Ultimate Hunting Arrows

By

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On any given shot, when a hunting arrow impacts real tissues a number of arrow design features and characteristics come into play, all of which ultimately determine the arrow's penetration. What are these features and characteristics; what part do they play in determining the penetration; how important is each; and why?

From the outset, let's set aside the factor some cite as "the *only* critical thing", and many cite as being "the *most* critical thing" in determining the lethality of a shot; "shot placement". I've yet to hunt with, or even meet, a bowhunter of significant experience who will not admit, at least off-the-record, to making a less than perfectly placed shot from time to time. It happens.

Such imperfect hits may result from a muffed shot, the animal jumping the string, deflection of the arrow by unseen or misjudged obstacles in the arrow's path, or any of a myriad of other causes. The "reason" most commonly cited by my many high tech hunting friends and companions seems to be "equipment malfunction" … which can usually be interpreted as meaning they misjudged the range, picked the wrong sight pin, jerked the trigger on their release aid, shook the arrow off the arrow rest, or some other such common "equipment malfunction"!

In addition to these factors, the lethality study data contains abundant instances of ideally placed shots failing to result in a lethal hit, and not just on super-sized game. As a rule, such failures occur when a shortcoming in the "arrow system" prevents adequate penetration. Most assuredly, these instances become progressively more frequent as the size and/or toughness of the animal increases, but they also occur with lightly built animals; merely at a lower frequency.

Besides these facts dispelling shot placement as the only, or most, important factor in arrow lethality, here we are discussing hunting arrow features which will, ultimately, determine the resultant penetration on "any given shot", regardless of where that particular shot impacts the animal.

The purpose of the forgoing is not to deride shot placement. It is a simple statement of fact. In a hunting situation, both the target and the environment are dynamic. Because of the mutability of a hunting shot, no bowhunter has absolute control over all aspects of the shot. What he or she does have absolute control over is the hunting arrow used.

Next, let's set aside broadhead sharpness. This should be a given. No one should hunt big game with anything other than an extremely sharp broadhead. Broadhead sharpness is a factor in penetration, but the keenness of the broadhead's edge, and its ability to retain that sharpness throughout the entirety of its penetration, regardless of the tissues encountered, is a precondition for arrow lethality.

The bow is drawn; the arrow loosed. The arrow does not know what type of bow propelled it. All that matters from this point forward is the arrow's design features and characteristics, and what force it carries at the instant of impact.

Arrow Integrity. The number one factor; the single most important arrow feature; is the structural integrity of the arrow system: broadhead; shaft; and all shaft components. To reliably achieve effective and predictable penetration resulting in a lethal hit, both the broadhead and the shaft ***must*** remain totally undamaged; regardless of what tissues are encountered or the angle of arrow impact with those tissues.

The Broadhead. The broadhead is the single most important piece of bowhunting equipment one carries afield. It is the piece of equipment that should be selected first; and then the hunting arrow developed around the chosen broadhead.

The "ideal broadhead" will have several characteristics that affect the arrow's ability to penetrate. Based upon outcomes observed during the decades of the lethality studies, I have several criteria for just what makes a truly great broadhead. They are: (1) the blade must have reasonable metal thickness; (2) that it be of very good quality steel; (3) that it neither bend nor break when hard bone is hit; (4) that it have a Rockwell scale hardness from forty-nine to fifty-five; (5) that the steel from which it is made will tend to break before taking a bend; (6) that it have a long and narrow shape (high mechanical advantage); (7) that the ferrule taper is long, and fades very smoothly into the blade; (8) that there are no abrupt junctures anywhere on the head, and (9) that the blades have a straight taper cutting edge.

These criteria reflect the broadhead's integrity, its capacity to take and maintain a sharp edge, and its ability to make maximum use of the arrow's force. A broadhead that becomes damaged, even slightly, has an enormous detrimental effect on arrow penetration into tissues. I will neither elucidate further on each of these criteria nor delineate how each affects arrow penetration. That would be a full article unto itself, and has been covered thoroughly in previous study articles and updates.

The Arrow Shaft. The arrow's shaft must also remain undamaged. As with the broadhead, a shaft that becomes bent or cracked results in a tremendous loss of penetration. It is the broadhead which must ultimately perform if the shot is to be lethal; but the shaft must remain undamaged to permit the broadhead to do its task in an effectual manner.

The most common point of arrow shaft failure is at, or immediately behind, the broadhead taper. It is at this critical, high stress junction of broadhead to shaft that aluminum inserts and broadhead adaptors commonly give way. The farther the angle of arrow impact deviates from perpendicular the more frequent this failure becomes. Such a failure effectively destroys the arrow's penetration potential.

With synthetic shafting, use of steel broadhead adaptors with aluminum inserts, rather than the more common aluminum broadhead tapers, demonstrates a marked increase in strength at this weak point in the arrow system. Further strengthening can be achieved through the use of brass or steel inserts with the steel broadhead adaptor.

Use of long inserts, extending well into the shaft, show better resistance to damage than short adaptors, *providing the broadhead does not bend*. When the broadhead bends, using a longer insert merely moves the fracture point further up the shaft!

It is also at the broadhead/shaft junction that wood shafting most frequently becomes damaged on impact with tissues. When either strong or adverse angle resistance forces are encountered, the added strength of certain shafting woods; either as the primary shaft material, or in the form of a shaft footing; provides a great deal of structural integrity to this weak point in the hunting arrow system, greatly increasing the arrow's penetration potential.

Among the wood shaft materials showing the greatest strength during testing are: Forgewood; hickory; laminated birch; and several of the exotic hardwoods, such as ipe and purple heart. Forgewood and hickory shafts are the most tested wood shafts in the study, and the durability/structural integrity of both are unsurpassed. Though they have not received as great a number of test shots in the study as Forgewood and hickory, the other shaft woods mentioned have demonstrated excellent damage resistance.

Arrow Flight. Working hand-in-hand with arrow integrity is the quality of arrow flight. It is second on the list only because, even with perfect flight, an arrow which becomes damaged at impact, or during penetration, loses most of its penetration potential. Also lost when the arrow's structural integrity fails is all semblance of control of the arrow's path through the tissues.

Perfect arrow flight maximizes the gain achieved by all other penetration-enhancing features of the individual arrow. Poor arrow flight places additional stress on the arrow's component parts at the time of impact, and during penetration. Even on broadside shots, poor arrow flight causes the resistance forces to be encountered obliquely, rather than perpendicular to the arrow's direction of tack.

Less than perfect arrow flight also increases the degree of "shaft flex" that occurs secondary to the impact. The resultant shaft oscillation, or 'noodling', causes both a vacillation in the direction of the arrow's force vector during penetration, and increased frictional resistance between the tissues and the arrow components (shaft drag). If arrow flight is poor, penetration will severely suffer.

Decreased penetration secondary to shaft flex can be commonly observed. At *extremely* close ranges, the less than perfect arrow flight resulting from the arrow's paradox causes a conspicuous decrease in arrow penetration; compared to a like placed shot at a slightly longer distance.

Those who have labored long and hard to make double, or triple, shafted arrows for use on the 'behemoths of the bush', know how difficult achieving perfect arrow flight can be with these specialty arrows. They are also the individuals who can best tell one just how critical perfect arrow flight is to arrow penetration … regardless of the arrow's impact force.

Once an arrow having structural integrity and perfect flight impacts tissues a number of other arrow design features come into play. All influence the final degree of penetration achieved by the arrow. It is more difficult to rank the importance of these features, but current results from the arrow lethality studies *suggest* the following order of importance.

Shaft Diameter to Ferrule Diameter Ratio. This relationship is clearly defined from the last two decades of testing. When comparing structurally sound, good-flying arrows of equal specifications and impact force, excepting only the shaft's diameter: a shaft having a diameter greater than that of the broadhead's ferrule averages a 30 percent decrease in penetration through fresh, real animal tissues; compared with a shaft having a diameter equaling that of the broadhead's ferrule.

A shaft having a diameter that is less than that of the broadhead's ferrule results in a 10 percent average increase in penetration; compared with a shaft whose diameter equals that of the broadhead's ferrule. This design feature alone can change the outcome penetration by 40 percent; between a shaft diameter larger than the broadhead's ferrule and a shaft diameter smaller than that of the broadhead's ferrule.

The 30 percent penetration loss resulting from use of a shaft diameter larger than the broadhead's ferrule is a clear demonstration of the massive influence shaft drag has on outcome penetration. Reducing the resistance to arrow penetration is a "free gift"; often providing penetration gains equaling or exceeding *very large* increases in arrow impact force.

Total Arrow Mass. Placement of arrow mass this high on the list of design features important to arrow penetration results not only because of the increased momentum arrows of higher mass derive from a given bow, and the momentum they retain downrange, but also because of the "heavy bone threshold".

There is a persistent, repeatable threshold value of arrow mass at which the *frequency* of *heavy bone* penetration suddenly, and dramatically, increases. It lies somewhere very near 650 grains of total mass.

The heavy bone threshold is more dependent on arrow mass than impact force. A *substantial* increase in impact force is required to achieve the same *frequency* of *heavy bone* penetration with arrows having a mass weight below this threshold value. At threshold mass, a wide range of impact forces give an equal *frequency* of heavy bone penetration. Overall arrow penetration, *after breaching heavy bone,* is more closely related to arrow's impact momentum.

Author's Note: Penetrating a bone, as used here and in the study, refers to the passage of the entire broadhead through the bone. A portion of the broadhead extending from the off-side of a bone does not constitute "penetrating the bone".

It is *theorized* that the heavy bone threshold represents a "time of impulse" for the arrow's force which is of sufficient duration to exceed the flexional limit of most heavy bone; a point at which whatever force the arrow does carry is applied to the bone for a long enough period of time to surpass the bone's limit of elasticity. A detailed examination and explanation of the "heavy bone threshold" data can be found in 2005 Arrow Lethality Study Update, Part 6 [1].

Weight Forward of Center (FOC). Relatively recent testing with carbon shafting indicates that ***extreme*** *degrees* of weight FOC have a major influence on penetration. This is qualified to "carbon shafting" because I have, thus far, been unable to achieve perfect arrow flight with an extreme FOC arrow having any shaft material other than carbon. A substantial gain in penetration occurs with arrows having an FOC greater than 18 percent. "High FOC" arrows (as opposed to *extreme* FOC) show little, if any, penetration difference from "normal FOC" arrows.

When using test arrows of identical exterior construction, dimensions, profile, mass, flight characteristics and impact force; the amount of increase in penetration derived from extreme FOC arrows varied from roughly 20 percent for arrows of 800 grains mass to upwards of 50 percent for arrows of 650 grains mass. One must note that the forgoing does not imply that arrows of 650 grains total mass show greater overall penetration than those of 800 grains mass. The higher mass arrows, in their 'normal FOC' guise, have significantly greater penetration than those of lesser mass; ergo, the *percentage* of gain derived from extreme FOC was less for the higher mass arrows.

What is the theory behind the penetration increase shown by extreme FOC arrows? A low amount of shaft mass behind the arrow's center of gravity results in less shaft flex on impact, and during penetration. As with perfect arrow flight, reducing shaft oscillation reduces shaft drag, retaining more of the arrow's force for penetration.

In effect, the presence of extreme FOC means the arrow's front pulls the rear portion of the arrow through the tissues. The more rearward the arrow's center of mass, the greater the degree to which the shaft pushes the arrow's front portion through the tissues. To understand the effect, place a piece of string on a table. Place your finger on one end of the string and pull the string along. There is little flexion of the trailing string. Now try to push the string from the rear! The effect with an arrow shaft is exactly the same. The only difference is the degree of 'noodling' each exhibit.

It should be pointed out that all FOC testing was conducted with shafts having favorable shaft diameter to ferrule diameter ratios. While fresh tissue testing of extreme FOC arrows is still in the early stages, initial results are of such magnitude and consistency that no doubt remains they offer a significant penetration increase over normal and high FOC arrows. Further testing may well warrant placement of this factor higher on the list. Only time and more testing will tell. Initial testing indicates that extreme FOC arrows may represent yet another very significant and easily gained “free gift” in penetration.

Author’s Note: Penetration, as used here and in the study, is defined and measured as the length of the wound channel through the tissues; ergo, it is impossible to have “penetration” greater than the distance from entrance wound to exit wound. With animals of modest size, high mass arrows, regardless of the FOC, have a greater frequency of exit wounds and pass through shots, but the “penetration” cannot exceed the distance to the exit wound; effectively placing a maximum cap on measurable penetration.

Initial FOC testing was conducted on Asian buffalo, and at uniform impact force for a given arrow mass. A notable outcome from this testing is that only 2.7% of the shots with high mass arrows having “normal or high FOC” *penetrated* the off-side rib; and none gave an exit wound. High mass, high FOC arrows *penetrated* the off-side rib on 47.7% of the shots; with 10.5% resulting in an exit wound. This is a clear example of “saved arrow force”; resulting from reduction of resistance; being applied to increase penetration. Asian buffalo are incredibly tough animals, and very few expanding rifle bullets give an exit wound, even from calibers as heavy as the .500 Nitro Express, .505 Gibbs and .500 Jeffery.

A more detailed discussion of FOC and fresh tissue penetration, as well as definitions for “normal, high and extreme FOC” and the applicable formula used for calculating arrow FOC, can be found in 2005 Arrow Lethality Study Update, Part 2[1].

Edge Bevel. Testing, using sets of arrows identical in all aspects except the bevel of the broadhead’s edge, indicates that a single bevel edge offers a distinct advantage in penetration *when bone is encountered*. Depending upon each individual broadhead’s profile and mechanical advantage, when bone is encountered the penetration gain realized from a single bevel, as opposed to a double bevel, varies from 30 to almost 60 percent. When no bone is encountered, single bevel broadheads show little, if any, difference in penetration; compared with double bevel broadheads.

A single bevel broadhead causes the arrow to rotate during penetration. The direction of rotation caused by the broadhead must be in the same direction as that caused by the arrow’s fletching. Tissue testing indicates that failure to do so results in a substantial penetration *loss*. *On bone impact shots*, using arrows of identical dimensions, and several sets of broadheads matching in all aspects except edge bevel, the penetration loss when broadhead and arrow rotation did not match ranged from 40 to 70 percent (again, depending on the individual broadhead’s profile and mechanical advantage). The effect of opposing bevel and fletching induced rotation on soft tissue penetration has not yet been tested.

The increased bone penetration of single bevel broadheads occurs because of their marked tendency to split bone apart rather than simply force a path through. Bone splits are the norm, rather than the exception, when using single bevel broadheads. Both the frequency and magnitude of single-bevel-induced bone splits is greater in rib, humerus, and femur than in scapula, pelvis, sternum, or spine, but occurs commonly with all.

Shaft Profile. With shafts having normal to high amounts of weight FOC, and *possibly* with extreme FOC arrows as well, shaft profile is a factor in penetration. Testing with normal to high FOC arrows indicates that, in fresh tissues, a tapered shaft out-penetrates either a parallel or barrel-tapered shaft, of the same mass, force, material and shaft finish, by 8 to 15 percent.

Whether the tapered shaft’s penetration gain is an effect of the slight increase in weight FOC, or other factors, is still unclear. With like shaft materials, a tapered shaft will have a slightly higher weight FOC. Also plausible is the theory that a tapered shaft may act as a reverse inclined plane; showing a constantly lowering *rate of increase* in shaft drag the deeper it penetrates. A third possible explanation is that, during penetration, the progressively increasing cavity between shaft and tissues may facilitate the flow of shaft-lubricating blood; reducing the coefficient of friction between shaft and tissues. Very likely the answer lies with the combination of these factors.

Shaft Finish. The ‘slicker’ the shaft’s finish, the less the friction between the shaft’s surface and the tissues penetrated. The result will be less resistance to the arrow’s passage. This permits the arrow to retain more of its impact force, which is then applied to overcoming other resistance forces encountered during penetration. Some finishes become ‘slicker’ than others in the presence of blood. In fresh tissues, this enhances the blood’s lubricating effect, further reducing shaft friction (shaft drag).

Broadhead finish. When compared with uncoated broadheads of like dimensions, Teflon coated broadheads shows a noteworthy penetration gain in both *soft and extremely fibrous tissues*. The exact degree of penetration gain has not yet been quantified. This coating appears to offer little measurable difference in bone penetration. There may, however, be enough gain in retained arrow force to be of significance, especially on shots where the arrow is required to penetrate either very fibrous tissues or substantial amounts of soft tissue prior to encountering a bone. Its use certainly offers potential benefits, and no disadvantage.

Impact Force. Last on the list comes the impact force of the arrow. Here we are discussing the arrow's total expendable momentum at the instant of impact. In over two decades of testing on fresh, real animal tissues; conducted immediately after expiration, before tissue changes become an influencing factor on the outcome; the impact kinetic energy of an arrow shows no correlation as a predictor of outcome penetration. The arrow's impact momentum shows a positive correlation. Comprehensive information on the physics of arrow penetration can be found in Momentum, Kinetic Energy, and Arrow Penetration (And What They Mean for the Bowhunter)[2], with additional information in 2005 Arrow Lethality Study Update, Part 5[1].

Those who place great store in bow draw weight and energy output may be surprised that impact force is placed at the end of the list of factors. This placement is appropriate for a number of reasons. In the final analysis, it is the hunting arrow which must perform; regardless of the force it arrives on target with.

The arrow's force can easily be squandered through use of arrows lacking the aforementioned qualities. In fresh tissues, a perfectly modeled, perfectly flying arrow which maximizes the penetration potential of whatever force it does carry generally out-penetrates a poorly constructed and/or poorly flying arrow of vastly greater impact force.

This is not to say that bow efficiency is of little consequence. It merely means that maximizing the force one puts into the arrow only becomes a significant penetration factor when arrow flight is perfect and the arrow system is capable of performing its function without failure.

Even the most potent bowhunting setup generates a very low level of impact force relative to other hunting weapons. A hand-thrown spear, of mass typically used by many primitive tribes, can generate up to ten times the impact momentum of a high-performance bowhunting rig.

Into the arrow's working parameters one must also incorporate all the "what if" situations. To reach vital areas on a less than perfect shot, greater penetration potential is generally required if the arrow is to overcome the resistance forces encountered.

Test data shows that inadequate penetration is, overwhelmingly, the number one cause of *either* a well placed shot, or any reasonably placed shot (those directed such that the arrow's projected path would intersect a vital area), failing to result in a lethal hit. With very low levels of impact force available to the hunting arrow it is necessary to maximize its penetration potential by: (1) minimizing the resistance the arrow encounters and, (2) maximizing the "work" (as the term is applied in physics) the arrow can do with the limited force it does carry.

Increasing the penetration potential of one's hunting arrows has other advantages. With any given shot, the likelihood of an exit wound is increased. Presence of an exit wound is one of the major factors in the degree of resultant blood trail. Increased penetration potential means that well placed shots will be more likely to give complete arrow pass-through. Medical data from human arrow wounds indicates that hemorrhaging occurs far more rapidly when the arrow shaft does not remain in the wound channel, applying direct pressure to the tissues. Based on that finding it would appear that complete arrow pass-through is the desired shot outcome.

From the available data, the forgoing is the order in which I would rate the influence of arrow design features on penetration, but one should not think of them as a "ranking of importance". Take a look at your hand. Which digits are most important for it to accomplish its many tasks?

Certainly the thumb comes in as number one. The use of an opposable thumb allows one to grip things securely and to perform many delicate tasks; but which digit is next most important? Most people would rate the index finger as the next most important, for its ability to make the best use of the opposable thumb for task requiring extreme dexterity and precise manipulation. Few, however, would willingly give up any of their hand's digits, and giving up any would significantly diminish the hand's ability to perform certain task with the efficiency and versatility available when all digits are present.

The components of the hunting arrow are the same. Integrity of the broadhead/arrow system is as crucial to the hunting arrow's performance as the thumb is to the human hand. If it is removed, the arrow's main function is effectively negated. The arrow's flight is analogous to the index finger; vital to getting the most efficient and versatile performance from a structurally dependable arrow. The other factors enhance the ability of the hunting arrow to perform the task at hand under a verity of circumstances; delivering a quick and humane killing shot under as many hunting situations as possible.

[1] The 2005 Arrow Lethality Study Update, Parts 1 through 6, are scheduled for publication in 2006 issues of Archery Action with Outdoor Connections; Artemis Productions; PO Box 227; Aspley, QLD; Australia, with simultaneous availability on line at www.tradgang.com and other selected web sites.

[2] Momentum, Kinetic Energy, and Arrow Penetration (And What They Mean for the Bowhunter) is available on line at www.tradgang.com or www.bowhunters.org.au and other selected web sites.

At 18 yards, on a Whitetail doe, this 450 grain arrow hit heavy bone at an adverse angle, causing broadhead and aluminum shaft to give way. Impacting with 68 ft. lbs of KE, and 0.53 slug-ft of momentum, penetration was 3 inches. (Courtesy of Wesley Mulkey)


Even tiny bends to a broadhead’s tip show an average reduction in tissue penetration of 14 percent.


This aluminum adaptor and insert, on a heavy double shaft arrow, gave way on right angle impact, fracturing the shaft (Courtesy of Kai Fisher)

Steel adaptor and long insert prevented bending back of taper, but bent broadhead deviated arrow’s path, reducing penetration and breaking shaft further up. Predictable performance requires total arrow integrity: broadhead, broadhead taper, insert and shaft.

Bone impact fractured these carbon and wood shafts just back of the broadhead taper.

This broadhead bent on impact with the scapular flat, fracturing the shaft.

Aluminum adaptors/inserts are a decidedly weak point in the synthetic shaft arrow system.

Favorable shaft to ferrule diameter ratio (R) averages 40 percent more tissue penetration than when ratio is unfavorable (L).

Typical single bevel bone split (R) and double bevel hole (L). Five-inch split in heavy rib bone of an Asian Buffalo is from single bevel Grizzly Extreme, 11/16" wide.


Except for a Teflon broadhead coating, this Grizzly Stik Alaskan shows it all: strong single bevel broadhead of high mechanical advantage; steel adaptor with long brass insert; favorable shaft to ferrule ratio; mass well above the heavy bone threshold; 24.6% FOC; tapered carbon shaft with ‘slick’ finish; and perfect flight from the ACS-CX bow it’s matched to.