High Speed Video Analysis of Force by a Bowstring on an Arrow

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Introduction

- Bows and arrows have been used for years for both hunting and recreational purposes, and over time innovations have been made to the bow to make it easier for the user. An arrow needs to have high force on it in order to accelerate to high speed, but the user must also be capable of drawing back and easily holding the string in this position.

- Straight bows, that do not employ technological advances, require the user to hold all of the force back until he needs to release the string, which would be incredibly difficult for an extended period of time. The straight bow would show a linear force versus distance relationship and would follow Hooke’s Law.

- New bows use technology, including Let-off and Cams, to ease use for the archer. Let-off decreases the draw-weight as the user comes to full-draw. As the string is drawn the cam turns and imparts force to compress the limb. Once the cam turns all the way around a much smaller force is required to hold the string.

- Archers report that it is initially very hard to pull the string, then it becomes easier to pull, and finally is extremely easy to draw and hold.

- These innovations change the relationship between the force and the distance such that the compound bow does not follow Hooke’s Law.

Materials

- To study the force versus distance relationship of more advanced bows a Mathews Solocam FeatherMax Bow was used.

<table>
<thead>
<tr>
<th>Bow Specifications</th>
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<tr>
<td>IBO Rating: 235 fps = 71.6 m/s</td>
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<td>Axle-to-Axle: 36” = 914 m</td>
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<td>Bow Weight: 7 lbs = 3.25 kg</td>
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<td>Draw Weight: 56.5 lbs = 251 N</td>
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<td>Let-off: 65%</td>
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<td>Draw Length: 29” = .736 m from handle to fully drawn</td>
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Results and Conclusion

- The force versus distance relationship was non-linear as expected.

- The video was shot with a Casio EX-F1 camera that records at 1200 frames per second.

- LoggerPro software was used to analyze the motion of the arrow and calculate the force versus distance.

Procedure and Experiment

**Purpose:** The purpose of this project was to analyze the force by a bowstring of a Mathews Solocam Bow on an arrow.

**Data Collection:**

- The video was trimmed and imported into LoggerPro for analysis.
- The x-axis was aligned with the axis of the arrow so that the variation in Y would be negligible.
- The origin was placed at the location where the arrow leaves the string.
- The distance was calibrated by filming a meter stick in the video and then setting that distance equal to a meter in LoggerPro.
- To account for the fact that the high-speed video records at 1200 fps but plays at 30 fps, a column was created to calculate the real-time of the video.
- Two point series were used to track the motion of the arrow. The red point series was on the right side of the tail-feather and the blue was on the left side of the tail-feather.

**Force v. Distance Stretched Graph**

- The center of the tail-feather location was then calculated by finding the mean of the left and right point series points.

\[ x_{center} = \frac{x_1 + x_2}{2} \]

- This was done to attempt to eliminate some of the uncertainty of the exact feather-center location.
- The velocity and acceleration of the center point were then calculated using the derivatives of the center points.

\[ v_y = \frac{dx_{center}}{dt} \quad a_y = \frac{dv_y}{dt} \]

- The force was calculated using:

\[ F_y = m a_y \]

- The mass of the arrow was .2645 kilograms.
- Data points were only collected until the arrow reaches the origin, thus leaving the bow string.

**Let-off:**

- At full-draw the force is very small, which makes it easier for the user. Once the string is released the force initially increases rapidly, then increases linearly, and then reaches a nearly constant force. The constant force is for a little more than half the distance the arrow travels when still in contact with the string.

- The results were consistent with the design and innovations of the compound bow.

**Materials**

- The minimum force required to hold the string was 8.0 N.
- The force began to increase linearly at around .473 m and 64.85 N, which is comparable to the 65% left-off reported on the bow. 65% of the maximum force of 154 N is 99.3 N.
- The force increases linearly with a slope of 413.8 N/m for 17 meters.
- The average maximum force was nearly constant at 154 +/- 5 N, for a distance of about 0.3 meters.
- The maximum velocity achieved in the video, 71.67 m/s, was very close to the IBO rating, 71.63 m/s, provided for the bow.

Acknowledgements

The author would like to thank Cody Tyres who was the archer used in the filming of the project

References