Introduction

The following conversational discussion summarizes the high points of Dr. Ed Ashby's 2007 research on arrow lethality. To set the stage, if you've not already done so, this would be a good time to drop back an issue and read Part I, providing Ashby's personal biography and research history.

Overall, Ashby's 2007 research results not only serve to reconfirm his previous findings, but forge ahead into new territory. For example, the 2007 research arsenal included a 54-pound bow in addition to the heavyweights Ashby has used exclusively in previous studies, making these new data all the more useful to the "average" bowhunter.

As an aging lifelong traditional bowhunter (well, since age eight) who's made my share of "innocent" mistakes, I never want to wound and lose an animal again — and especially not because I went out blissfully under-equipped, which erases all innocence from the equation. Ed Ashby is motivated by precisely the same concern. The following 13 "findings," summarized below, lay out a near-perfect arrow design that, if maximized to the extent possible, will *absolutely* enhance penetration and quick kills on big game, especially in the nightmare scenario of a glancing scapula or other heavy-bone hit.

— *David Petersen*

Dr. Ed Ashby

Arrow Lethality Update: Part II Rating Penetration Factors

By David Petersen

1. Structural Integrity

Ed: Structural integrity — the ability to hold together on impact, even with heavy-bone hits — is *the* most important factor of arrow design. This applies to every aspect of the arrow system, from the broadhead's tip and edge strength, to the nock. Even a *tiny* broadhead tip bend results in an average penetration loss of 14%. Together with the proverbial "shaving sharp" blades, arrow structural integrity is an assumed 'given' and a necessary precursor for every finding to follow.

Dave: What are some of the most common elements that erode arrow structural integrity? Certainly, we can include inferior broadheads and shaft materials, weak attachment joints on screw-in heads … and what else?

Ed: While broadhead mechanical advantage (MA) is a 'maximizer' factor — that is, it enhances other penetration-enhancing elements — it's also a structural integrity factor. A good broadhead design allows the arrow to penetrate more easily, resulting in a lower peak resistance force, which, in turn, lessens stress on the entire arrow system. There are frankly too many structurally strong but low-MA broadheads out there. Other enemies of structural integrity include:

(1) Fragile shafts. Our beloved Port Orford cedar, alas, doesn't hold up well on hard impacts, direct or oblique. Neither do silverwood, Scotch pine, or Hexwood. But many *hardwoods* do perform well. In fact, among the hardwoods I've tested, ash is the least durable but still *far* ahead of aluminum and carbon. Best are Forgewood and hickory, closely followed by laminated birch, purpleheart, and ipe.

(2) On forceful bone impacts, both aluminum and carbon shafts show a damage rate roughly 10 times greater than the above-named hardwoods.

(3) Aluminum *inserts* are a weak link. Using steel broadhead tapers with aluminum inserts helps some on direct impacts. Use of steel or brass inserts with a steel adapter shows even more direct-impact strength; yet even these are causal to shaft-breakage behind the insert on angular bone impacts.

(4) Aluminum *broadhead adapters*, in my opinion, should *never* be used. They are the weakest link in the synthetic-shaft arrow system. Aluminum

Above—What the wrong setup can do. At 15 yards, this 3-blade broadhead on a 710 grain arrow shot from a 90# longbow stopped on this warthog's ribs. The second 710 grain arrow with a 2-blade broadhead was a pass through.

If a broadhead has any weakness, heavy bone will find it.

adapters and/or inserts initiated *many* of the direct-impact shaft failures I've recorded.

In sum, the primary arrow-integrity factors are a strong broadhead that never bends or breaks, and a highly durable shaft. The best shaft materials include the strong hardwoods, double-shafted synthetics, and synthetic shafts with *at least* steel or brass inserts and a steel broadhead adapter.

Recovered from a rifle shot Georgia whitetail, this Spitfire mechanical only penetrated 3/8" in the entrance-side rib. All the blades are bent to the side, and two failed to deploy.

2. Arrow Flight

Ed: Perfect arrow flight is the enabler for all other penetration and lethality factors, delivering maximum usable force on target and permitting the other factors to work at full efficiency. Poor flight squanders arrow force.

Dave: This is largely a tuning question, is it not?

Deer have heavy bone too. A Georgia whitetail doe damaged this broadhead, limiting penetration to three inches.

Ed: Precisely. If you don't get perfect tuning, allowing perfect arrow flight, you're spinning your wheels trying to maximize arrow penetration. Having tried many methods, bare-shaft tuning has given me the best results.

3. Extreme Forward-of-Center (FoC) Arrow Balance

Ed: Except for perfect arrow flight, and in addition to its own intrinsic values, extreme FoC contributes more than any other element to maximizing the penetration gain from all other factors discussed here. "Extreme" FoC is study-defined as 19% or greater, measured using the AMO Standard method.

Dave: Please explain.

Ed: The AMO Standard percent FoC is determined by measuring the length of the arrow's shaft from the bottom of the nock's throat to the back of the broadhead. This is "shaft length."

With the broadhead mounted on the shaft, the arrow's balance point is determined by balancing it on a knife edge. The distance from the bottom of the knock's throat to the balance point is the second key measurement.

Divide the distance from knock throat to balance point by the shaft length. This gives the decimal equivalent of the percentage of overall shaft length at which the balance point falls. From this quotient, subtract 0.50, the decimal equivalent of 50%. The resulting decimal fraction is converted to the percent FoC by multiplying by 100; or simply moving the decimal point two places to the right. Between 12% and 19% is study-defined as high FoC, with 20% and over rated extreme. At or below 12% is normal FoC.

Dave: I've played with this concept using both cedar and hardwood shafts, and have problems getting above 10%

These 1000+ grain arrows managed to hit only one lung.

FoC even with tapered shafts and the heaviest shootable heads. What more can a woody shooter do to increase FoC, short of going to expensive footed shafts?

Ed: I've had the same problem. I've never found another wood that comes close to delivering the FoC of the original Forgewood that I used back in the days of the Natal studies, which were just shy of 19% (with the 190 Grizzly head). I've found no easy answer so far, but I'm working on it. For now, my advice is to shoot tapered shafts and the heaviest heads that fly well … and if you can afford it, try hardwood-footed shafts, which will increase arrow integrity as well as FoC. But even without extreme FoC, if a shooter maximizes all the other arrow-efficiency factors discussed here, my data show that average penetration will be *more than double* that produced by a twin arrow lacking these features.

Dave: Do the benefits of extreme FoC vary with bow draw weight and arrow speed?

Ed: Absolutely, but not in the way you might expect! Using arrow sets identical in all aspects except their amount of FoC, *all* tests show high penetration gains, no matter bow weight or speed. This effect is now quantified, at least between otherwise-identical high performance arrows embodying most of the other penetration enhancing features. Gains range from approximately 40% to upwards of 60%. And here's the surprise: The highest *degree* of gain comes in lower draw-weight bows – but don't confuse *degree* (percentage of gain) with the total *amount* (actual inches) of penetration gain. All else equal, more arrow force still means more penetration.

For these tests I used 82, 70, and 54-pound straight-end longbows of similar efficiency. On average, the 54-pound bow's penetration-maximized extreme FoC arrows out-penetrated the 82-pounder's standard arrows by a whopping 48.8%. That's almost half again as much penetration. Even when considering identical broadheads, the 54-pound bow's extreme FoC arrows still averaged a 17% penetration advantage over the heavier bow's normal FoC arrows.

To say that the implications here are good news for those hunting big game with lighter draw-weight bows is an understatement! Using extreme FoC arrows that also have most of the other penetration-maximizing factors is analogous to adding 30 pounds to the bow's draw force, when compared to a similarly efficient bow using arrows that have "common" penetration features.

4. Broadhead Mechanical Advantage

Ed: Broadhead mechanical advantage (MA) ranks number four in importance. It has a more pronounced influence on the penetration of a perfectly flying and structurally sound arrow than any other factor except extreme FoC. Given the chance to apply its

Dr. Ed examining a broadhead found in a rifle-killed deer.

advantage, and regardless of other arrow-design features, higher MA increases the "work" your arrow does on-target with whatever force is available. Its advantage is applicable to all arrows, of all designs. However, the more efficient the overall arrow, the more penetration-gain a given higher broadhead MA yields.

Dave: Many TBM readers will recall that among your most significant findings in the early Natal Studies was that almost all rigid single-blade broadheads out-penetrate and hold up better on bone hits than do almost all multi-blade heads. Has anything changed?

Ed: No. All subsequent testing simply confirms the all-around advantages of a well-built and designed single-blade. More precisely, the *highest* MA *multi-blade* tested — the Wensel Woodsman — has a poorer MA than *almost* any single-blade. Exceptions are among the so-called single-blade mechanicals, such as the G-5 Tekan, and a few "radical design" single-blades, such as the highly concaved Sharks and severely truncated Bone Buster. However, the Woodsman's MA is only slightly worse than many short, wide, single-blade "delta profile" heads. The Woodsman shows almost as much penetration as standard double-bevel delta profiles, and exceeds that of the radical designs. This does not hold, however, when *single-bevel* delta profiles are compared with the Woodsman; one more indicator of the single-bevel's advantage on bone impacts.

5. Shaft Diameter to Ferrule Diameter Ratio

Ed: There's an average 10% penetration gain when the arrow's shaft is at least 5% smaller than the broadhead's ferrule diameter, compared to shafts and ferrules having equal diameter. When shaft diameter exceeds ferrule diameter, penetration is *decreased* by an average of 30% compared to systems having equal diameters. That means a 40% difference in tissue penetration between a shaft-ferrule having a favorable ratio and one with an unfavorable ratio.

Dave: Is it safe to assume that most glue-on heads and wood shafts will meet the 5% requirement?

Ed: Most? Yes, so long as the shaft is accurately sized. Some are not.

6. Arrow Mass

Ed: Whether of normal or extreme FoC, lower mass arrows use their force less productively, having less "useful momentum." That is, more of their momentum is represented by speed and less by arrow mass. Arrow velocity is rapidly shed during penetration, but the mass remains constant. Heavier arrows take longer to stop. Their time of impulse is greater.

Dave: Please clarify arrow *mass* versus arrow *weight*.

Ed: For our purposes here, we can equate arrow mass with arrow weight, though a physicist would make distinctions. Arrow mass increases bow efficiency, absorbing more of the bow's stored energy off the string. That means more arrow force (momentum) delivered on target, resulting in better penetration under all hit circumstances. Allow me to explain:

Momentum *belongs to* the arrow; it's a property *of* the arrow, carried within it. It is derived from the arrow's forward motion and mass. As an arrow abruptly slows during penetration, velocity is rapidly shed but its mass remains constant. Because of this, the contribution that mass makes to momentum results in a longer time of impulse, or movement through flesh and bone. In other words, the more of an arrow's momentum that's represented by arrow mass, as opposed to speed, the deeper that arrow will penetrate tissue. Given equal impact force, arrow design features, and tissue resistance, the heavier your arrow, the longer it takes to stop. Real-tissue testing resoundingly confirms this.

It's not all fun and games. Dr. Ed literally gives his body and soul to his testing!

Arrow-mass advantage is available and applicable to all arrows, of all designs. You should use the heaviest arrow that acceptable trajectory permits.

7. Broadhead Edge Finish

Ed: A smooth, beard-shaving-sharp,

Any arrow system failure destroys penetration, and this is a common one with "normal" synthetic shafts, inserts and adapters.

lovingly honed and stropped cutting edge works best. Its advantage is most evident in penetrating fibrous tissues — skin and connective tissues – where, on identical broadheads, it shows a 26% average gain over a smoothly filed but "merely sharp" edge, and more than 60% advantage over "Hill type" serrated edges.

8: Shaft Profile

Ed: Single-tapered shafts show an 8% penetration advantage over parallel shafts, and 15% over barrel-tapered shafts. Even parallel shafts show a 7% advantage over barrel-tapered shafts. This is applicable to all arrows and shaft materials, and with all types of hits.

Dave: Is the single-tapered shaft's advantage due to shaft shape alone, or does the slightly enhanced FoC of tapered shafts figure in?

Ed: Good question. While I too am curious about whether the slightly higher FoC of tapered shafts *might* be a contributing factor in their superior penetration, I have no data suggesting it to be true. It may merely owe to the reverse wedge effect, which lowers friction and drag on a tapered shaft's rear as the arrow penetrates. At this point, all I can definitely confirm is that when all else is equal — materials, mass,

Even thin scapula stops inadequate arrow setups. The best setups penetrate the thickest buffalo scapula flat and thorax over 90% of the time.

broadhead, shaft finish, and force — tapered shafts out-penetrate parallel shafts, which, in turn, out-penetrate barrel-taper shafts.

9. Arrow Silhouette

Ed: While rough or irregular broadhead and shaft surfaces increase arrow drag in *all* tissues, the loss is greatest in bone. The less "bumpy" an arrow's silhouette, the more effortlessly it passes through tissue. Aside from smoothness, enhanced broadhead and shaft "slickness" helps too.

Dave: On broadheads, "bumps" obviously include ribbed ferrules, serrated edges, and protruding welds. What else?

Ed: Many broadhead ferrules are not a straight taper, having some shape other than a simple wedge. This includes not only most modular broadheads, but some fixed-blade heads as well. Fairly common are ferrules resembling a mini toilet-plunger (the newer screw-in Razorheads), or a Coke bottle turned on its side (Silver Flames). Many others have a distinct bump where the leading edge of the ferrule meets the blade (Howard Hill and Steel Force). "Vented" blades are a detriment because "stuff" — bits of bone and tissue — gets caught in the vents, increasing friction and drag and retarding penetration. This creates a situation where the blade spreads tissue as it slices through, only to have that opened tissue collapse into the vents, requiring the tissue to be spread apart *again* by the back edge of each vent. Small things, but they add up fast.

Dave: What do you mean by broadhead and shaft "slickness"?

Here are the seven tip profiles that Dr. Ashby used to ascertain their resistance to damage and their effect on penetration.

Ed: While I don't list it as a distinct penetration factor, broadhead and shaft finish have a demonstrated penetration effect, though the degree has not been quantified. While one finish can certainly be compared to another, I've found no reliable way to define the frictional coefficient of various finishes in a blood-suffused tissue environment. Clearly, a Teflon broadhead finish offers advantages. The Eclipse is the only brand I'm aware of that currently uses this technology, and it's really good Teflon too, providing a tougher exterior surface than any other broadhead finish I know of. When comparing the same broadhead with and without Teflon finish, the coated heads average 12% more penetration on soft tissue hits. There *appears* to be no gain, however, on bone penetration.

Slicker finishes aside, the crucial element is to have as few "ups and downs" along the entire arrow profile as possible. This of course excludes the one step-down an arrow system *should* have: immediately rearward of the broadhead's ferrule.

Dave: What about shaft slickness?

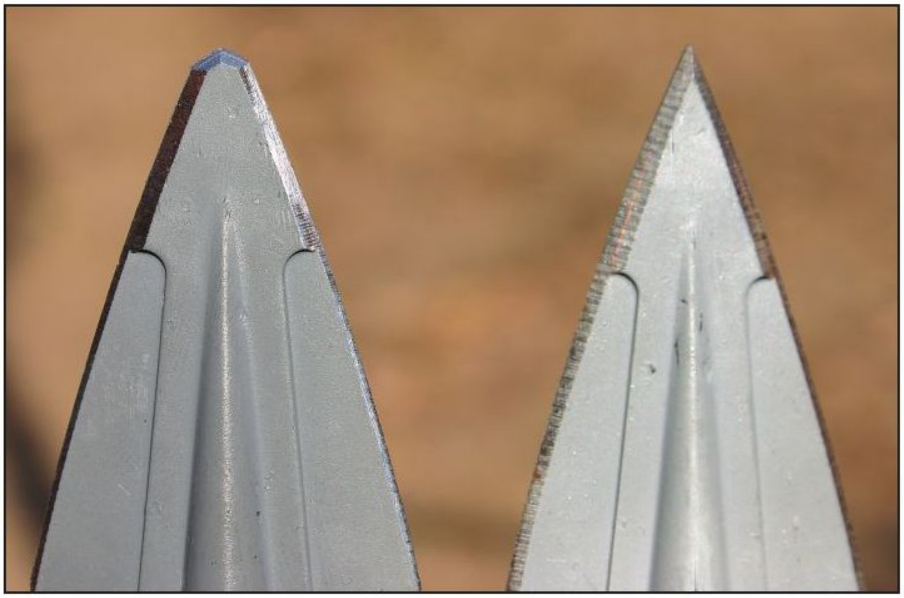
Ed: It counts too! I've experimented with various finishes, waxes, and more … too detailed a discussion for this space. At the least, I encourage woody shooters to "burnish" their hunting shafts with 4-0 steel wool — before and after applying dip or wipe-on commercial finishes, as well as between finish coats — to reduce shaft friction.

10. Type of Edge Bevel

Ed: When broadheads identical in every way except edge bevel are mounted on identical shafts and shot into identical tissue, single-bevel heads demonstrate sizable penetration increases in all cases involving bone impact. The gain varies by broadhead profile, but ranges from 14% to 58%. And most hunting hits, let's remember, do involve bone impact of one type or another.

Dave: Does the single-bevel's advantage owe to the blade's edge being thinner, sharper, stronger, or …?

Ed: Several things. The thinner edge slices deeper at any given level of tissue tension. The lower and longer edge-bevel means higher MA for the cutting edge, slicing equally well with less force, or better at the same force. However, the biggest advantage is the *rotation* that single bevels induce during penetration, helping to *split* bone rather than merely "pushing through." In flight, the average arrow rotates about one revolution in 60 inches of travel. The modified Grizzly 190 El Grande single-bevel (modifications include a 1" cut width, reduced rate of blade taper, cut-on-impact Tanto point, and edges re-beveled to 25 degrees, resulting in a 170 grain weight) induces one full rotation in



The Tanto tip profile, left, shown on an Eclipse broadhead. The factory needle point is on the right.

Most bowhunters never give it a thought, but tiny tip bends reduce penetration by 14%. Think of it as 11.4 inches, rather than 10". Occasionally, that's important!

just under 16 inches of soft-tissue penetration. In bone, this rotation applies torque during penetration; *trying* to "twist" the entire broadhead some 70 degrees as the 3-1/8" length of blade passes through. This twisting force splits bone. Try pushing even a very narrow blade through a fresh bone while also twisting. The bone splits – big time — and resistance instantly drops.

Dave: Since the Grizzly is right-beveled, I presume you use right-wing fletching to compliment the rotation?

Ed: Yes. If you don't, you'll actually lose penetration.

Dave: Are there any single-bevels other than Grizzly you can recommend?

Ed: The 125 Abowyer is outstanding quality, but its MA is lower, and you'll have to watch skip angle. Outback's Hunter is also short and wide, and, like their Supreme, has an aluminum ferrule. I've tested a steel-ferruled version of the Supreme that's very good, but it's a custom item. The Cheetah comes in either right or left beveled, but has an open-ring ferrule. That's about it; I wish there *were* more. I know of a couple in the works, but they're not on the market yet. I've had some input to the design of one, but neither is precisely what I'd make if building them myself. I think it's pretty hard to improve on the modified Grizzly, though there are a couple of features I'd love to see – like a Teflon coating. Just a "field ready" factory-modified Grizzly would really be a help.

Dave: Are the smaller Grizzlies as good as the El Grande?

Ed: I've had some problems with the lighter versions, including the 160. The

160's problem could be corrected by increasing hardness to match the 190 El Grande. Recent testing with R52-53 samples confirmed this. But even at R50, the Grizzly 160 is stronger than most other factory heads. You can also reduce the problem by modifying them like I do the 190: narrowing the back of the head to reduce the rate of blade taper. The resulting higher MA lowers peak resistance – meaning less stress on the broadhead's structure.

Dave: Do single-bevels have any influence on arrow flight?

Ed: On bare shafts they do exhibit a consistent "flight effect." It's possible they may actually *improve* arrow flight.

A trophy water buffalo bull taken going away at a 25 degree angle.

11. Broadhead Tip Design

Ed: The greatest importance of tip design is on shots impacting bone. The Tanto tip shows the best overall performance and lowest damage rate of any design tested. When applied to identical broadheads, it showed the best bone penetration, averaging 110% more than the worst performer tested (concave), and 27.5% more than the second-best performer (rounded). Additionally, of all common tip profiles, the Tanto demonstrates the lowest tendency to skid off bone on angular impacts. Data suggest that needle tips *might* do as well, or even better, at retarding bone-skids, but any potential advantage was more than nullified by their high damage rate. ("Needle tip" should not be equated to conical or pyramidal tips that come to a sharp point, both of which appear to initiate bone-skids.)

12. Mass Arrow Weight above the Heavy-Bone Threshold

Ed: This factor differs subtly but significantly from Arrow Mass (number six on our scale), and ranks 12 only because it has little significance on hits impact-

Dr. Ed with his favorite big game stopper, a .500 Nitro Express.

ing only soft tissues. On *any* heavy-bone impact this factor jumps to very near the head of the list, trailing only structural integrity and, perhaps, quality of arrow flight. Regardless of the broadhead or tip design used, there is a marked decrease in efficiency in penetrating heavy bone when total arrow mass falls below a study-defined threshold of about 650 grains. (To date, extreme FoC has demonstrated no effect on the heavy-bone threshold.)

Dave: No matter the bow draw weight or arrow speed?

Ed: Correct! And since bone impacts of one or another type occur on *most* game hits, I will not hunt big game with an arrow whose weight is below the 650- grain threshold. Meanwhile, every ounce above the threshold enhances penetration gains.

13. Arrow Force, as derived from the Bow

Ed: Any bow, be it compound, recurve, or longbow, is capable of imparting only a certain amount of energy to an arrow of a given mass, producing a finite amount of *arrow force*. As demonstrated by the 54-pound longbow, the penetration gain obtained by increasing bow force pales in comparison to that achieved through better arrow design, which is why it falls last on the list.

Dave: Is it OK for this conversation to simplify "bow force" as "speed delivered to an arrow of a given weight," or is that an oversimplification?

Ed: It's complex. Bow force, basically, is bow *efficiency*. With any given bow, arrow speed "off the string" will be the same for any given arrow weight. By increasing arrow *mass* can we translate a bit more of the bow's stored energy directly to the arrow. How the arrow uses that energy after departing the string is a different kettle of fish. Bottom line; a heavier arrow will be slower *coming* off the string, but will show both more kinetic energy and more force at the instant it *departs* the string.

Though modest arrow-force gain can be obtained through use of higher-mass arrows, any *substantial* arrow-force gain requires either obtaining a more efficient bow or increasing the bow's draw-weight. Let me be clear on this point: It's the force delivered to the arrow by the bow we're talking about here. It's not an arrow *speed* thing at all, but an arrow *force* thing. Increasing a bow's draw weight or efficiency offers the *potential* for better terminal arrow performance, but that's all too easily squandered by a poorly performing arrow. Maximizing arrow performance reaps far richer rewards than does increasing draw weight.

Other Factors

Ed: A variety of other factors also influence arrow penetration and lethality, but are difficult to quantify so I haven't listed them here. The *length of a broadhead's cutting edge* is definitely a factor in creating hemorrhage; in general, longer is better. A blade's *angle of attack* — which is also a function of broadhead length vs. width — affects how easily and cleanly it slices tissue. Edge (bevel) angle is another factor, both for its mechanical advantage and the depth of slice achieved at a given degree of tissue tension.

And there are more factors, but since we lack the space to explore fully even the 13 primary, quantifiable penetration factors listed, I'll stop here.

Dave: You should write a book!

Ed: Maybe ... when I get too old and bush-whipped to hunt ... I mean *really* hunt, the good old-fashioned way!

Dave: More power to you, Dr. Ashby, and thanks for this truly important work, which is all the more meaningful because you do it at your own expense, not to develop a product for sale but for the good cause of reduced wounding loss and increased hunter success.

Note: A complete and permanent archive of Dr. Ashby's research methods, results, discussions, and recommendations — including graphs, charts, and photos — is posted on www.TradGang.com