2008 Study Update, Part 1

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A primary focus of the 2008 testing was the Heavy Bone Threshold, with special attention on whether or not the percentage of an arrow's weight forward of center (FOC) has any effect on threshold value.

FOC Terminology

Prior testing has shown a substantial increase in penetration when arrow FOC is above 19%. This created a need to divide arrow FOC into different classes. Conventionally "Normal" FOC has been recognized as any amount up to 12%, with "High" FOC being all amounts above that. The Study has kept the Normal FOC definition, but has subdivided FOC's above 12%. "High FOC" is Study-defined as being between 12% and 19%. Between 19% and 30% is "Extreme FOC" (EFOC). FOC above 30% is defined as "Ultra-Extreme FOC" (Ultra-EFOC). For a complete discussion of what FOC is, how it's measured and what it means for arrow performance see; *Prologue to the 2007 Updates, Understanding FOC.*

The Heavy Bone Threshold

Of all terminal performance factors the most misunderstood seems to be the Heavy Bone Threshold. Most folks think the Heavy Bone Threshold means any arrow above this mass always penetrates heavy bone, and/or no arrow below this mass ever penetrates heavy bone. This is incorrect. The Heavy Bone Threshold represents a point of arrow mass where there is *an abrupt increase in the <u>frequency</u> of heavy bone penetration*. All broadheads tested, of all types, exhibit this sudden increase in the rate of heavy-bone penetration.

The abruptly increased penetration-rate consistently occurs in the vicinity of 650 grains of arrow mass. The *specific* mass value varies slightly, from between about 625 grains for a broadhead like the very long and narrow, experimental Grizzly Extreme to around 675 grains for a short-wide multiblade, such as a 160 grain Snuffer. For the most tested broadhead, the single-beveled 190 grain Grizzly, the threshold falls almost precisely at 650 grains.

Prior to 2008 all threshold-specific testing has involved arrows of normal and high FOC. In 2008 a test sequence was conducted to specifically evaluate if and how arrow FOC might affect the Heavy Bone Threshold. Before immersing ourselves into this discussion it might be helpful to review what prior testing intimates about the mechanics of the Heavy Bone Threshold.

Broadhead design affects the *frequency* of breaching heavy bone but its effect on threshold arrow-mass is slight. At a given arrow mass a well-profiled broadhead having a high mechanical advantage (MA) will breach a heavy bone more frequently than a broadhead having a less efficient design. That's because a high efficiency broadhead requires a lesser *impulse of force* to breach a given bone. Higher efficiency broadheads conserve arrow energy, allowing the arrow to 'push longer' against the bone, if need be. As an added advantage, because they require a lower impulse to breach the bone and use whatever force the arrow retains after the bone is breached more efficiently, on a given shaft setup they also show more post-breaching penetration.

Assuming a structurally intact arrow, at threshold mass a broadhead having a low MA might show a jump in the bone-breaching rate from 15% up to 25%, or so. The bone-breaching rate for a moderate MA broadhead might change from 35% up to 60% or more. At threshold arrow mass the bone breaching rate for a high MA broadhead with sleek profile and smooth ferrule fade-in typically jumps from a below-threshold rate near 50% to a full 100%. Some non-production, experimental broadheads having very high MA, such as the Modified Grizzly and Grizzly Extreme, show below-threshold breaching rates above 50%, but no broadhead tested has approached a 100% heavy-bone breaching rate on arrows below threshold mass.

Two-point-six (2.6) appears to be the critical MA for structurally intact single blade broadheads having a sleek profile, with smooth ferrule fade-in. The above-threshold penetration jump for all such broadheads has consistently been to the 100% level. (See *Another Look at Broadhead MA's Effect*, 2007 Update, Part 4.)

Both above and below threshold, many other broadhead design features also affect the bone-penetration rate. Tip design has a marked effect on the rate, both from a durability standpoint and the effect it has on a broadhead's skip-angle during non-perpendicular bone impact. The Tanto tip design shows the best performance. The conical and 'bone-breaker' tips found on many replaceable blade broadheads have not shown good skip angles, and frequently induced broadhead skip on angular impacts. (See 2005 Update, Part 1.)

Blade configuration also affects a broadhead's skip angle and bone penetration rate. Most bones have multi-dimensional curved surfaces. This means most bone impacts are non-perpendicular, even on broadside shots. Single-blade broadheads show a better skip angle than multi-blade broadheads. Most *rigid* four blade broadheads show a better skip angle than three-bladed broadheads. Within each blade configuration broadhead MA retains its own influence. Just as for single-blade broadheads, a long-narrow 3 or 4 blade broadhead shows a better skip angle and bone penetration rate than one that's shorter and/or wider. (See 2004 Update, Part 2.)

For single-blade broadheads edge design shows a marked influence during heavy bone impact. Single-bevel broadheads induce rotation during penetration. This rotation exhibits a tendency to split bone rather than having to smash its way through. Test results indicate that single-bevel broadheads use less of the arrow's available force in breaching a bone. On otherwise identical arrow setups, single-bevel broadheads show both a higher heavy-bone penetration rate (in testing where MA of both broadheads was below 2.6) and greater post-breaching penetration than a double-bevel broadhead of matching profile. (See 2004 Update, Parts 1 and 2; and 2007 Update, Part 4.) Single-bevel testing on multiblade broadheads has been limited, but is *suggestive* that a single-bevel *might* show a similar bone-penetration advantage on these broadheads too (See 2007 Update, Part 5).

Breaching a heavy-bone requires an *impulse of force*. The impulse of force is the amount of the arrow's force used up as the bone is breached, multiplied by the time that force acted while breaching the bone (how long the arrow had to 'push' in order to breach the bone). In formula format we have: Force Used X Time of Action = Impulse of Force.

Understanding impulse of force is the key to understanding the Heavy Bone Threshold. It's really pretty simple. The arrow needs to push on the bone long enough to exceed the bone's level of structural integrity. Bones have flexible attachments that allow them to move when an outside force impacts them, and that movement is cushioned by underlying tissues and supporting ligaments. The curved surfaces of bones deflect impact forces. These body-protecting skeletal features are tailor-made to dissipate and redirect impact forces, forestalling penetration.

For a given arrow, impact force and shooting angle, and assuming a solid hit and total arrow integrity, 3 primary components determine the penetration frequency: (1) the bone's innate structural strength, profile and thickness; (2) the bone's ability to move and flex, draining the arrow's energy to forestalling bone-breach and; (3) the broadhead's design, which determines its mechanical advantage, coefficient of friction and ability to split the bone.

For a given broadhead/arrow setup the Heavy Bone Threshold shows only minor change when impact force is significantly increased. How long the force is able to act is more important than the arrow's total force in breaching a heavy bone. Another way of saying this is: how long the arrow is able to continue pushing on the bone is more important than how much total force the arrow has at impact.

For a given broadhead and shaft setup, arrow weight is the dominant factor in bone-breaching. That's because the arrow's weight significantly lengthens the time of impulse. The heavier an object in motion is, the longer it takes for a given resistance force to stop its forward movement.

Momentum (force) is mass multiplied by velocity, but not all arrow momentum has equal effect on the Heavy Bone Threshold. How the arrow attains its momentum is important. A substantial increase in the momentum of a below-threshold arrow, achieved through increased arrow velocity, shows little effect on the Heavy Bone Threshold. Increasing arrow mass to above-threshold value has a pronounced effect on the Heavy Bone Threshold, even when total momentum is reduced - such as when comparing arrows of like external dimensions from both a heavy and light draw weight bow. Why? Velocity is shed rapidly during penetration (and as the bone recoils and flexes) but arrow mass remains constant throughout the course of penetration, regardless of the resistance encountered. Indeed, the mass of a structurally intact arrow is still exactly the same after all forward motion stops.

At any given amount of forward movement (any velocity), the higher the arrow's mass-weight the longer it takes for any given level of resistance to stop the arrow's forward movement. Ergo, regardless of how much velocity is shed, as long as it's not 100%, the heavier the arrow the longer it can keep pushing on the bone.

Testing Arrow FOC's Effect on the Heavy Bone Threshold

The initial testing was conducted using a 40#@27" Bear Formula Silver recurve. The test shots were taken broadside from 20 yards on a young adult Asian buffalo bull. Selection of this specific size test animal was based on the rib thickness, which closely approximates the rib thickness of a truly massive bull elk. Over the thorax area, where all test shots were delivered, this buffalo's rib thickness ranged from 7.15mm (0.281") to 8.1mm (0.319"), depending on the specific location of measurement.

Do not be misled by the descriptive size classification. The test animal is an adult buffalo and, as can be seen in the following photo, not a small animal. However, body size and rib thickness are not as massive as that of a fully mature Asian buffalo bull. Comparative-location rib thickness measurements between this young bull and the single largest buffalo bull recorded in the Study differs by approximately 28%.

Because of the large number of shots involved, test shots were split into two strings, with six arrows from each set being fired into the left side of the thorax and six into the right side. In each string the arrow sets were fired in turn; Set 1 first, then Set 2, and so on.

The young adult Asian buffalo bull used in testing

The Arrow Setups Tested

The test series consisted of four arrow sets, with each set having 12 arrows. Except for shaft length the external dimensions of all arrows tested were identical. Each setup was bare shaft tuned to show matching fletched/un-fletched impact to 40 meters with field points, as well as matching fletched field-point vs. fletched broadhead impact. In the field-point/broadhead impact testing the 190 grain Abowyer was used, rather than the 190 Grizzly used for the actual test shots.

TIP: Because of its high wind shear factor, an un-vented, wide-for-length 2-blade broadhead works best for fine-tuning the dynamic shaft-spine of fletched field-points vs. fletched broadheads. They are also useful as an initial step in determining the amount of fletching required to stabilize arrow flight.

One major advantage of higher FOC is that it permits the use of a smaller amount of fletching to obtain arrow stabilization during flight, compared to an arrow of lower FOC.

Smaller fletching size means less arrow drag, less cross-wind drift, more retained downrange velocity and arrow force, flatter trajectory and quieter arrow flight. An amount of fletching sufficient to stabilize a wide, non-vented single-blade broadhead is sufficient for any broadhead having a lesser degree of wind shear.

When trying to develop *extremely high* amounts of arrow FOC it is useful to reduce the amount of fletching as much as possible, as this reduces the weight on the shaft's rear. The lower the wind shear factor of your broadhead the less fletching you'll need to stabilize the broadhead's flight. As an example: On arrows used for testing, where different broadheads of like weight might be used from time to time, I fine-tune the fletching size using the widest non-vented single blade I can. On my serious hunting arrows, where I know exactly which broadhead will always be used, I tune to the least amount of fletching that gives total stabilization with that specific broadhead.

Determining the minimum amount of fletching required for a specific broadhead is something done *after shaft tuning* is completed. During initial fletched field-point vs. fletched-broadhead tuning you must use sufficiently large fletching to be absolutely certain it is enough to counteract spine-induced deviation of the field-points, and then use a matching amount of fletching on the broadhead tipped arrows. This permits you to evaluate what influence the shaft's dynamic shaft is having on the arrow's flight, between the field points and broadheads.

When both your bare-shaft/fletched-arrows and your 'sufficiently fletched' field-point/broadhead arrows show matching points of impact the shaft's dynamic spine is well tuned to your bow and shooting style. Only then may you begin determination of the minimum fletching required to stabilize your specific broadhead.

Set 1. The Below Threshold Ultra-EFOC Arrows: Shaft: 3555 G.T. Ultra Lite; Broadhead: 190 grain Grizzly; Adaptor: 125 gr. steel; Insert: 100 grain brass; Arrow Mass: **620 grains; FOC 31.9%;** Impact Momentum: 0.347 Slug-Feet/Second; Impact KE: 21.85 Foot-Pounds.

Set 2. The Below Threshold Normal FOC Arrows: Shaft: 3555 G.T. Ultra Lite, internally weighted with one (1) piece 2.7mm weed-eater line; Broadhead: 190 grain Grizzly; Adaptor: 44.5 gr. aluminum; Insert: Factory supplied aluminum; Nock: weighted with JB Weld; Arrow Mass: **623 grains; FOC 11.8%;** Impact Momentum: 0.349 Slug-Feet/Second; Impact KE: 21.96 Foot-Pounds.

Set 3. The Above Threshold EFOC Arrows: Shaft: 3555 G.T. Ultra Lite, internal weight tube; Broadhead: 190 grain Grizzly; Adaptor: 125 gr. steel; Insert: 100 Grain Brass; Arrow Mass: **691 grains; FOC 26.2%;** Impact Momentum: 0.368 Slug-Feet/Second; Impact KE: 22.09 Foot-Pounds.

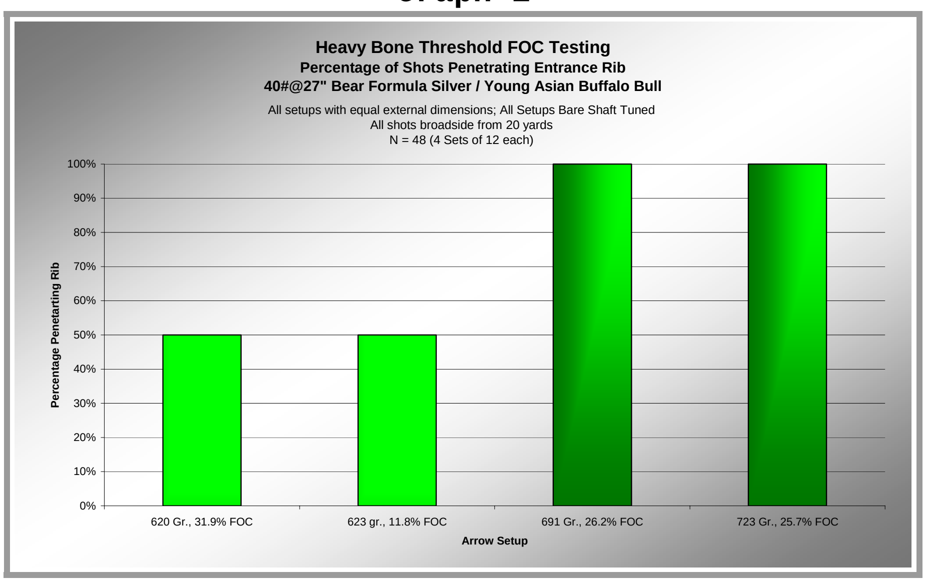
Set 4. The Above Threshold Internally Footed EFOC Arrows: Shaft: 3555 G.T. Ultra Lite, internal weight tube; Broadhead: 190 grain Grizzly; Adaptor: 125 gr. steel; Insert: 50 Grain Brass; Internal Footing: 7" Tasmanian Oak; Arrow Mass: **723 grains; FOC 25.1%;** Impact Momentum: 0.379 Slug-Feet/Second; Impact KE: 22.35 Foot-Pounds.

As a reminder: "penetrating the bone" implies *complete passage of the entire broadhead through the bone*. If a shot stops with any portion of the broadhead still in the bone, the bone was not penetrated by the broadhead; the bone stopped the arrow's penetration.

Outcomes

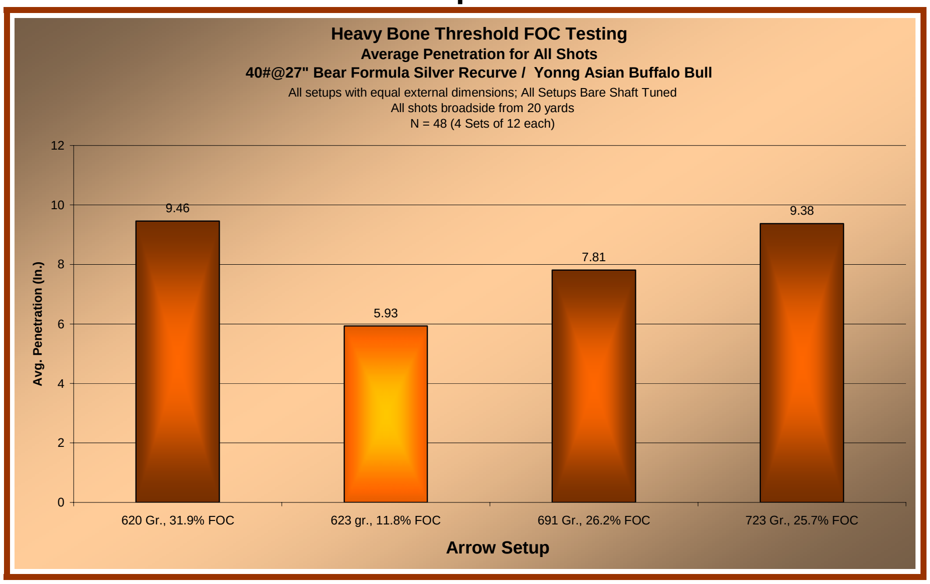
Graph 1 shows the resulting heavy-bone penetration rates.

Graph 1



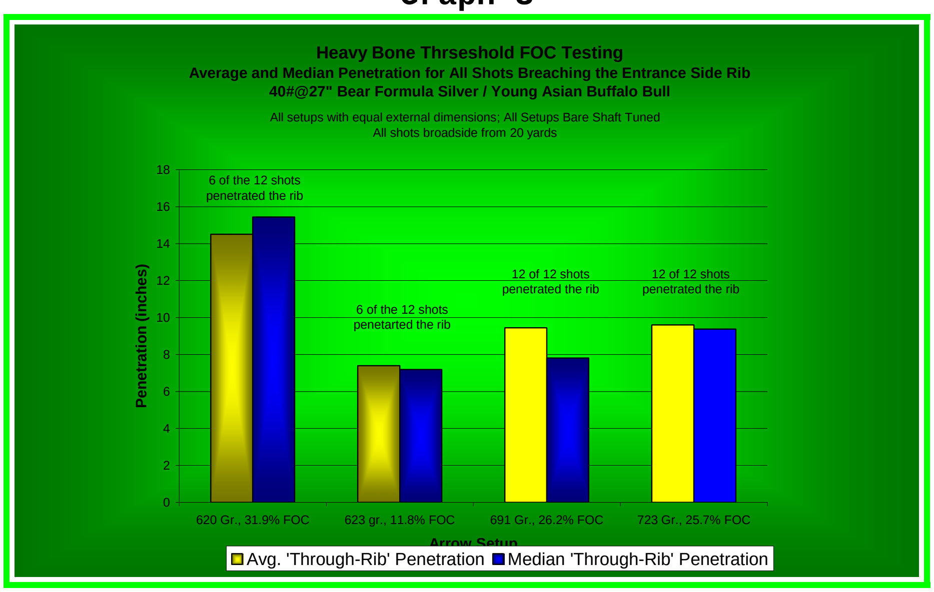
Both the EFOC (Set 1) and Normal FOC (Set 2) below-threshold arrows show a 50% heavy-bone penetration rate, with six of the twelve arrows in each group penetrating the bone. All arrows (100%) in the two above-threshold sets penetrated the bone. This result is consistent with prior testing for the 190 grain Grizzly using Normal and High FOC arrows. As prior results had suggested the degree of FOC showed no effect on the heavy-bone penetration rate.

Graph 2



Graph 2 shows the overall average penetration for all twelve shots in each group. What instantly jumps out is the very high average penetration shown by Set 1's arrows, despite having only a 50% heavy-bone penetration rate. This implies that each of Set 1's six bone-breaching shots achieved extraordinarily high penetration after passing through the bone. Let's delve further into what these shots show.

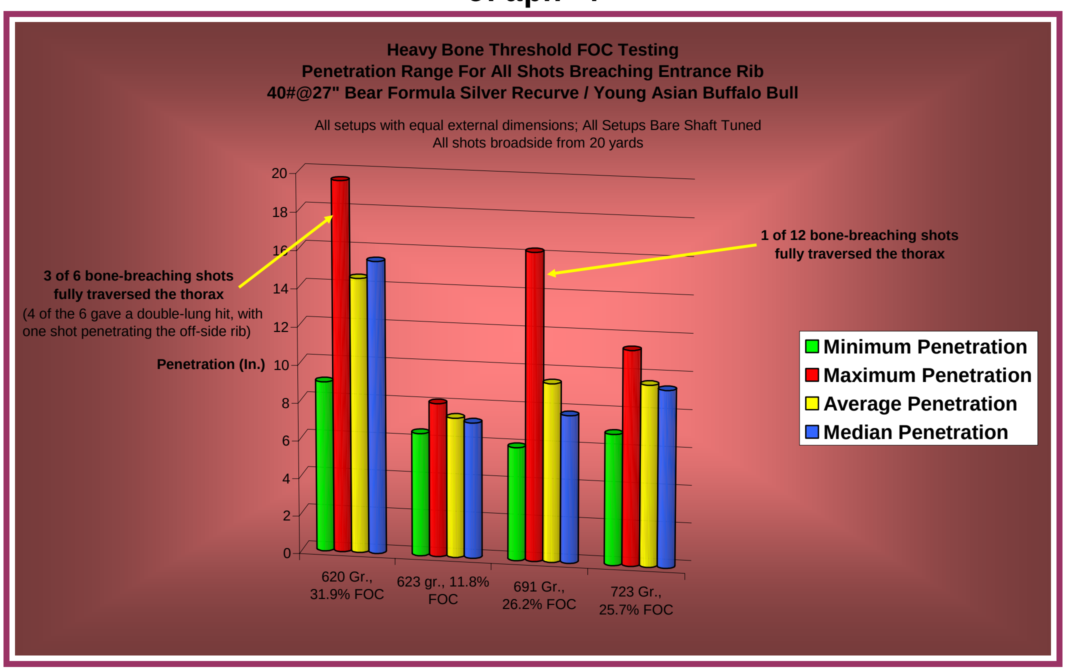
Graph 3



Graph 3's yellow bar shows the average penetration *for all shots breaching the entrance rib*. This would be for the six bone-breaching shots in both Set 1 and Set 2, and for all 12 shots in Sets 2 and 3. The blue bar in Graph 3 shows the median penetration. The median value represents the mid-point of the penetration measurements, where ½ of the shots penetrated to a greater depth and ½ penetrated a lesser amount.

The bone-breaching hits with Set 1's Ultra-EFOC arrows show an amazing amount of penetration. Note that the median penetration for Set 1's arrows shows a greater value than the average penetration. This means that more than one-half of the bone-breaching shots exceeded the average penetration. Indeed, that was the case. Four of the 6 bone-breaching shots gave deep, double-lung hits. Three of those shots fully traversed the thorax, with 2 sticking solidly into the off-side rib and 1 penetrating the off-side rib. Graph 4 gives a more startling image of the Ultra-EFOC arrow's post-breaching penetration.

Graph 4



Graph 4's green bar reflects the minimum penetration shown by any of the bone-breaching shots for each set. The red bar shows the maximum penetration shown by any shot in each set. Compare each set's relationship between the minimum and maximum values and its average and median penetration (the yellow and blue bars) then compare Set 1 to the other Sets. What does this show, and what are the implications?

Closely examine the outcomes for Set 1's bone-breaching shots. Most obvious is the fact that both the minimum and maximum penetration shown for Set 1 exceeds the breached-bone penetration shown by any of the other sets. Set 1's average and median penetration is closer to its maximum penetration than to its minimum penetration. This indicates that most shots resulted in penetration closer to the maximum than to the minimum; something not shown in the other sets.

Except for their degree of FOC Sets 1 and 2 are identical. Their shaft length is the same (691mm) and set 2's arrows weight only 3 grains more than those in Set 1. Arrows in both sets are equally well tuned. Impact force is virtually identical (0.347 Slug-Feet/Second for Set 1 vs. 0.349 for Set 2). Set 1 and Set 2 show an identical rate of breaching the bone; 50%. Nonetheless, the minimum post-breaching penetration shown by any of Set 1's Ultra-EFOC arrows exceeds the maximum penetration of any of Set 2's Normal FOC arrows. Set 1's bone-breaching shots show almost double the average penetration (96.2% more) of those for Set 2, and their median penetration is over double (115% more). This means that once the bone is breached the *likely outcome* penetration on a shot with Set 1's Ultra-EFOC arrows will be double that for a shot taken with an 'externally identical' arrow from set 2. This marked difference in outcomes results from the difference in arrow FOC.

Between sets 1 and 2 the difference in FOC shows no influence on the rate of breaching the entrance bone but does show a marked effect on penetration once the bone is breached.

Set 1's six bone-breaching shots also show better penetration than shown for the above-threshold EFOC arrows in Sets 3 and 4. It is, however, important not to underestimate the performance level represented by these two sets of EFOC arrows from this light draw-weight recurve. In Part 2 of this Update series we'll see how the penetration of both the EFOC and Ultra-EFOC arrows from the 40# bow compares with that shown by 'commonly used' arrows from the heavier bows tested.