Work, Energy, and Efficiency of a Recurve Bow

Sedthasard Kasetcharoenkit and Patrick Nguansamarng

International School Bangkok
39/7 Samakee Rd, Pakkret,
Nonthaburi, 11120, Thailand
Email: Khawton.kj@gmail.com

Abstract
The shooting of a recurve bow was varied in two ways, changing draw distance and string length, to determine the relationship between work done in drawing the bowstring and the resulting kinetic energy of the arrow. It was shown that the kinetic energy of the arrow launched increases as the work on the string increases, with the efficiency decreasing as work increases, giving similar results to Allain's investigation of a longbow.

Keywords: bow, arrow, work, kinetic energy, efficiency.

I. INTRODUCTION

Bows and arrows have been an essential part of hunting since the stone age. When hunting, archers can either change the draw distance or the bowstring length to control arrow speed. Ideally, archers want to find the condition which maximizes arrow speed while minimizing energy loss. This paper aims to investigate the relationship between draw length of a recurve bow and the force, kinetic energy output, and efficiency, as well as how string length impacts these variables.

Work (W) done is defined as the integral of a force-displacement (F-s) graph, shown in the equation:[1]

$$W = \int_a^b F(s)\, ds \tag{1}$$

Work is done in drawing the bowstring, and when released, is converted into the kinetic energy (KE) of the arrow, which can be represented by equation:

$$KE_{avg} = \frac{1}{2} m v^2 \tag{2}$$

where m is the mass of the arrow and v is the launch velocity of the arrow. Efficiency is the ratio between the work input and the kinetic energy of the arrow, indicating relative energy loss.

In research conducted by Rhett Allain, the work done in drawing the string of a longbow and the resulting kinetic energy of the arrow were measured. It was found that there is a positive linear relationship (Figure 1) with the equation:

$$KE_{avg} = 0.55\, J \cdot W + 0.29\, J \tag{3}$$

This indicates that efficiency decreases as the draw length increases. Allain's data are not evenly distributed across the range tested. It is assumed that the data is linear between 10 and 30 J.

A longbow and a recurve bow are shown in Figure 2. The longbow is made of a straight limb, forming a simple D-shape when strung. The recurve bow, forms a double-S shape, as the tips curve away from the archer. The tips of the recurve bow are said to store more energy when drawn, resulting in shots that are smoother and more powerful than

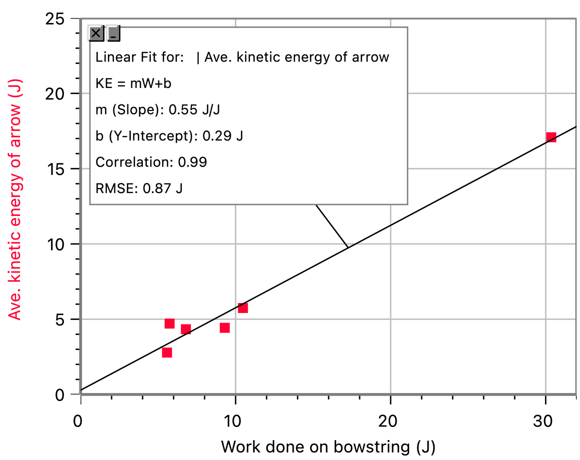

Figure 1. Allain's experimental results.[2]

Figure 2. Longbow (left) and recurve bow (right).

from a longbow.[3] As the two bows are similar, results from this investigation are predicted to be similar to Allain's conclusions, with the efficiency of the recurve bow expected to be greater.

II. METHODS

To measure the work done in drawing the bow, the force as a function of draw distance on a recurve bow with a stated draw weight of 48 pounds was determined. The bow was fixed horizontally, and masses varying from 0.999 to 9.400 kg were hung at the midpoint of the string, as shown in Figure 3. The distance the bowstring was drawn back was measured for each weight.

The bow was then drawn with distances varying from 0.228 to 0.480 m and the arrow released. The velocity of the arrow was measured with a chronograph.

For the second part of the investigation, the string length was changed by twisting the string using a serving machine. More twists in the string result in a shorter string length, and thus a higher tension in the bow. String lengths ranging from 1.585 to 1.632 m were tested. The same methods were used to measure the work done drawing the bowstring for each string length, and the arrow velocity was measured for each string length tested at a constant draw distance of 0.71 m. It should be noted that the range of the string length that could be tested

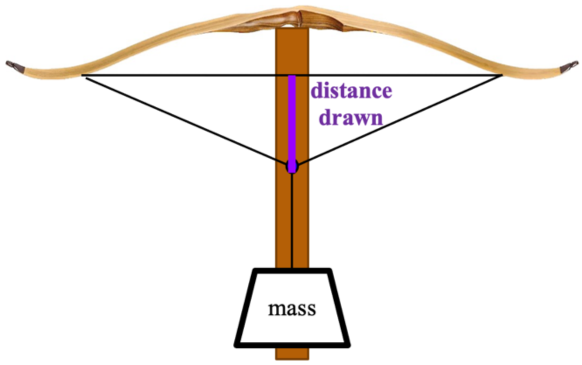

Figure 3. Experimental setup.

was very limited, as changing the length of the bowstring too much would result in damage to the limb of the recurve bow.

III. RESULTS AND DISCUSSION

The relationship between the force on the recurve bowstring and the draw distance is shown in Figure 4, with a cubic function fit. The function was integrated, following Equation 1, for each draw distance to determine the work done.

The relationship between average kinetic energy and work for the recurve bow is shown in Figure 5 (in red) to obtain a linear relationship of:

$$E_{KE} = 0.61J \cdot W + 0.87J \tag{4}$$

There is a positive linear relationship between work done and kinetic energy, implying that, like the longbow, the efficiency of the energy conversion decreases as the work done increases. Compared to Allain's results (Figure 5, in blue) it

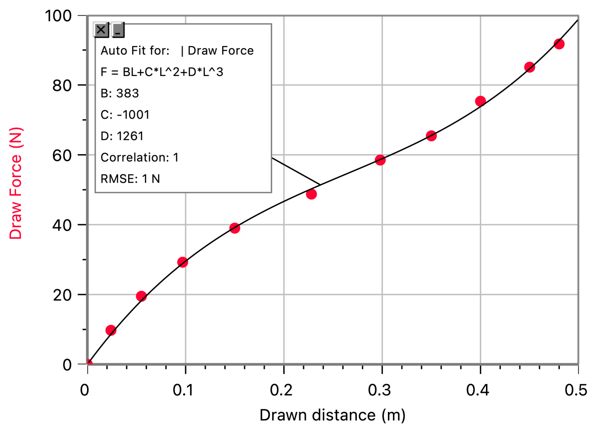

Figure 4: Force-distance graph for fixed string length to calculate work done on string.

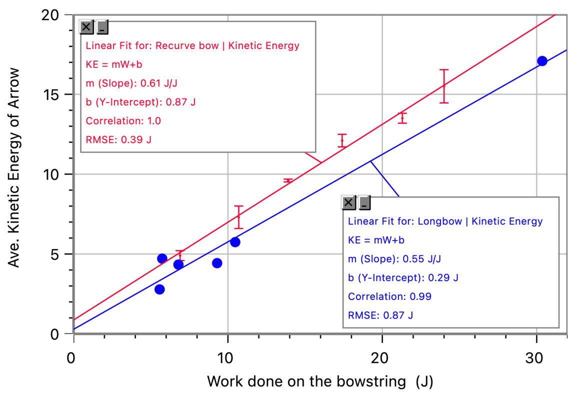

Figure 5: Average kinetic energy of the arrow vs work on the bowstring, with comparison to Allain's longbow experiment.

is clear that the conversion of work to kinetic energy is greater for the recurve bow than for the longbow. Also, as draw distance increases, the recurve has higher efficiency, as expected.[3] Interestingly, given the linear fit with positive y-intercept, the efficiency decreases as work done increases for both bow types.

The relationship between efficiency and draw length for the recurve bow is shown in Figure 6 (in red), showing a negative linear relationship of:

$$e_{Recurve} = -0.26m^{-1} \cdot d + 0.77 \qquad (5)$$

Compared to Allain's results (Figure 6, in blue) the results indicate that efficiency of the recurve bow is higher at the typical larger draw distances. The efficiency of both types of bow decreases as draw distance increases, however, the efficiency of the longbow decreases more with greater draw distance.

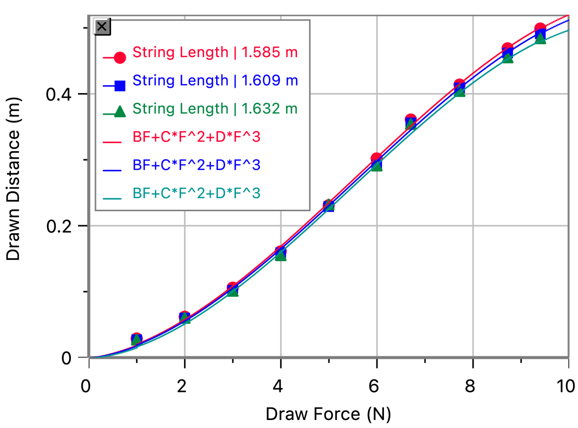

Figure 7: Force of string drawn vs displacement graph for selected string lengths.

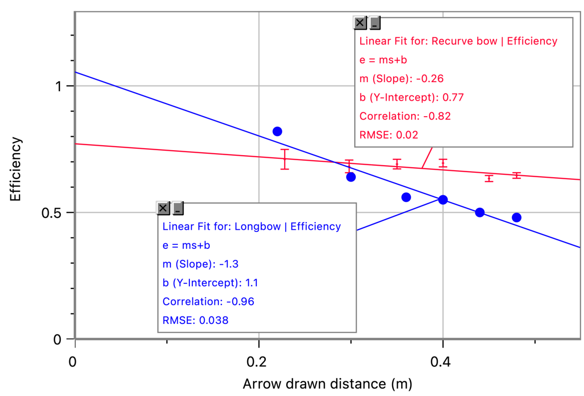

Figure 6: Efficiency of the bow vs draw length, comparison to Allain's longbow experiment.

Figure 7 gives a selection of the data of drawing force versus string displacement for the second part of the investigation, showing the shortest, middle, and longest string lengths tested. The relationship is similar to Figure 4, as expected, since a recurve bow was used for both parts. The work done in drawing the string to a fixed distance was calculated for each string length. Interestingly, the force needed to draw the string to a fixed distance is less for shorter strings, as can be seen from Figure 7. The work done in drawing the bowstring to a fixed distance increased with increasing string length, however, given the small range of lengths that could be tested, the difference was small.

The relationship between work done in drawing the string versus the kinetic energy of the arrow for the range of string lengths tested is shown in Figure 8. The efficiency of around 66% falls within the range shown for the recurve bow in Figure 6.

To further our knowledge of the efficiency of the kinetic energy of the arrow converted from the

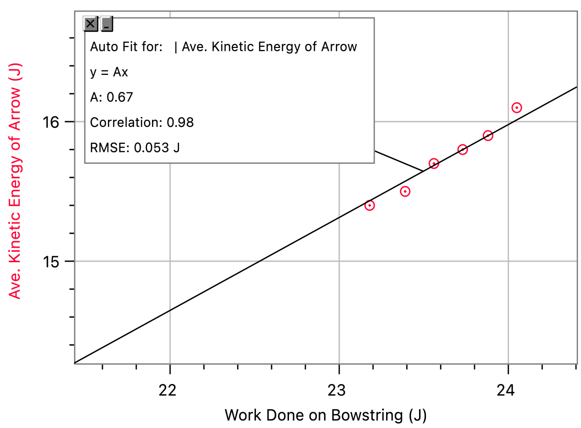

Figure 8: The work done and kinetic energy of the arrow for the string lengths tested.

work done in drawing the bow, different types of the bow such as compound and crossbow should be investigated. Research could also be done on different masses of the arrow. This would give the archers an idea of the best bow and arrow conditions to choose to maximize efficiency.

IV. CONCLUSION

The work done in drawing the bowstring and the kinetic energy of the arrow for both draw distance and string length was found to have a positive linear relationship. The average recurve bow efficiency was found to range from 65% to 71%, with efficiency decreasing with increasing draw distance. This trend was similar to Allain's finding for the longbow, with the longbow showing a less efficient conversion of work to kinetic energy for most draw distances, as expected.

V. REFERENCES

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