Effects of Fin Offset Angle on Static Torque and Drag for an Archery Arrow

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This paper is a study of the varying drag and static torque of an arrow due to the offset of its fins in regard to its longitudinal axis. Data was collected in a 3x4 wind tunnel using a super-scaled arrow connected to a torque sensor. The results were compared to a separate test conducted at the National Institute for Aviation Research -NIAR- ballistics range where the rotation rate of the arrow was compared to its forward velocity. The introduction provides a brief update for the reader on the current industry "beliefs" about the importance of the spin stabilization for an arrow. Following this, an overview of previous testing that has similar relation to the current object will be presented. The test procedure for both tests will then be presented with the accompanying data. The results of this test indicated that there was a direct relation between static torque and rotation rate for an arrow. However, there was not a significant change in velocity of the arrow at the ballistics range to confirm the changes on drag measured in the wind tunnel.

I. Introduction

Accuracy has always been an imperative component of an archer's shot throughout the ages. Whether a bow was used for war, sport, hunting, or any other activity, the ability to accurately and consistently place arrows where they were aimed was –and is- vital. A large amount of variables must be accounted for in the process of attempting to accurately shoot an arrow. Fortunately for the archer, modern manufacturing technology, "shooting form" built through practice, and a basic understanding of the physics involved in an arrow's flight can now provide extremely accurate and precise shots in a moderately ideal environment. However, a favorable environment is not always present for many individuals such as bow-hunters and those who shoot outdoors. A strong gust or steady wind distributed over the flight distance of the arrow can cause the arrow to veer from its intended course. This is where the fins attached to an arrow –otherwise referred to as "vanes" or "fletches"- have significance.

The fletches on an arrow act in a similar way to the fins on an aircraft; they provide a resisting drag to maintain stable flight if an external force is placed on the moving body. Arrows also have an advantage over aircraft since they are only intended to have one direction of travel. Due to this lack of maneuverability, arrows have the option to be spin stabilized. Spin stabilization, also known as gyroscopic stabilization, occurs when a body spins at a high enough rate to the point where any external force acting on it appears –to the body- to be acting on it from all directions which leaves the body in equilibrium. Since the body is seemingly in equilibrium it will not be affected by the applied external force. So by spinning an arrow it is believed that the arrow will be further stabilized from winds and thus maintain a higher level of accuracy.

The archery industry has devised many different vane configurations in order to attempt to maximize the stability of an arrow. With the most common vanes on the market it is possible to purchase various fletching jigs in order to twist the fins into a helical fashion or simply attach them at an offset angle. Both options are supposed to increase the spin on an arrow, with many claiming that helical is ideal. Another popular option is using a set of feathers on the arrow. These are much lighter than manufactured vanes and are rigid against side forces yet can fold downward upon entering a target; they also have a natural curve to them. The most recent advances in fin technology for arrows are what will be referred to as “specialty vanes.” There are brands such as the “NAP QuikSpin” and the “Nockturnal Helios” that are made specifically to increase an arrow’s spin rate in the best sense possible.

This test was devised under the assumption above: that an increase in an arrow’s rotation rate would increase its gyroscopic stability. While investigating what would cause the increased spin of an arrow, a hypothesis was fabricated. If the offset of a fin was increased in order to increase the rotation rate, the new fin orientation should create a notable increase in drag. In addition to the drag increase, some of the arrow’s initial kinetic energy would be converted into rotation. The basis for this test was to note the increase in rotation rate compared to the overall loss in forward velocity due to both drag and energy conversion.

II. Background Information

The topic of testing archery arrows through wind tunnel testing is one that has been very rarely explored. In fact only one document relating to a wind tunnel test that was conducted in Japan in 2010 was found.[1] Unfortunately, the authors were unable to obtain any data in regard to the rotation of an arrow. They did obtain some good data on the lift and drag produced by a Japanese arrow at various angles of attack.

Since the popularization of fluid mechanics and flow visualization, mathematical models have been generated to more accurately describe the behavior of missiles with some form of control surface protruding from their shafts. Due to the ‘typical’ shape modern arrows have, it is possible to use existing experimental and theoretical data on rockets to predict the behavior of arrows, so because of that this literary review will be broken up into different components of missiles.

Arguably one of the most crucial components of an arrows stability is the shaft of the arrow, and how the fletchings effect the shaft. Pechier, Guillen, and Cayzac find that when fletchings are added to the aft end of a rotating slender cylinder, the Magnus effect is there locally magnified in the opposite direction as the rest of the cylinder, linearly proportional to the shaft’s angle of attack below 8°.[2] Though this would initially suggest that fletchings degrade the aggregate performance of such a missile, Mikhail uses wind tunnel and experimental data to show that inflight oscillation in missiles (A major factor in arrow instability) can be reduced by as much as 50% with the introduction of a variety of fletching.[3]

An older article was discovered that was originally by the Air Force. It gave very good information of fin offset on a missile pertaining to being mounted at angles other than perpendicular to the main shaft. This data proved that the most stable fin configuration on a missile (and thus a great crossover to arrows) is to keep the fin vertically mounted perpendicular to the shaft.[4]

There were numerous other "unofficial" articles that were found from outdoor magazines and user forums all discussing fin offset and arrow stability. Many others talked about what fins gave the best amount of spin and made recommendations for various types of archery shooters. However, they were not included in this article since they were not peer-reviewed and at many times seemed unscientific and opinionated. These articles have only been mentioned here since there was a general consensus that the helical type of fletching configuration was the best for spin rate. Feathers were also a highly favored option due to their low mass and the fact that they come from birds which many claim make them naturally aerodynamic. However with test being what seems to be the first of its kind with respect to arrows -and due to the difficulties of producing such a configuration from wood- angle of offset with straight fletchings was decided upon.

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