.22	
	5	3.28	3.23	3.28	
	6	3.31	3.27	3.32	
	7	3.32	3.29	3.34	
	8	3.34	3.30	3.37	
L (mm)	*9*	3.35	3.32	3.39	
176	***10***	**3.37**	**3.32**	**3.41**	**2.83**
Bending Stiffness kNmm^2	***10***	**383009.7**	**377535.6**	**387019.1**	**321769.9**
Bending Stiffness S kNm^2		0.38301	0.377536	0.387019	0.32177

Figure 9: Bending stiffness for Mongoose Bat 2



Bat 4					
Moongoose					
slope		P1	P2	P3	P4
F=2100-3800					
Max F=4 kN	1	2.05	2.30	2.29	1.92
Const rate 5mm/sec	2	2.87	3.11	3.18	2.36
	3	2.99	3.19	3.28	2.46
	4	3.11	3.22	3.33	2.51
	5	3.13	3.25	3.37	2.53
	6	3.16	3.27	3.40	2.56
	7	3.20	3.28	3.43	2.56
	8	3.22	3.30	3.44	2.59
L (mm)	9	3.24	3.30	3.46	2.59
176	**10**	**3.26**	**3.33**	**3.47**	**2.62**
Bending Stiffness	**10**	**370602.5**	**377713.3**	**394668.6**	**297237.3**
kNmm^2					
Bending Stiffness S					
kNm^2		0.370603	0.377713	0.394669	0.297237

Figure 10: Bending stiffness for Mongoose Bat 3



Bat 5						
Woodworm						
slope		P1	P2	P3	P4	P5
F=2100-3800						
Max F=4 kN	1	1.55	1.74	2.09	1.67	
Const rate 5mm/sec	2	2.27	2.90	2.22	2.20	
	3	2.34	2.99	2.26	2.26	
	4	2.39	3.07	2.29	2.31	
	5	2.40	3.10	2.31	2.34	
	6	2.42	3.13	2.33	2.36	
	7	2.47	3.13	2.35	2.38	
	8	2.45	3.14	2.36	2.39	
L (mm)	9	2.49	3.18	2.38	2.41	
176	**10**	**2.49**	**3.18**	**2.36**	**2.43**	**2.49**
Bending Stiffness	**10**	**282769.7**	**360702.6**	**267499.2**	**275996.2**	**282517.2**
kNmm^2						
Bending Stiffness S						
kNm^2		0.28277	0.360703	0.267499	0.275996	0.282517

Figure 11: Bending stiffness for Woodworm Bat

3.2 Vibration Analysis

Vibration analysis was completed for two Mongoose bats and the Woodworm bat. Frequency data are summarised in Table 1 below.

Bat	2nd mode of vibration frequency in Hz (SD)	3rd mode of vibration frequency in Hz (SD)	4th mode of vibration frequency in Hz (SD)
Mongoose 1	130 (2)	408 (3)	736 (6)
Mongoose 2	130 (2)	405 (2)	732 (4)
Woodworm	142 (2)	467 (4)	789 (4)

Table 1: Frequency of the three main bending modes of vibration

Vibration energy results for all three bats are shown in Figures 12 – 15 below. These demonstrate that the energy imparted to the batsman through vibrations is equivalent for all three bats tested.

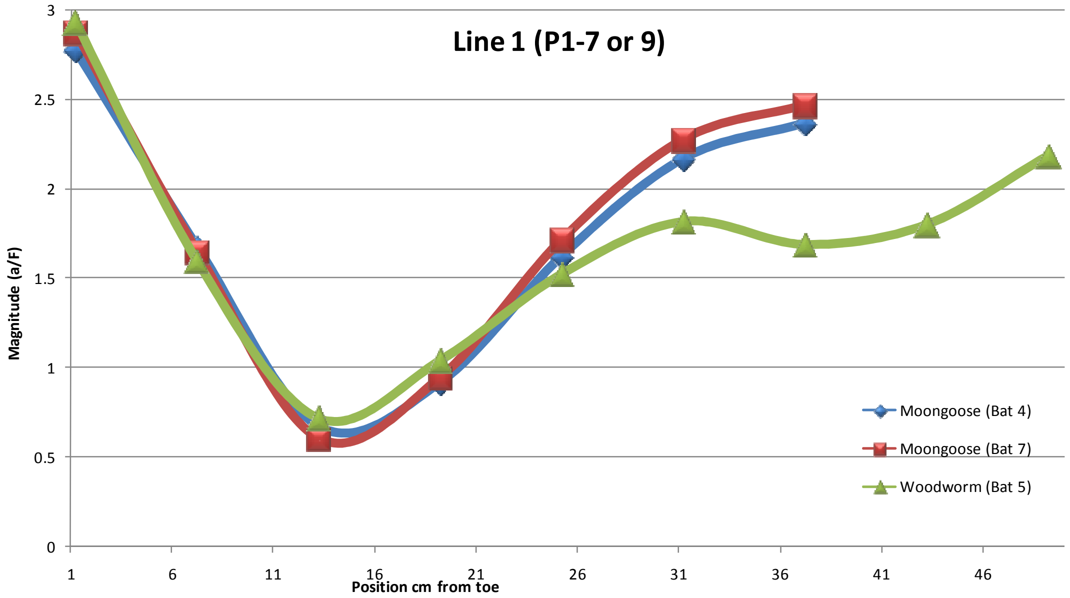


Figure 12: Vibration energy along first lateral edge of the bats.

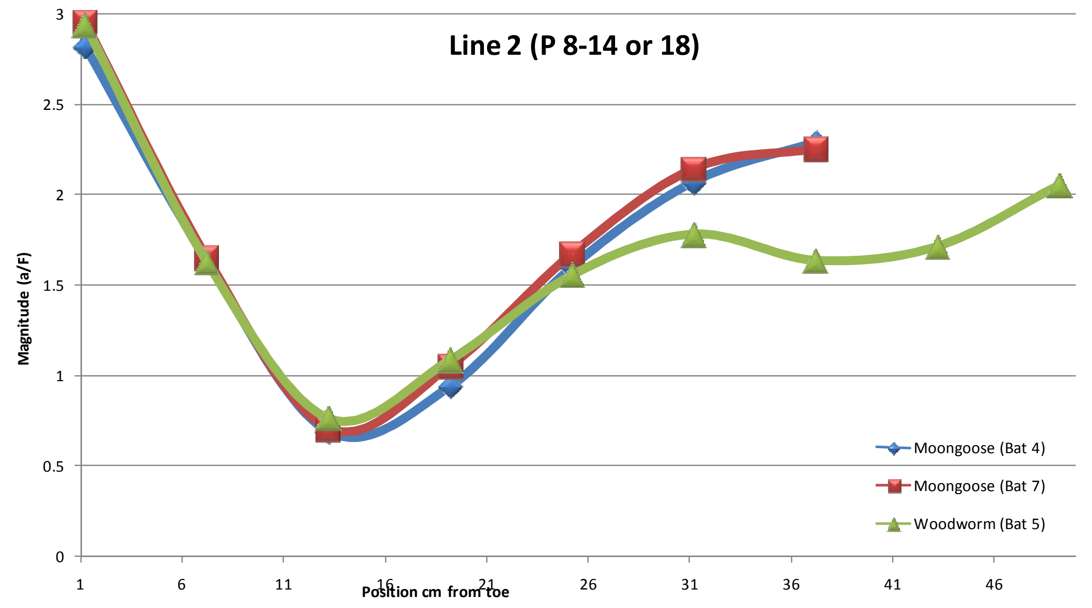


Figure 13: Vibration energy along a line central to the bats.

Figure 14: Vibration energy along a second line central to the bats.

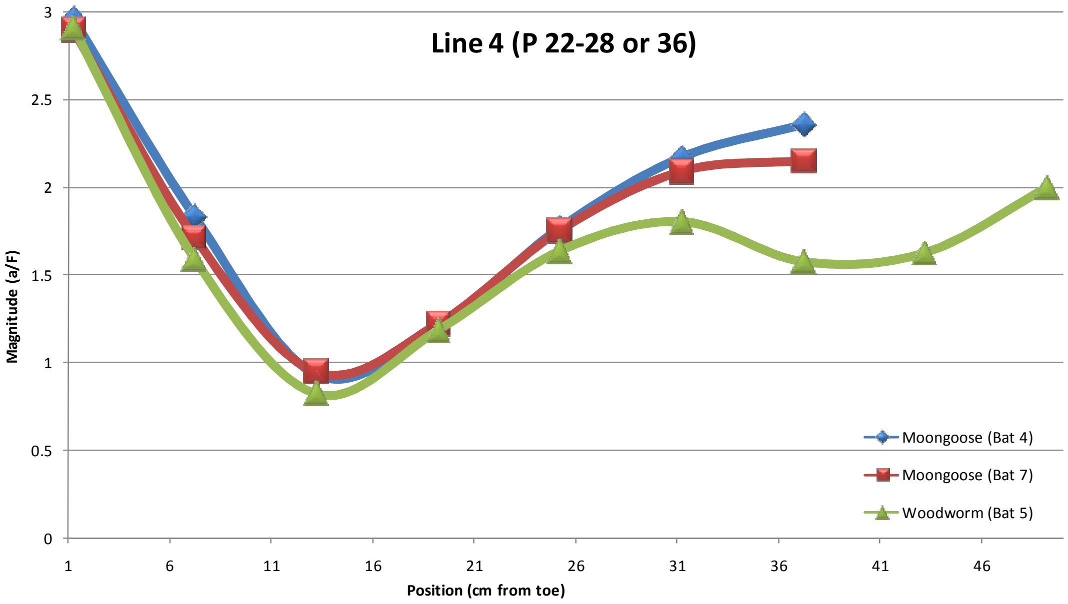


Figure 15: Vibration energy along second lateral edge of the bats.

3.3 Moment of Inertia

Bat	Mass (kg)	Distance to CoM (m)	Moment of Inertia (kgm^2)	Normalised MoI (kgm^2)
Mongoose 1	1.272	0.479	0.3535	0.3390
Mongoose 2	1.274	0.471	0.3436	0.3290
Mongoose 3	1.272	0.480	0.3491	0.3348
Average for Mongoose	*1.273*	*0.477*	*0.3487*	*0.3343*
Woodworm	1.220	0.461	0.3124	0.3124

Table 2: Moment of Inertia for all four bats tested

The Mongoose bats have on average an 11.6% higher MoI than the Woodworm. When scaled to an equal weight this is 7.0% higher. The CoM of both types of bat are within 3% of one another.

4. Discussion

The Mongoose bats have a stiffer blade. This is due to the robust rectangular cross section that is maintained along the length of the blade and is different from the Woodworm. It is known from the baseball bat literature that a stiff blade (hitting surface) combined with a relatively less stiff handle is an optimum for imparting maximum energy to the ball combined with minimising vibration discomfort to the batsman (hitter). The traditional cricket bat design achieves this partially through the cane and rubber handle (less stiff) and willow blade (more stiff). The Mongoose seems to have taken this a little further by stiffening up the blade more without stiffening up the handle. This is likely to have a performance advantage without compromise of batsman comfort.

The Mongoose bats have vibration frequencies that are similar to the Woodworm. This is likely due to the consistency of materials and manufacture methods employed; the bats were all manufactured by the same manufacturer. The vibration energies were equivalent between the two bat designs up to 26 cm from the toe and demonstrated that they had equivalent 'sweet spots'. When the ball strikes above this point, the traditional design has a lower vibrational energy than the Mongoose. This is clearly due to the longer blade.

It is likely that the most significant performance difference between the bat designs is that the Mongoose has a higher MoI for the same mass of bat. This means that holding both bats vertically will 'feel' equivalent, but the bat 'pick up' will feel heavier for the Mongoose. Conversely, swinging the bat with the aid of gravity and providing a rotational pivot about the hands will feel lighter for the Mongoose due to the dynamics of the bat. This will enable a higher striking velocity on the ball. It is hypothesised that based on this significant finding, the Mongoose will strike the ball further. In addition, although not quantified in this study, as the surface area of the Mongoose blade is less than the Woodworm, so it will experience less resistance when swung through air. This further enhances the blade striking velocity.

5. Conclusions

The Mongoose bat has been optimised in order to redistribute mass along a smaller blade. This has resulted in a bat that for the same pick up height has the potential to impart more energy to the ball. This is due to an increase in moment of inertia. The relative stiffness of the bat and lower air resistance is predicted to enhance this effect. This prediction is based on prior work that involved finite element analysis of baseball bats in which the blade is stiffened and the handle is reduced in stiffness in order to provide the same optimisation.

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