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Title	Arrow-mounted ballistic system for measuring performance of arrows equipped with hunting broadheads
Authors	Barton, John;Včelák, Jan;Torres-Sanchez, Javier;O'Flynn, Brendan;Ó Mathúna, S. Cian;Donahoe, Robert V.
Publication date	2012
Original Citation	Barton, J., Včelák, J., Torres-Sanchez, J., O'Flynn, B., O'Mathuna, C. and Donahoe, R. V. (2012) 'Arrow-mounted Ballistic System for Measuring Performance of Arrows Equipped with Hunting Broadheads', Procedia Engineering, 34, pp. 455-460. doi: 10.1016/j.proeng.2012.04.078
Type of publication	Article (peer-reviewed)
Link to publisher's version	http://www.sciencedirect.com/science/article/pii/S1877705812016918 - 10.1016/j.proeng.2012.04.078
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Download date	2026-11-16 19:11:36
Item downloaded from	https://hdl.handle.net/10468/953

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SciVerse ScienceDirect

Procedia Engineering 34 (2012) 455 – 460

Procedia Engineering

www.elsevier.com/locate/procedia

9th Conference of the International Sports Engineering Association (ISEA)

Arrow-mounted Ballistic System for Measuring Performance of Arrows Equipped with Hunting Broadheads

John Barton[a]*, Jan Včelák[b], Javier Torres-Sanchez[a], Brendan O'Flynn[a], Cian O'Mathuna[a], Robert V. Donahoe[c]

[a]*Clarity Centre for Sensor Web Technologies, Tyndall National Institute, University College Cork, Lee Maltings, Cork, Ireland*
[b]*CTU in Prague,FEE, Technicka 2, Prague 6, CZ,*
[c]*Full Flight Technology LLC, Cambridge, MA 02142, USA*

Accepted 05 March 2012

Abstract

Measuring an arrow's ballistic performance such as arrow velocity on impact, total time of flight and arrow shaft oscillation is challenging because of the dynamic nature of arrow flight. This challenge becomes increasingly difficult as the distance of the shot increases. It is also of great interest to bowhunters to understand the ballistic performance of arrows that include hunting broadheads. A miniaturized, sensory data acquisition system, located in the arrow tip and engineered to withstand the high accelerations experienced at launch and impact, enables the precise measurement of arrow ballistics in flight. By continuously recording arrow drag in flight, the system enables measurement of the ballistic performance of an arrow as it travels downrange. The authors have also built an adapter that is connected to the housing of the sensing system to allow for comparative ballistic tests to be performed on hunting broadheads. Here, we present results obtained using the sensing system to perform initial testing on two commercially available broadheads at shot distances of approximately 45 m.

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Keywords: Arrow; broadhead; ballistic; kinetic energy; velocity; drag; microelectronics

1. Introduction

Archery is a global sport offering an athletic environment that includes elements of both art and science. Today's archer can choose to participate in Olympic style archery using hi-tech recurve bows, 3D

* John Barton. Tel.: +353 21 490 4088; fax: +353 21 490 4058.
E-mail address: john.barton@tyndall.ie.

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doi:10.1016/j.proeng.2012.04.078

competition with compound bows and bowhunting using any of compound bows, modern crossbows and traditional longbows and recurve bows [1]. The demographics of participants also widely vary and include elementary school children in gym class, world-class athletes, and senior citizens who continue to participate in the sport.

Regardless of the niche within the field of archery, advances in technology have created new standards of performance. Over the past 20 years huge advances have been made in bow designs and in materials of construction of bows and arrows. For example, it is now common for compound bows to launch arrows at over 91.4 m/s (300 ft/s) and a small number of companies offer crossbows that launch arrows at 121.9 m/s (400 ft/s) or more. Modern bow designs have also reduced the noise at arrow release and the shock and vibration felt by the archer when the arrow is loosed from today's bows. Arrow designers have taken advantage of the stiffness and durability of carbon fiber to develop modern carbon arrows. However, archery equipment performance measurement has not kept pace with the advances in the materials and performance of archery equipment. The dynamic nature of arrow flight has been captured in high speed video [2]. However, cameras with suitable frame rates cost tens of thousands of dollars and it is difficult to setup equipment to capture an arrow shot at a distant target with sufficient resolution for more than a small portion of the arrow's flight. It is also difficult to generate discrete values suitable for comparing shaft oscillation from one shot to the next or the distance covered by the arrow in a series of video frames. The introduction of the ballistic chronograph [3] over 20 years ago encouraged some to try to determine arrow drag using a "double-chronograph" method in which a first chronograph is located at the bow to capture the arrow launch speed while a second chronograph is located at the target to capture arrow impact speed. Drawbacks to this approach include the fact that chronographs use optical sensing and results can be affected by ambient lighting conditions. In addition, the arrow's flight path must be precisely located so the arrow travels directly above the optical sensor. This is an increasingly difficult challenge as the distance of the shot is increased. The double chronograph method also introduces the measurement uncertainty of two instruments. Furthermore, neither of the preceding methods actually measure arrow drag nor allow the precise capture of the time-of-flight of the arrow.

2. Arrow Mounted Sensing System for In-flight Ballistics Measurements

The Velocitip [4] miniaturised arrow ballistic measurement system was presented in [5]. This was realized as an electronic data acquisition system built into the arrow tip capturing acceleration data in all 3 axes for the entire flight duration. The overall tip body diameter is 9mm and the total length of the tip (including cap) is 40mm. The system housing is equipped with industry standard 8/32 UNC thread in order to fit standard arrow shaft inserts [6]. The durability of the mechanical enclosure and assembled printed circuit board (PCB) was tested using drop tests at 5000G in the positive and negative axial directions. The inner cavity with inserted PCB was then encapsulated for extra protection.



Fig. 1. Electronic Arrow tip construction. © Full Flight Technology LLC

The PCB electronics consists of an ATtiny84V microprocessor, an AT24C512 512kB EEPROM memory, 3-axis digital accelerometer ADXL345 (10 bits, 16G range), SQ-ASA-150 shock switch with 150G threshold and a power management circuit. The whole system is powered by two coin cell batteries. Communication between tip and docking station is provided by a custom 1-wire protocol. The tip body is made from an aluminium alloy and is used as a negative ground conductor. The communication line is fed through the threaded shaft at the rear of the tip body. The positive battery contact is a custom brass contact that is soldered directly to the PCB.

3. Archery Equipment Performance Test

The use of arrow drag recorded in flight provides new opportunities for testing archery equipment performance because the recorded data can be used to generate discrete values for any point in flight. For example, the system allows a determination of arrow velocity, trajectory and energy at any point of the arrow's flight.

Archery equipment performance can generally be divided into three related but distinct elements: 1) the performance of the bow launching the arrow; 2) the performance of the arrow in flight; and 3) for bowhunters, the performance of the arrow-broadhead combination on impact. Shooting machines and strain gauge sensing provide a way to measure the efficiency of today's bows. Broadhead performance is the subject of countless debates. Rudimentary tests on carcasses and other test materials provides some data but generally are not conducted in a highly scientific manner.

The system provides a substantial improvement to prior approaches for testing the performance of the arrow in flight. In addition, the authors have found that arrow shaft oscillation (a product of both the bow's performance at launch and the construction of the arrow) can also be evaluated by using the measured arrow drag as a proxy for instability in flight because greater instability increases arrow drag.

3.1. *Accessory Component Allows Testing of Archery Broadheads*

The authors have developed an add-on accessory component, an adapter that is attached to the forward end of the housing for the sensing system. The adapter allows any arrow point using industry standard threading to be attached at the forward end of the arrow. See Figure 2(b) ii). The resulting assembly integrates the sensing system with the arrow point for comparative testing of the downrange performance of different designs. The electronic housing combined with the adapter adds approximately 8.42g (130 grain) to the overall weight of the arrow.





Fig. 2. (a) Crossbow and foam target; (b) Possible configurations of the equipment used during testing with a crossbow bolt i) fixed blade broadhead without electronics ii) mechanical broadhead attached to Velocitip electronics with adapter iii) Velocitip electronic field point. © Full Flight Technology LLC

Because of the added mass at the forward end of the arrow, initial tests were conducted using a 0.51m carbon cross bow bolt. This style arrow provides a center of mass that is typically located more toward the rear of the arrow than arrows used with other styles of bows.

This is sometimes referred to as having a low front-of-center (FOC). During shooting tests the authors achieved repeatable and accurate arrow flight even with the addition of 14.9g (230 grain) of mass at the front of the arrow (8.42g sensing system with adapter and 6.48g broadhead).

3.2. *Equipment Specifications*

Tests were conducted using the following equipment:

- Bow: Parker Safari Magnum Crossbow 150 lbs
- Arrow: Easton Carbon Power Bolt; 0.51m length; 0.102m plastic vanes; weight 20.02g (309 grain)
- Broadhead: Fixed Blade Broadhead
  - Mfg: Tight-Point Shuttle T-Lock 1 1/8
  - Weight: 6.48g (100 grain)
- Broadhead: Mechanical Broadhead – Practice Head
  - Mfg: Grim Reaper
  - Weight: 6.54g (101 grain)

A mechanical broadhead flies with the blades tucked into the body until impact when the blades open. A practice broadhead mimics the flight of the mechanical broadhead it is intended to replicate but does not open on impact and is used only for practice.

The individual weights of the system and tips attached to the arrow can be summarized as follows:

- Velocitip (with field point tip) – 6.48g
- Velocitip (with adapter) – 8.29g
- Velocitip (with adapter and fixed blade broadhead) – 14.77g
- Velocitip (with adapter and mechanical practice point) – 14.84g

4. Results

The following tables summarises the results obtained for 4 shots taken by each of the configurations listed in Section 3.2 (arrow/Velocitip/adapter and either Fixed Blade or Mechanical Broadhead) at a distance of 45.72m. The Velocitip recorded data throughout the flight and the tables present the velocity at launch and impact, the average velocity, the momentum at launch and impact, the kinetic energy at launch and impact and the retained energy, the time of flight and the arrow drag average. Tables 1 and 2 present different data for the same shot set.

Table 1. Velocity and Momentum for Shot Set (Standard Deviation in parentheses)

Broadhead	Vel_Launch (m/s)	Vel_Impact (m/s)	Vel_Avg (m/s)	Mom_Launch (kg*m/s)	Mom_Impact (kg*m/s)
Tight-Point Shuttle T-Lock 1 1/8	88.04(0.22)	80.91(0.35)	84.48(0.28)	3.063(0.0083)	2.815(0.0124)
Grim Reaper	87.7(0.29)	80.24(0.38)	83.97(0.34)	3.056(0.0097)	2.797(0.0138)

Table 2. Energy, Flight Time and Drag for Shot Set (Standard Deviation in parentheses)

Broadhead	KE Launch (J)	KE Impact (J)	Retained Energy (%)	Time Of Flight(ms)	Arrow Drag Average (mg)
Tight-Point Shuttle T-Lock 1 1/8	134.83(0.66)	113.89(0.96)	84.47(0)	552.02(1.84)	1385(28)
Grim Reaper	134.03(0.86)	112.21(1.06)	83.72(0)	555.33(2.24)	1441(13)

5. Discussion and Conclusions

This initial application of the system to measure the in-flight ballistic performance of arrow's equipped with different style hunting broadheads shows great promise. Although the data set presented here shows small differences in the ballistic performance for the two selected broadheads, the precise nature of the collected data and the ability to provide discrete values for immediate comparison are apparent. In addition, the ability to easily capture the arrow's terminal performance at shot distances of 45 meters or more enables the study of the cumulative effects of the arrow drag. The preceding also simplifies the study of the relative change in arrow performance with changes in distance. Thus, the system can be used as a tool to evaluate whether flight characteristics of different arrows show that performance-advantages of an arrow relative to other arrows increases or decreases as the shot distance increases. The system enables such differences to be directly measured using arrow drag.

5.1. *Sensitivity and Precision*

The weight of the two arrows differed by 0.065g out of a total arrow mass of over 34g (a difference of approximately 0.2%). This small change in arrow weight is expected to result in a small change in arrow launch speed. The data recorded with the system does identify the lighter arrow as traveling faster at launch with the percentage difference (0.34 m/s or approximately 0.4%) between the two arrows being slightly higher than the percentage difference in arrow weight. In addition, the arrow-mounted ballistic system records time-of-flight with a resolution of 0.3ms. In the collected data, the arrow equipped with the fixed blade broadhead left the arrow at a higher rate of speed and traveled to the target 3.31 ms more quickly than the arrow equipped with the mechanical broadhead.

5.2. *Shot Distance and Cumulative Effects of Arrow Drag*

The system records ballistic data for each shot for a maximum flight time of 800 msecs. Here, the total time of flight for a relatively heavy projectile shot from a crossbow to a target over 45 meters away was approximately 555 msecs. These results demonstrate that the system can be utilized at even greater distances where the cumulative effects of arrow drag are most pronounced.

5.3. *Uses as a Tool for Equipment Selection and Design*

The system provides various measures of performance including time of flight, and launch and impact values of arrow speed, kinetic energy and momentum. The system also provides a percentage of retained energy determined as kinetic energy at impact divided by kinetic energy at launch.

The system is currently being used by archery manufacturers and archery professionals to determine whether changes in equipment, equipment adjustments and shooting form aid performance. For example,

a number of factors including accuracy, speed/energy loss in flight and performance on impact are used to select broadheads and to design broadheads. These results illustrate one example of a difference in ballistic performance between two types of broadheads. The measured difference in terminal performance (a difference of 0.75% in retained energy) in collected data suggests that a selection between the two hunting broadheads tested here will most likely be made based on factors other than speed/energy loss in flight. However, the authors note that bowhunters using traditional equipment hunt dangerous game with equipment that delivers significantly lower kinetic energy than found in these results. For these bowhunters, small increases in retained energy can be a deciding factor in equipment selection.

Bowhunters value a broadhead that flies most like a conventional arrow field point because their bowsights do not need to be adjusted when they move from the practice range using field points to a hunting situation where broadheads are used. These results demonstrate that further testing will be valuable to gain a more comprehensive understanding of how the performance of various broadheads compare with one another and with the performance of conventional field point configurations.

Acknowledgements

The authors thank Paul Sabin and Jay Avis of Fikst Product Development, Woburn, MA for their contribution to the product design. The authors would like to acknowledge support by Science Foundation Ireland under grant 07/CE/I1147.

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