2007 Study Update, Part 5

By

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Parts 3 and 4 were devoted to results of Internal Footing and Extreme FOC testing. A few left over items remain, before beginning the discussion of other test. Let's begin where we left off.

Extreme FOC's Demonstrated Advantage

In Part 4 we saw that the penetration-enhanced Extreme FOC arrows provided an enormous increase in terminal performance. They allowed a 54# bow to *outperform* an equally-efficient bow having 28 pounds more draw force, when that heavier bow employed 'common arrows'. Does this imply heavy-bow shooters no longer have any advantage over those shooting lighter draw-weight bows? Not in the least. All the heavy-bow shooter needs to do to recapture his potential advantage is maximize his own arrow's penetration potential.

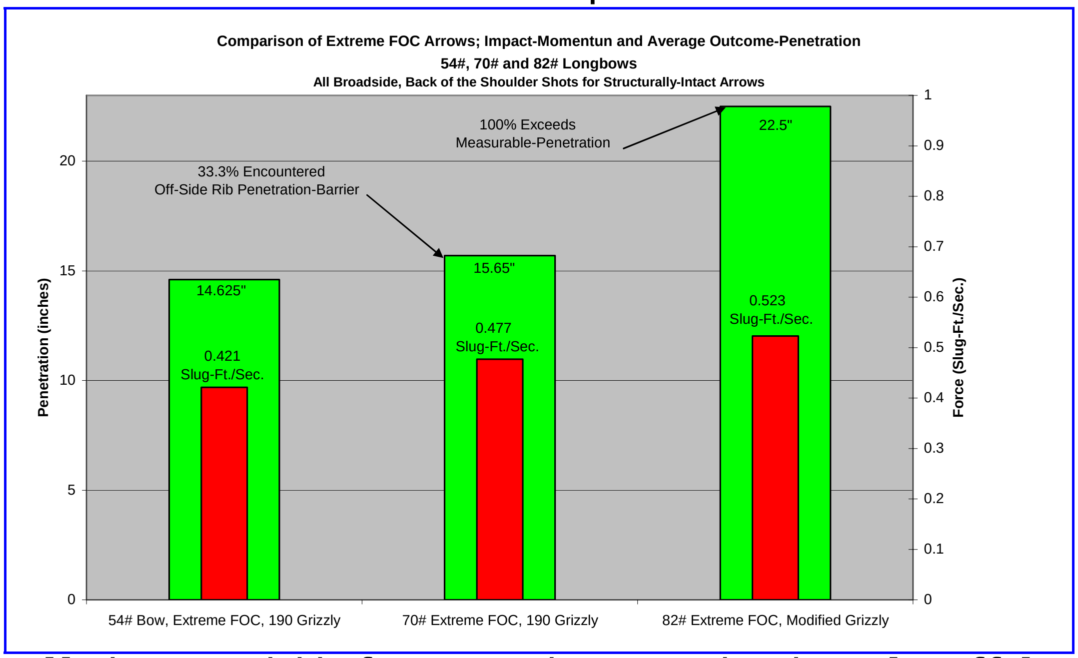
Comparative Analysis of Each Bow's Extreme FOC Arrows

While less captivating to the average bowhunter, analysis of test outcomes is the most significant part of Study results. It is through such inquiry that we learn what factors affect arrow terminal performance, how they affect it and their degree of influence. It gives an understanding of how and why each different arrow setup affects the results. As we'll soon see, even *how* a particular arrow is used makes a difference in the results. When choosing his arrow setup, without an understanding of arrow performance the bowhunter must relying on either luck, blind faith in subjective opinion (usually drawn only from successful hits, because few ever get to see *why* a non-lethal hit failed to work) or manufacturer's 'hype'.

'Claims' and 'product reviews' aren't always reliable. Note mangled results when these self-proclaimed "World's Best Penetrating and Toughest Broadheads Ever Made" were tested … and their penetration was poor! Understanding the "how and why" of arrow performance makes your choices easier. You'll not find mention of unfavorable product results in very many advertiser-dependent publications.

Let's begin this analysis with a look at arrow-momentum and the resulting penetration for the three sets of Extreme FOC arrows. While examining the following chart, note that: (1) one-third of the Extreme FOC arrows from the 70# bow reached the off-side rib's penetration-barrier and; (2) 100% of those from the 82# bow passed through this barrier, carrying on to provide an exit wound and exceeding the limit of measurable-penetration. With these facts in mind, examine the impact-force (red bar) and outcome tissue-penetration (green bar) for all three arrow sets.

The Extreme FOC Comparison Chart



All Shots Broadside from 20 Yards, on Trophy Size Male Buffalo

Note that the arrows from the 70# bow show a momentum increase over those from the 54# bow of 0.056 Slug-Feet/second, and the arrows from the 82# bow show only a 0.046 Slug-Feet/second increase over the arrows from the 70# bow. The increase in arrow force between the 82# and 70# bows is less than that between the 70# and 54# bows. Consider that the arrows from the 54# and 70# bow have near-identical dimensions.

Though the arrows from the 82# bow have a different shaft, and are Internally Footed, their shafts *do* have the same outside diameter as the other shafts. They also have the highest mass, but are only 66 grains heavier than those from the 54# bow, and 34 grains heavier than those from the 70# bow. However, they use a broadhead of significantly higher mechanical advantage (MA); the Modified Grizzly, rather than the 190 Grizzly. Data analysis shows many interesting features.

Momentum's Correspondence with Penetration

Looking through earlier Updates, for '*like arrows*' you'll find *numerous* examples demonstrating a near-perfect 1 to 1 correlation between the percentage of momentum increase and the percentage increase in average tissue penetration. It has been manifest *every single time* a 'like-arrow' (apples-to-apples) comparison opportunity appeared, without penetration-limiting constraints.

However, it is important to note that in all prior momentum-to-penetration comparisons for 'like arrows' the same bow has been used with each of the arrows. In each of those cases all increase in arrow momentum resulted from an increase in arrow mass. Increasing the arrow mass also caused a simultaneous decrease in arrow velocity. In this case each 'like arrow' is used from a different bow, and the majority of the arrow's momentum increase is derived from an increase in arrow velocity. Keep that fact in mind as we progress through the discussions.

How does the momentum to penetration increase compare here? We'll make comparisons as closely as measurement-limits permit.

Examine the outcomes for the 54# and 70# bow. There is pragmatic similarity between each arrow set. Total mass varies by 32 grains (4.4%). Both have the same shaft. Each uses either brass or steel insert. Both have identical steel broadhead adaptors. Both have the same broadhead, identically sharpened. FOC's differs by 1.3% (27% for the 70# and 25.7% for the 54#). All shots are comparably placed. All test animals were of like-size. All shots were fired from the same distance, at the same shooting angle, and the shots were equally distributed between the test animals.

The arrows from the 70# bow show a 13.3% impact momentum increase over those from the 54# bow. If we use the 'average of averages' for both the mean penetration and that shown by one standard deviation (an attempt to normalize the 33.3% of arrows from the 70# bow encountering the penetration-barrier) the 70# bow shows a 'calculated penetration' gain of 13.2%. That's right at our usual 1 to 1 ratio; which would suggest that 100% of the velocity-supplied momentum increase went into 'penetration increase'.

If one accepts this as being the penetration increase that would be yielded in absence of the penetration barrier, it implies that the arrow's increase in impact momentum once again resulted in an equal increase in arrow penetration. However, if the actual measured penetrations are used - disregarding the 1/3 of the arrows encountering the off-side rib penetration barrier - the penetration increase is only 7%; which is 52.6% of the (13.3%) percentage increase in impact momentum. That's a significantly large difference in ratios when one considers that 2/3 of the arrows from the 70# bow *did not* encounter the penetration barrier.

It's a certainty that, in absence of the penetration barrier the actual-penetration increase to momentum-increase ratio would lie somewhere between these two increase values: the 'measured ratio' (52.6%) and the 'calculated ratio' (100%). I'll venture a guess that it would be significantly less than the 'usual' one to one ratio we've commonly seen in the 'like arrow' comparisons; where the same bow was used for each arrow.

Why do I think that? First, all the arrows from the 54# bow are tightly clustered, and show less than half the standard deviation of those from the 70# bow. Secondly, the arrows from the 70# bow that didn't encountering the off-side barrier (2/3 of the total shots) are also tightly clustered. These differences *strongly suggest* that the 'corrected' average penetration should be significantly less than that shown by the 'adjusted' calculation above. There is also another, more concrete reason, but I'll save it until we get to the discussion of the kinetic energy and penetration.

Penetration shown for the 82# bow's Extreme FOC arrows can not be used for direct momentum-effect comparison purposes with those from the other bows. Not only is there a substantial difference in efficiency (MA) of the broadhead used, but each shot exceeds the limit of measurable-penetration. However, it does serve as an excellent example of the huge difference in penetration arrow efficiency can make, and the magnitude of influence that the *force* and *time* multiplying-effect has on outcome penetration. Let's examine it more closely.

The Broadhead's Mechanical Advantage Effect

Despite exceeding measurable-penetration, note the enormity of the penetration gain shown by the 82# bow's Extreme FOC arrows, in relation to their modest increase in impact force over those from the lighter bows. FOC is 27% for the 70# bow's arrows, and 26.3% for those from the 82# bow. Arrows from the 82# bow have 34 grains more mass (4.3%), 9.6% more impact momentum and 15.1% more impact kinetic energy than those from the 70# bow; but their *measurable* penetration is 43.8% greater. Were it not for their penetration exceeding measurable limits, the *actual* penetration increase would be even higher. Why is it so great?

Though there are modest differences in mass-weight, impact force and energy, the massive increase is primarily because arrows from the 82# bow have the Modified Grizzly. The Modified Grizzly [1" wide X 3.15" long, with a main-blade tissue attack-angle of 7.4 degrees] has a much higher MA than the 190 gr. Grizzly. What you are observing is an illustration of the arrow's total force being applied with higher efficiency. This increases the amount of 'work' the arrow can do with the force available; which gives a longer time of impulse. Each of these, force and time, *multiply* the other's influence to give a disproportionally large penetration increase.

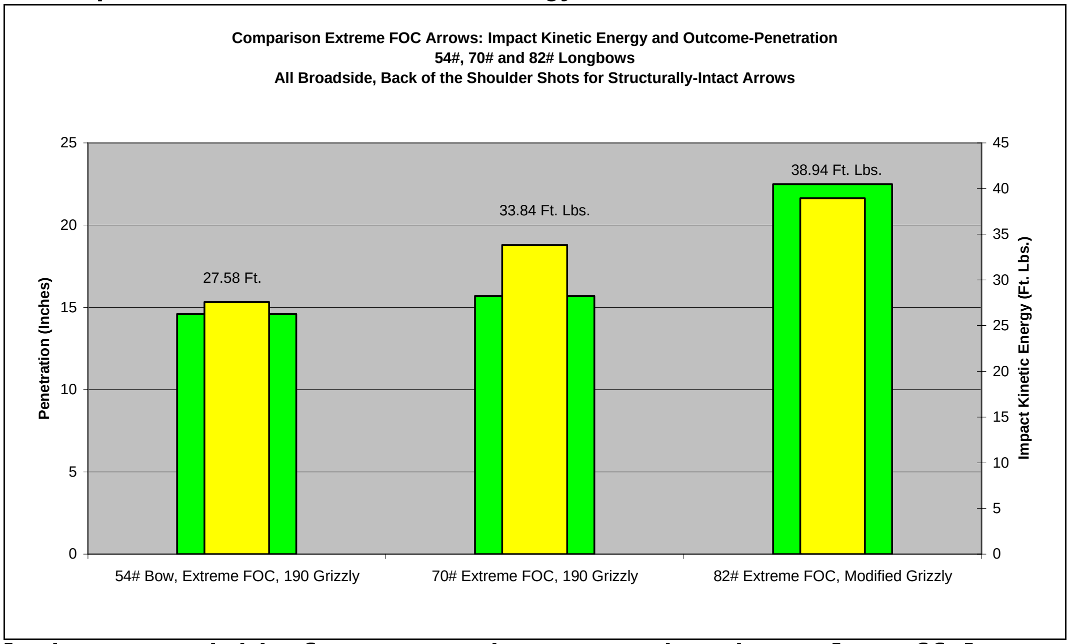
This chart illustrates the "efficient arrow's" compounding effect of *force* and *time* on arrow penetration, as discussed in earlier parts of the current Updates. It presents precisely as *impulse mechanics* says it should. Momentum, and its application via the impulse of force formula, forecast such outcomes, explaining why they *must* occur. The kinetic energy equation(s), as applied to arrow penetration, does not allow for the profound implications of such mechanisms, yet their immense influence on tissue penetration is an unswerving data feature.

Now let's take at look at what the data tells us about the relationship between the kinetic energy of these arrows and their resulting penetration. There are some extremely interesting observations to be made.

Kinetic Energy's Correspondence with Penetration

The following chart depicts the relationship between impact kinetic energy (yellow bar) and outcome-penetration (green bar) for the three sets of Extreme FOC arrows.

Comparison Chart: Kinetic Energy and the Extreme FOC Arrows



All Shots Broadside from 20 Yards, on Trophy Size Male Buffalo

The kinetic-energy to tissue-penetration ratio is a very useful tool for comparing the *relative* terminal efficiency of various arrow setups in tissues … after we know the results of the shot(s). It factors in not only the efficiency with which the arrow applies its available force, but also any changes in tissue resistance that might occur.

It might help if you think of this ratio just like you would the fuel efficiency of your car. The more efficient your car is the higher its fuel mileage. However, you can't figure the actual 'mileage' it's going to give, under any given type of driving conditions, until after you make the drive; and it's the same with the kinetic-energy to penetration ratio.

We're all very familiar with what our car's fuel efficiency ratio means. It's the average miles per gallon (MPG) our car gets. The kinetic-energy to tissue-penetration ratio reflects exactly the same type of relationship as our car's fuel mileage, but its units are flip-flopped. It would be like expressing your car's fuel mileage in 'gallons per mile' rather than 'miles per gallons'.

We're also familiar with the different ways our car's MPG ratio is used. There's one MPG ratio for stop-and-go city driving and another for the open road; and there's also one for when we're pulling a heavy load – such as towing a trailer or pulling a boat. All these different "average MPG ratings" are used to compare the relative efficiency of various cars; under various, but similar, driving conditions. It's so useful for this purpose that we find the 'expected average mileage' information placed on the window-sticker of every new car sitting on the dealer's lot.

Just as for your car's mileage, the kinetic-energy to penetration ratio can be calculated for a single trip or for the average mileage shown by a number of trips. Its measurement units are foot-pounds per inch of penetration.

Unlike the many ways we use our car's MPG ratings, the kinetic-energy to penetration ratio is never used to reflect our arrow's 'fuel mileage' for an entire trip. It's used only for the trip's final leg; from arrow impact onward.

Perhaps you would prefer to visualize the relationship this way. Think of the arrow's entire journey like starting off in your car in the flatlands and then driving into the mountains. You'll get a lot better mileage getting to the mountains than you will once you start driving up the mountains. Why? Because your car has to do more "work" to travel any certain distance when it's going uphill, so your MPG ratio goes down for that part of the trip. When you flip-flop that ratio your gallons of fuel used per mile would go up as the 'work' your car has to do is increased.

Our arrows use up some of the energy they 'fueled up with' at the bow in getting to the target. Whatever 'fuel' (energy) they have left when they arrive at the target is all they have to work with. This is their "impact kinetic energy". When its impact kinetic energy is all used up the arrow comes to a stop, just as your car will when all its fuel was gone. The kinetic-energy to tissue-penetration ratio tells us the arrow's 'fuel mileage' during that final, difficult uphill climb. Thusly, it reflects both the 'steepness of the grade' the arrow has to climb (the amount of tissue resistance) and the efficiency with which the arrows use their 'fuel' (kinetic energy).

Now that we all know precisely what we're talking about and what it means, let's take a look at the 'fuel efficiency' of these Extreme FOC arrows relative to each other during penetration, to see how they compare. Their relative 'mileage' has a great deal to tell us about the relationship between kinetic energy, momentum and arrow penetration.

The Comparative Efficiency for the Extreme FOC Arrows

Though the arrows from the 54# bow and 70# bow are very similar, the relationship each shows between impact kinetic energy and outcome penetration is non-proportional. The arrows from the 70# bow were traveling 20 fps (16%) faster. Primarily as a result of this increased arrow speed they carried 22.7% more 'fuel' (kinetic energy) at impact; as well as their 13.3% increase in momentum. The tiny increase in mass (4.4%) they have over the 54# bow's 'like arrows' makes a near-negligible kinetic energy contribution; because kinetic energy's formula considers only ½ of the arrow's mass, but squares the arrow's velocity (see page 26; *Momentum, Kinetic Energy and Arrow Penetration*).

The *impact* kinetic-energy to penetration ratio for the arrows from the 54# bow is 1.89 foot-pounds per inch of penetration (1.89:1). The ratio for the arrows from the 70# bow is 2.16 foot-pounds per inch of penetration (2.16:1). This means the arrows from the 70# bow; with near-equal mass, identical external profiles, equal design features and equal quality of flight; used up and average of 14.3% more 'fuel' (kinetic energy) than those from the 54# bow … for every inch of tissue they traveled through.

If, instead of the actually measured penetration used in the above calculation, we use the adjusted (calculated) penetration difference for the arrows from the 70# bow - as we did in the momentum comparison, to theoretically adjust for the 1/3 of the arrows encountering the off-side rib's penetration barrier - the kinetic-energy to penetration ratio is 2.04:1. This 'adjusted penetration' ratio still implies an average 'fuel' (kinetic-energy) usage 7.9% greater than that of the arrows from the 54# bow; for each inch of tissue penetrated.

Regardless of which penetration value is used, the difference between their kinetic-energy to penetration ratios indicates arrows from the 54# bow are getting 'better mileage' from their 'fuel' (their kinetic energy) than those from the 70# bow.

Now; we *know* that the arrows from the 70# bow had to consume less than 14.3% more fuel per inch indicated by the actually measured penetration, because 1/3 of the arrows were stopped by the off-side rib barrier. No matter how small the amount, whatever additional penetration they would have yielded, had they not been stopped by the barrier, would increase the average distance traveled. We're also *implicitly certain* they required more than the 7.9% 'fuel increase' the 'calculated penetration' would suggest; because median penetration is markedly less than the 'average penetration' and all arrows not encountering the barrier were tightly clustered. Therefore let's take the average of these two 'fuel consumption' increases; 11.1%; as being a fairly close 'guesstimate' of the actual increase in 'fuel consumption' (kinetic energy used) per inch of penetration.

But hold on a minute, how can this be? The arrows from each bow have identical external profiles and equally good flight. Those from the 70# bow have both a bit *more mass* and a bit *higher degree of FOC*. Shouldn't each of those design features result in an arrow slightly more efficient than those from the lighter bow? Why would they 'consume' an approximate average of 11.1% more 'fuel' (kinetic energy) *for each inch* they traveled through the tissues? If the arrows are more efficient, shouldn't their 'fuel consumption' be less per inch than the arrows from the 54# bow?

The answers are simple. Though the arrows from the 70# bow *are* a bit more efficient they are being required to 'climb a steeper slope' than those from the 54# bow. They have to perform a greater amount of 'work' for every inch they travel.

What's that? Both arrows are near-identical, and they're penetrating the same identical animals, under identical shot conditions. How can it be harder 'work' for one than the other?

Well, the shot conditions are not entirely "identical". The arrows from the 70# bow are impacting at a higher velocity. This causes an increase in the tissue's resistance to penetration. How much increase? Tissue's resistance to penetration increases as the square of the velocity increase – or at some compounding rate that's darned close to that.

To put an exponentially increasing rate of resistance increase into perspective, it means that a 50% increase in arrow speed implies the arrow will encounter two and one-forth times as much tissue-resistance (a resistance *increase* of 125%). Doubling arrow speed (a 100% *increase* in arrow speed) implies the arrow will encounter four times as much tissue-resistance (a resistance *increase* of 300%).

Even the modest 20 fps increase in arrow speed between these two arrows has a demonstrably marked effect on tissue resistance …

and arrow penetration. For their 16% increase in speed, the arrows from the 70# bow encounter a *calculated* tissue resistance increase of 34.6%.

Calculation, for those interested: The resistance increase is derived from the velocity of the arrows from the 70# bow expressed relative to the velocity of the arrows from the 54# bow; which is then squared, with the amount of *resistance increase* expressed as a percentage; i.e. 1.16 X (velocity, 54# bow's arrows) = velocity of arrows from the 70# bow. Then the relative velocity is squared: $1.16^2 = 1.3456$. This indicates a resistance force 1.346 times greater that what the arrows from the 54# bow encountered; which is a resistance-increase of 0.3456. Rounding off and converting to a percentage gives a 34.6% increase in the tissue's resistance to penetration.

The difference in kinetic-energy to penetration ratios between these near-identical arrows is an example of exponentially increasing tissue resistance as velocity increases; which forms the basis for penetration *decrement*.

Decrement means that each equal-increment increase in velocity yields a *progressively* lower amount of increase in tissue penetration. This occurs because the tissue resistance increases *as the square* of the velocity's increase. Because of decrement, and kinetic energy's disproportionate formula-dependency on velocity, even when arrows are identical (or nearly so) neither the increase in impact kinetic energy nor the increase in velocity-derived momentum *accurately* forecasts the resulting penetration-gain (though one comes much closer to doing so than the other).

Okay; if we assume that the tissue resistance *has* increased exponentially with velocity's increase how well does that reflect the penetration outcomes shown? Let's take a look.

Consider that the kinetic energy increase for these 'like arrows', when fired from the 70# bow, is 22.7%. That's a lesser increase than the calculated 34.6% increase in the tissue's resistance that resulted from their higher speed. The difference between energy-increase and resistance-increase indicated is 11.9%. That's pretty close to the 'guesstimated' 11.1% increase in energy-consumption per inch of penetration we got when we averaged the 'fuel consumption' shown by the 'actually measured' penetration and the 'adjusted' penetration for the arrows from the 70# bow, isn't it?

Rhetorically, the above implies the following. For arrows from the 70# bow; when we use the 'actual' penetration increase (the one measured), for the additional 22.7% increase in 'fuel' (kinetic energy) used they show a penetration increase of 7%. If the average for both the 'actual' and 'calculated' penetrations is used, for their 22.7% increase in 'fuel' (kinetic energy) they achieve a 10.8% increase in penetration over the 54# bow. If we use the 'calculated penetration' (as suggested by the arrow's increase in impact-momentum), for the 22.7% increase in kinetic energy they achieve a 13.2% boost in penetration.

If we were to assume that the 22.7% increase in kinetic energy would have yielded a full 22.7% increase in average penetration, it means that <u>*each*</u> of the arrows that were stopped by the off-side rib barrier would have had to penetrate <u>*6.2 standard deviations*</u> farther than the 2/3 of the arrows that did not encounter the barrier. This amount of penetration variation is a virtual impossibility under the testing conditions. For all *arrow sets* tested to date; when only those breaching the on-side rib-barrier are considered, no penetration-disparity remotely approaching one-half that level has *ever* been shown - and all arrows in this test set *did* penetrate the on-side barrier.

There is no doubt that the tissue-resistance increase was *some amount* greater than the amount of energy increase. Regardless of how small or large that amount of difference was, it also implies the arrows from the 70# bow did, indeed, apply what force they had with a bit more efficiency than those from the 54# bow. To make this implication easier to understand, again relate it to your car.

If your car has 10 gallons of fuel you can drive it a certain distance across the flatlands. Let's assume your car's normal fuel mileage is 20 miles per gallon. That means you could travel 200 miles across the flatlands. If you then increase your car's available fuel by 22.7% that means it would have 12.27 gallons of fuel in the tank. On the flatlands, against the same resistance and at the same level of efficiency as before, you could drive 245.4 miles.

Now let's put those 12.27 gallons of fuel in the tank and drive up a steep mountain – one so steep that it requires your car to do 34.6% more 'work' for each mile it travels. If your car's engine performs with the same efficiency - delivering the same amount of 'work' from each gallon of fuel as it did on the flatlands - it will now consume 34.6% more fuel for each mile you travel. That means your car's mileage going up the steep mountain will be reduced to 13.08 miles per gallon. With the 12.27 gallons of fuel, at a fuel consumption rate of 13.08 miles per gallon, you'll only be able to drive 160.49 miles up that steep grade before all the fuel is used up; only 65.4% as far as on the flatlands.

The slightly heavier 'like arrows' from the 70# bow did make better use of the 'fuel' (energy) they had than did the arrows from the 54# bow. Against an increased resistance, they used it efficiently enough to show an increase in the distance traveled, but not with enough increase to totally offset the exponentially increased tissue resistance created by their increased velocity. Had they been able to do that, the kinetic-energy to penetration ratio for each set of arrows would be equal.

But wait. If the tissue-resistance always increases more than the increase in kinetic energy, what would have happened if the arrow didn't have those slight increases in mass and FOC? What if the efficiency of the arrow's design hadn't changed any at all? Wouldn't that mean that increasing the velocity of any individual arrow would *always* result in less total penetration than it shows at a lower impact velocity? We all know that's not what actually happens when we increase the velocity of an individual arrow. So, if resistance is increasing at a greater rate than the increase in arrow energy, how and why could this seeming paradox occur?

Once again, the answer is simple. The change in kinetic energy does not accurately reflect the change in the arrow's *force*, or how that force is used. Why? Because "*energy*" and "*force*" are not the same thing. That's why there are different formulas and different units of measurement for each.

In actuality our arrow is coasting through the tissues. Our car kept an even speed until it ran out of fuel. Our arrow has its maximum speed (for the journey's last leg through the tissues) at the instant of impact. It begins to slow down the instant it starts 'up the slope', and continues to slow down until it coast to a stop against the resistance. Because of this, we must turn to the arrow's momentum for our answer. We must see what effect the velocity change had on the *force* our arrow carried at impact, and how the arrow used that resulting *force*.

Our arrow's force is, literally, the *momentum* it carries at the instant of impact. Since all 'fuel' has already been 'burned', and our arrow is 'coasting', the force it has at impact is all it has to use. When that's used up the arrow stops; and the force used will equal the resistance encountered.

Here the explanation must get a bit more complex, but I'll try to keep it understandable. Even though tissue resistance increases at a faster rate than the momentum (as arrow velocity increases), it is not simply the increase in the arrow's momentum that determines the outcome penetration; it is how much total 'work' the arrow can accomplish with its 'new' total force … and this is where the *impulse of force* comes in.

The impulse of force tells us *how much work* an individual arrow can perform with the force it has. In the *impulse of force* formula the arrow's ***momentum*** (which is the amount of **force** the arrow has to work with) is multiplied by the ***time*** the arrow spent penetrating tissue. The arrow's momentum is determined by multiplying the arrow mass (expressed in Slugs) by the arrow's velocity.

When our arrow stops in the tissues its total *impulse of force* will equal the arrow mass (in Slugs) multiplied by the velocity multiplied by the time of penetration. In equation form this is: Mass X Velocity X Time = Total Impulse of Force; which will also equal the total amount of tissue resistance our arrow can overcome before it comes to a stop.

The velocity will be a given amount, depending only on how fast we drive the arrow. It has but a single influence on the equation; it increases the momentum. For a given velocity increase, the momentum increase will be proportional to the arrow's mass.

Why isn't the momentum increase also proportional to the increase in velocity? That's because "*mass*" is the weight in pounds multiplied by the gravitational constant and divided by the force of gravity. That means "mass" is the fractional value:

$$\frac{\text{Weight in pounds X } g_c}{\text{Force of gravity}}$$

What this conversion does is change the object's 'weight' in pounds into its 'mass" in Slugs (the standard unit of measurement for "mass"). This is where it becomes imperative to distinguish between "mass" and "weight". Though their numerical value can be equal each carries a very different significance when used in calculations.

When the velocity is multiplied by the "mass" it means that the product of the velocity times the weight in pounds times the g_c ends up being divided by the force of gravity. Therefore, the increase in momentum is not directly proportional to the increase in velocity. However, "mass" IS the weight in slugs, and therefore the increase in momentum IS directly proportional to any increase in the "mass".

The arrow's mass has a major influence on both the resulting *momentum* and the *time* of the impulse; and this influence is *compounded* when the momentum and time multiply each other to determine the total impulse of force.

Increasing our arrow's velocity increases its forward force (impetus) and, just like increasing the speed of our car, makes it more difficult to stop. The amount of impetus increase is also proportional to the arrow's mass. The greater the impetus a given arrows shows when its velocity is increased, the longer period of time it can continue to move forward against any given level of resistance. This means the time of the impulse will have increased; relative to what would have been shown by the 'new level' of tissue resistance and the 'old' level of force.

After arrow mass has exerted its influence on both the arrow's momentum and the arrow's time of impulse, the *force* (momentum) and the *time of impulse* multiply each other to determine the total impulse of force the arrow will apply to the tissues. Thus, the total impulse of force increases by an amount greater that the combined (added) amount of increase in *time* and *force* (momentum).

What the above means is that whenever arrow velocity changes the arrow's mass applies a 'triple whammy' to the arrow's *impulse of force*. First it directly increases *both* the momentum and time of the impulse. Then these two values are multiplied together; compounding whatever direct effects the arrow's mass had on the momentum and time of impulse. The arrow's mass has an enormous, compounded influence on how well an arrow of a given design applies the total force it has available – even when the mass stays the same and only the velocity changes.

But there is still more to consider. Perhaps the most often overlooked factor influencing the time of arrow impulse is the mechanical efficiency of the arrow itself.

The higher the arrow's overall MA the more 'work' it can achieve with the total force the arrow has. Increasing velocity of any given arrow will increase its total force (momentum). The *totality* of the arrow's force (its 'original' momentum plus the increase in momentum) will be applied to the resistance at the mechanical advantage ratio of the arrow. This also increases the time of impulse against whatever level of resistance is encountered - *in addition* to whatever 'time increase' resulted purely from the effect of the arrow's mass.

This too is easier to understand if you relate it to cars. The more efficiently your car uses its fuel, the more 'work' it can do with any given amount of increase in its fuel supply. Now let's relate that to two cars with differing levels of efficiency – just like two arrows having a different mechanical advantage.

The difference in the amount of 'work' each car can achieve with any given increase in fuel will be proportional to the ratio of each car's efficiency. If one car is twice as efficient as the other, the more efficient one will gain twice as much driving time and twice as much travel distance from the same amount of fuel increase – when both are driven against any identical resistance load.

Does all of this mean that increasing the velocity of a given arrow will always result in some amount of penetration increase? For the velocities arrows are capable of, yes. However the relative amount (degree) of penetration increase becomes less for each incremental increase in impact velocity. High-speed projectiles, such as some rifle bullets, can reach velocities so great that their penetration does show a decrease as their velocity is further increased. With a given bullet (even "true solids") this becomes measurably noticeable at around 2500 fps impact velocity – the same point where hydrostatic tissue shock first appears.

The Implications

The *amount* of penetration-difference shown by the same arrow impacting at different speeds will depend on: (1) the arrow's mass, (2) the velocity change, (3) the amount of resistance-change resulting from the arrow's increased speed and, (4) the change in the time of impulse. (Remember that the increase in the time of impulse will be influenced by: (a) the momentum increase, (b) the contribution arrow mass makes to the momentum increase and (c) the mechanical efficiency at which the individual arrow applies the increased momentum.)

There are several factors that should be obvious from the explanation(s):

- The lighter your arrow, the less momentum increase you will realize from a given increase in the arrow's velocity.

- The lighter your arrow, the less increase in the time of impulse you will realize from a given increase in the arrow's velocity.

- The lighter your arrow, the less the resulting impulse of force for a given increase in the arrow's velocity.

- The lighter your arrow, the less efficiently it uses its momentum.

- The lighter your arrow, the less the net penetration gain you'll realize from a given increase the arrow's velocity.

- The lighter your arrow, the greater the offset between the velocity-induced tissue-resistance increase and the arrow's impetus.

- The greater the proportion of the arrow's momentum that's represented by arrow mass the greater the increase in BOTH the momentum AND the time of impulse will be; and the greater the total amount of usefully applied, penetration producing *impulse of force* the arrow will have.

- The higher your arrow's mechanical advantage, the more 'work' it can accomplish with any given increase in arrow force.

Kinetic Energy, as Commonly Applied to Arrow Penetration

As commonly-applied, the use of kinetic energy as a penetration-predictor makes a number of phantasmal assumptions. Foremost among these are:

1) That, since kinetic energy reflects the "capacity to do work" it also accurately reflects the *factuality* of the 'work performed'; thus giving kinetic energy a directly proportional relationship to tissue penetration. [This fails to consider that having the *potential* to accomplish a task and actually accomplishing the task is not the same thing. Kinetic energy gives our arrow the potential to penetrate, but the actual amount of 'work' that can be accomplished with that energy depends on how the arrow applies that kinetic energy.]

2) That tissue-resistance cannot be treated as a 'fluid', and therefore its resistance to penetration does not disproportionally increase as velocity increases.

3) That a change in arrow kinetic energy has more influence on penetration than does a change in arrow mass.

4) That a change in arrow kinetic energy has more influence on penetration than does a change in arrow momentum.

5) That arrow efficiency has a negligible effect on arrow penetration.

Under such constraints it is impossible to account for the above observed results – and we haven't reached the results that are *really difficult* to explain.

When the kinetic-energy to penetration ratio was applied to the 'like arrows' from the 70# bow, and the total 'work' they accomplished was compared to the amount of additional energy required in order to accomplish that 'work' it indicates that either: (1) the tissue resistance IS increasing at a nearly exponential rate OR, (2) the increase in arrow momentum did, indeed, accurately predict the arrow's outcome penetration OR, (3) the momentum increase produced by the increase in velocity did not result in the same *degree* of increase as shown when momentum is increased by increasing arrow mass - which implies that the impulse of force determines the penetration. The one certainty is that the increase in kinetic energy between these 'like arrows' DID NOT result in anything remotely resembling a proportional increase in tissue penetration.

The exponentially increasing penetration resistance of tissues as velocity increases comes from fluid dynamics, and is based on a fluid viscosity equaling that of water. Why is it applicable to tissues? The entire body is over 70% water. Blood is 83% water. Firm muscle is 70% water. Even the hardest of fresh bone is comprised of at least 22% water.

Some contend it is inappropriate to apply this fluids-dynamic to tissues, because tissues are not pure fluids. However, it is extremely difficult to account for the observable results, such as those shown above, unless the exponential increase in resistance in tissues does, indeed, exist.

Though not a 'perfect fluid', the body's response to penetration is certainly far more like a fluid than a solid. Most rifle hunters have experienced, or at least heard of, the absolute instantaneous death of an animal from a very poorly, remotely placed high-velocity rifle bullet. Such occurrences result from hydrostatic shock (also known as a "ballistic shock wave").

The high magnitude ballistic shock waves often observed in tissues is something even ballistic gel can't replicate. Ballistic gel shows the temporary cavitation caused by a high-velocity impact well, but replicates neither the magnitude nor transmission-distance of force that's shown in tissues. It is documented that real tissues are capable of *remotely transmitting* a force of sufficient magnitude to shatter bone. The ability to remotely transmit such an amount of force requires the hydraulic compression of a fluid.

Tissue's fluid-like constitution is merely *one* among the many reasons why you won't find arrow penetration into artificial substances, even ballistic gel, correlating well with the penetration shown into real tissues. I've tried ballistic gel, both alone and in combination with such things as fresh hide and bones. The results of arrow penetration testing into ballistic gel simply does not correspond to the results shown by test using fresh, in situ tissues.

Perhaps the very newest technology in 'artificial tissue simulation' would work *somewhat* better. That involves the imbedding of an anatomically accurate replicated skeleton of artificial bone into a ballistic gel matrix, which is then molded into a facsimile of the body's shape.

I've not tried this medium, and don't plan to. It is frighteningly expensive technology, and (apparently) is only valid for a single use, since disruption of the ballistic gel radically alters the level of resistance; affecting subsequent results. Apparently, from all I can find out, it still fails to replicate the remote transmission of the ballistic shock wave.

The very fact that this tissue-simulation technology has been developed, and is being used despite the enormous cost involved, reflects the great difficult laboratory researchers have encountered in validly replicating the ballistic results observed in real tissues. Since their main use is in trying to replicate human trauma, the researchers can't exactly use the real thing for testing, so cost becomes irrelevant in their quest for accurate results. If ballistic gel with some bones stuck into it, and then covered with a bit of fresh hide, gave accurate results, you could bet that they wouldn't be wasting research dollars on such a high-cost testing medium.

Reality vs. Fantasy

As was the case in the momentum comparison, penetration shown by the Extreme FOC arrows from the 82# bow <u>can not</u> be used to *directly* compare kinetic energy's effect against the shots from the other bows; for the same reasons. However, it is interesting to make the comparison without consideration of these arrow design differences. Why? Because that is *precisely* how kinetic energy, as a predictor of arrow penetration, is commonly applied - with total disregard for differences in the efficiency with which the arrow's force is applied.

For the 54# bow, the arrow's kinetic-energy to penetration ratio was 1.89:1. For the 'essentially equal' arrows traveling 16% faster from the 70# bow it was 2.16:1 – 14.3% greater. [Or, if you prefer to use the 'calculated penetration' for the 70# bow, the kinetic-energy to penetration ratio was 2.04:1 – still 7.9% greater.] For the higher-efficiency arrows from the 82# bow the impact kinetic-energy to penetration ratio is only 1.73:1 – and would be even lower, had the arrows not exceeded the limit of measurable penetration.

The arrows from the 54# bow used 9.3% more kinetic energy per inch of penetration than those from the 82# bow. Those from the 70# bow used 17.9% to 24.9% more (depending on whether the actual or calculated penetration is used). This is despite the arrows from the 82# bow having a higher impact velocity than those from either of the other bows – which increased tissue resistance. The 'high mileage' shown by the arrows from the 82# bow reflects the efficiency with which their higher mass and higher MA used the available force.

None of the Study's data supports the applicability of kinetic energy as a gauge of how well an arrow will penetrate tissues. In fact, it's very easy to construct a low-mass, fast arrow setup delivering 80 to 90+ foot-pounds of kinetic energy which will not consistently penetrate the entrance rib on a trophy-size buffalo bull.

All test arrows with a mass of 450 grain or less have been tested at velocities in excess of 300 fps (Range: 306 to 326 fps) and impact kinetic energy levels between 76.6 and 94.5 foot-pounds. Most of the shots were on large adult buffalo bulls, but some were on a trophy size bull.

For those shots on the trophy size bull, 75% of the lighter, faster arrows failed to penetrate the entrance rib. [Remember that "penetrate" requires passage of the entire broadhead through the rib.] Average penetration for these shots was 7.9". That's 14% to 25% less penetration than *either* of the two high-mass *normal FOC* arrows tested from the 54# longbow. It's roughly half the average penetration of the 54# longbow's Extreme FOC arrows.

Even when the shots on the 'large adult' bull are included, the lighter, faster arrows still averaged 16.6% less penetration that the Extreme FOC arrows from 54# bow showed on a trophy-size bull. All of the 54# longbow's arrows carried less than 28 foot-pounds of kinetic energy – less than 37% of the kinetic energy carried by *any* of the lighter, faster arrows.

It's true that none of these lighter, faster arrows had the same high MA broadheads as the arrows from the 54# longbow; but kinetic energy proponents don't consider that anyway. Would the lighter, faster arrows have been able to reliably penetrate the ribs with such a broadhead? That's hard to say. There's the heavy bone threshold to consider; and there are no high MA broadheads permitting arrow weights that low, so it can't be readily tested.

Nonetheless, it is interesting to compare the kinetic-energy to penetration ratio of all these light, fast arrows to that of the Extreme FOC arrows shown above; for the comparable shots - those on trophy bulls. Because there are several different light weight arrows involved, lets be generous and use only the very lowest impact kinetic energy carried by any of them; 76.6 foot-pounds. Using this *absolute minimum* kinetic energy carried by ANY of the light, fast arrow groups gives a kinetic-energy to penetration ration of 9.70 foot-pounds per inch of penetration (9.70:1).

This means that all of the light, fast arrows required *at least* a bit over five times as much kinetic energy per inch of penetration as the 54# bow's Extreme FOC arrows. Is the difference between the kinetic energy and the tissue penetration these arrow show a significant amount? Does it strongly suggest that tissue resistance is increasing exponentially as arrow velocity increases? I'd certainly say so. These outcomes are *really* difficult to explain using only the arrow's kinetic energy. Is it any surprise that an arrow's kinetic energy, as commonly applied, fails to be useful as a predictor of arrow penetration in tissues?

Kinetic Energy's Incongruity

The kinetic energy formula considers only the amount of energy, not *how the energy is used* (or is going to be used). That's the great fallacy of using kinetic energy as a predictor of arrow penetration; it ignores both the exponentially increasing tissue resistance and *how* the energy is, or will be used. It tells you only the amount of energy available; nothing more.

Using kinetic energy as a penetration predictor for arrows is precisely like telling you that you have 20 gallons of fuel available, and then telling you just how far you'll be able to drive with it … without asking you whether you're driving a moped or a top fuel dragster!

On the other hand, the *impulse of force* tells you how much 'work' is accomplished by the available energy when it's used by an individual tool (your arrow) for a particular task (the tissue(s) penetrated). Analogously, instead of telling you only how much fuel you have to use, it tells you can go about four miles on those 20 gallons of fuel if you deposit it into the tank of a top fuel dragster, or 2500 miles if you deposit it into the tank of a Moped.

Once you settle on how efficiently you're going to be using it you have some idea how far you can expect to travel on those 20 gallons of fuel. All you won't already know is what the 'workload' will be; exactly how steep a mountain you're going to have to climb! For our arrow, that will depend on the hit you make. [Hint: If you plan for the steepest grade out there you'll always find the lesser slopes easily ascended!]

Kinetic energy, as commonly applied, is useful as neither indicator nor predictor of an arrow's tissue penetration potential under real-world hunting conditions. Whether with the same bow and differing 'like-profile' arrows, or a different bow with a 'like arrow', the kinetic energy carried by the arrow does not permit you to compare expected terminal performance.

On the other hand; with a given bow, when an arrow's design is similar, and flight is of equal quality; *impact momentum* has *consistently demonstrated* a simple and direct, near one-to-one, proportional relationship with the average outcome-penetration in real tissues – at all distances. Though it won't give you an absolutely precise answer, it will give you an extremely close approximation. This is both useful and usable. It allows the average bowhunter to easily get a rough comparison of the relative penetration potential between two similar external-profile arrows when shot from his bow.

Even when comparing 'like arrows' impacting at differing velocities, so long as the differences are not extremely large, arrow impact momentum gives a *fairly close* approximation of the likely outcome penetration; one far more accurate than that given by comparing each arrow's impact kinetic energy.

The Fencepost Turtle

It is noteworthy that the Internally Footed Extreme FOC arrows from the 82# bow, with an impact kinetic energy of only 38.94 foot-pounds, provided exit wounds on 100% of their broadside, back of the shoulder shots on mature trophy-size buffalo bulls. Proponents of kinetic energy (as a determiner of penetration) maintain that 65 foot-pounds represents the *absolute minimum* adequate amount of kinetic energy for buffalo size animals. According to their 'minimum adequate' kinetic energy levels the 39 foot-pounds of kinetic energy the 82# longbow shows with these arrows isn't even adequate for hunting boars, elk or bear. I quote:

"Here is what is recommended as the *absolute minimum* levels of Kinetic Energy for a given animal. (Emphasis added.)

KE Hunting Usage

< 25 ft./lbs. Small Game

25-41 ft./lbs. Medium game (deer, antelope, etc.)

42-65 ft./lbs. Large Game (elk, black bear, wild boar, etc.)

> 65 ft./lbs. Toughest Game (Cape Buffalo, Grizzly, etc.)

This chart is for a fixed blade broadhead." – *www.texasoutdoorsman.com*

Following the above guidelines *all* the traditional bows used in the buffalo testing fall below the limit for "Large Game", the elk, black bear, wild boar, etcetera. Of all arrows discussed above, only the compound's light and fast arrows meet the 'absolute minimum' KE requirement for buffalo - indeed, they far exceed it. Nonetheless, the compound's light and fast arrows produced far poorer results against buffalo than the penetration enhanced arrows from any of the traditional bows tested. This is not to disparage the compound bow – which performs very well when used with an arrow that makes better use of the *force* derived from the bow's transferred energy.

Considering all of the above, why is it that one finds kinetic energy so widely recommended as the penetration-predicting guideline? Whenever you see a turtle atop a fencepost it's perfectly reasonable to suspect it had some help getting there.

I've actually seen a hunter spend over a thousand dollars to buy a new compound setup simply because it 'clocked' 4 fps faster than his old bow. Achieving high kinetic energy requires arrow speed; and speed sells. Convincing folks they *need* more speed - that it will make their hunting more successful - reaps substantial rewards. *Requiring* they have it (in order for their arrows to attain some purported 'minimum adequate' kinetic energy) would reap even more. I have absolutely nothing against arrow speed, but it is being consistently (and detrimentally) misrepresented as an indicator of terminal arrow performance in tissues.

The foregoing treatise has been a bit lengthy, but serves as an excellent example of the relationships between arrow kinetic energy, momentum and the penetration observed in real tissues. It has been the first opportunity to compare the tissue-penetration results of 'like arrows' with differing impact momentum as a result of velocity increase, as opposed to an increase in arrow mass. Hopefully there will be more.

Nothing presented here is likely to alter the opinion of the "true believer" in kinetic energy as a predictor of penetration, and it wasn't intended to. Its purpose has been to explain the results observed; examining which of the laws of physics fit the observed results, and which do not. The empirical results conform precisely to what the mechanics of the impulse of force predicts.

Other Extreme FOC Items of Interest

Several comments have been overheard suggesting that Extreme FOC arrows will 'nose dive' when shot, because of the forward weight. At least for distances significantly beyond my hunting range, this contention has not been apparent during testing. Within the 'zone' used as my limit for hunting shots, I can note no difference in arrow drop between normal and Extreme FOC arrows. At longer ranges, where my arrow's drop does become very noticeable, Extreme FOC arrows *appear* to shoot noticeably flatter than equal-mass arrows having normal FOC.

It is *conjectured* this *may* result from faster paradox recovery. The greater 'steering arm' Extreme FOC provides fletching may allow it to normalize flight more rapidly. That would result in less 'squandered' kinetic energy, leaving more 'useful energy' to be deposited into momentum's 'bank account'.

Extreme FOC's effect of lengthening the rear steering arm, which permits less fletching to be used while still exerting ample steerage, is precisely why FITA shooters use the highest amounts of arrow FOC of any target archers; it allows use of smaller fletching. Smaller fletching means both less arrow drag and less cross-wind effect. At the extreme distances Olympic-Style shooters compete that's very important.

Subjectively, with the 54# straight-end longbow, using the Extreme FOC arrows tested, I was able to 'point' directly at my intended target from 20 yards, allowing for no arrow drop. This is with 13.39 grains of arrow mass per pound of draw force, and from a relatively inefficient bow.

Unexpectedly flat trajectory with Extreme FOC arrows was also noted by both Tim Stone and I; while developing 'above the heavy bone threshold' matched-sets of normal and Extreme FOC test arrows for his 40#@27" recurve. That bow was a 'just in case' backup; should the 54# longbow also encounter the penetration barrier. If all goes as planned, this bow will be used for some 2008 testing. It should provide some insights into the heavy-bone breaching potential of a lower-poundage bow.

It would be interesting to see a side-by-side trajectory test of perfect-flying normal and Extreme FOC arrows having, otherwise, precisely matching dimensions; conducted at various ranges with a shooting machine.

Arrow Mass and the *Degree* of Gain from Extreme FOC

Why, in data presented in earlier Updates, did the 82# bow's lower-mass Extreme FOC arrows indicate a greater percentage gain in penetration than the higher-mass sets? Once again, the answer lies in understanding impulse of force. On any given hit, it is how well the arrow uses whatever force it has available which determines outcome-penetration.

Whether of normal or Extreme FOC, lower mass arrows have less 'useful force'. More of their momentum is represented by speed and less by arrow mass. Arrow velocity is rapidly shed during penetration, but the arrow's mass remains constant. Heavier arrows take longer to stop because their momentum – the 'useful force' they carry – is depleted more slowly. This results in a greater time of impulse.

The less total force (momentum) a given *normal FOC* arrow has available the more <u>*relative improvement*</u> a dimensionally-equal Extreme FOC arrow offers. Why? Because the 'unnecessary force-loss' Extreme FOC *prevents* by reducing shaft-flex represents a greater percentage of the total arrow force available. Therefore it also represents a greater percentage gain in outcome penetration.

The greater percentage of penetration-gain shown by lower mass Extreme FOC arrows does not mean they out-penetrate heavier Extreme FOC arrows carrying equal force. It merely means the lower-mass arrow gains a greater *degree* of benefit; not a greater *amount* of benefit. As arrow mass increases Extreme FOC's conserved-force represents a smaller portion of the 'useful force' the arrow has available.

Applying Extreme FOC

There is a clear relationship between arrow velocity, arrow mass and the arrow's net 'useful force'. *For any given bow*, comparison of arrows having 'like external-profile' and equal degrees of FOC and flight quality shows that increasing arrow velocity <u>*at the expense of arrow mass*</u> unfailingly results in a decrease in tissue penetration. This holds across the entire range of impact velocities tested, from 119 fps to 325 fps. This means that when you decrease arrow mass for a 'like arrow' in order to attain greater arrow speed you will always reduce the arrow's penetration potential.

However, when we compare normal FOC arrows against Extreme FOC arrows we are no longer comparing 'like arrows'. Extreme FOC arrows use their available energy much more efficiently, squandering less on resistance-producing shaft-flex and depositing more directly into penetration-producing momentum.

With a given bow, changing from a normal FOC arrow to an Extreme FOC arrow allows you to increase arrow speed to some degree, while maintaining penetration equaling or exceeding that of a significantly heavier normal FOC arrow. But there are cautions:

1) Extreme FOC has demonstrated no effect on the heavy bone threshold.

2) The penetration benefits of Extreme FOC *are predicated on achieving perfect bare shaft tuning*. Poorly tuned Extreme FOC arrows, stabilized in flight by large amounts of fletching, will not give you full benefit. With target or field points, a well tuned bare-shaft Extreme FOC arrow will shoot virtually as accurately as when fletched.

3) The most prudent use of Extreme FOC's penetration advantage is to simply change the distribution of your arrow's mass, converting them from normal to Extreme FOC. If the trajectory of your normal FOC arrow was sufficient to meet your needs then it should be sufficient with an Extreme FOC arrow of the same mass. If anything, they will fly slightly flatter than your normal FOC arrows did. What you'll gain is a huge boost in your arrow's terminal performance.

4) There is a lower limit of arrow mass where velocity's exponentially increasing tissue resistance will fully offset the penetration gains Extreme FOC offers. Go below that limit and the result will be a net-loss in penetration.

Bouncing around some *theoretical* calculations and assessing the results against what comparable empirical data I have available, it appears that the break even point *likely* occurs somewhere around a *very approximate* 20% reduction in arrow mass - assuming that: (a) the normal and Extreme FOC arrows have 'like external profiles', with equal broadhead MA, (b) they have equal quality of flight and, (c) that either the heavy bone threshold is not encountered or the reduced mass of the Extreme FOC arrow is still above 'threshold' value.

This calculated theoretical 20% figure appears to correlate well with the limited comparable test data. However, I must caution that there is *far* too little empirical data to confirm any solid conclusion. For the time being, if you are using Extreme FOC's penetration-advantage to permit greater arrow speed without sacrificing any of the penetration-potential of a heavier normal-FOC arrows of 'like-profile', I'd recommend that you confine your maximum reduction in arrow mass to something less than 20%.

This concludes current Extreme FOC data. Next, let's look at a couple of test areas where things just didn't work out well; some single-bevel test. The Study has made no prior attempts to test the effects of a single-bevel on broadheads having a concave blade profile or multiblade broadheads. The following represents the first attempts to do so.

Single-Bevel Testing: Concave Profiles and Three-Blades

Before going into specifics, there is a related item of interest. Tawkhaw Manufacturers (Big Five Broadheads), in South Africa, recently began marketing a line of modular (replaceable blade) broadheads having single-bevel carbon steel blades. They are available in three and four blade models, and weights of 125, 165 and 240 grains. In the 'product review' published in *Africa's Bowhunter* magazine, the manufacture states that testing by engineers at the South African Air Force showed that the single-bevel blades exhibit a 'flight effect'; i.e., they cause arrow rotation during flight, much as fletching does.

It was asserted that this additional stabilization at the arrow's front end (when, it is assumed, the direction of broadhead induced rotation matched the fletching-induced arrow rotation) provides additional stabilization during flight; giving the single-bevel Big Five broadheads more uniform accuracy than they show when fitted with double bevel blades.

What was so intriguing about this product review is that it came only days after Allan (Woody) Woodward, the manufacturer of Outback broadheads, contacted me to ask if I had notice any accuracy differences between single and double-bevel broadheads. Woody supplies his broadheads with a choice of either a single or double-bevel. He stated that several of his regular users, most of whom are compound shooters, reported they were routinely achieving tighter groups with the single-bevel version than with the, otherwise-matching, double-bevel version.

On the issue of accuracy I'm not much of a resource. My interest is in terminal performance; what happens from the time an arrow impacts tissues. If there is a difference in accuracy between single and double-beveled broadheads, I'm not nearly a good enough shot to notice … or to utilize the advantage.

The question of accuracy-difference has been passed along to some folks who have a shooting machine. It is hoped they will take a look at this issue. The only step I have taken along this line is to try some matching single-blade, single and double-bevel broadheads on bare shafts. There does *appear* to be a flight-effect imparted by the single-bevel. On bare-shafts, the single-bevel broadheads deviated in the same pattern; drifting left on each shot for right-hand single-bevels, and right for left-single-bevels. The matching double-bevel broadheads deviated in a random pattern, much as well-thrown a knuckle ball does. It would be easier to precisely compensate for a uniform deviation than for a random-pattern deviation; through arrow tuning. [A word of caution; if you wish to try bare-shafting broadheads, do so in a very safe area with a huge backstop. Many broadheads display spectacular amounts of wind-plane effect on bare shafts.]

For those interested, the product review appeared in *Volume 8;* either *Issue 4* or *5 of Africa's Bowhunter;* which would be the April or May 2007 issue (www.africasbowhunter.co.za). My attention was called to this particular issue because it contained an article by Cleve Cheney; "*What is TPI*"; that presented a summation of my Tissue Penetration Index, developed during the early 1990's.

As an aside, and as I responded in my letter to the editor, Study data still indicates the TPI is a useful predictor of tissue penetration <u>for arrows that are of moderate to high mass weight and having normal FOC</u> - the type arrow used during its development – but it is *not useful* for either light arrows at high velocity or the Extreme FOC arrows. The TPI significantly overestimates the penetration potential when applied to light, high velocity arrows and grossly underestimates the penetration potential shown by Extreme FOC arrows.

Testing a Single-Bevel Shark

Starting with a newly purchased supply of the largest Shark broadheads, the Safari (which weighed an average of 213 grains), each was modified. After regrinding some to a 25 degree *left* single bevel configuration, the balance were double-beveled; ground down and re-edged to the same weight. The same blade profile (rate of curve) was maintained as closely as possible. The finished weight of the modified Shark Safari's was 179 grains.

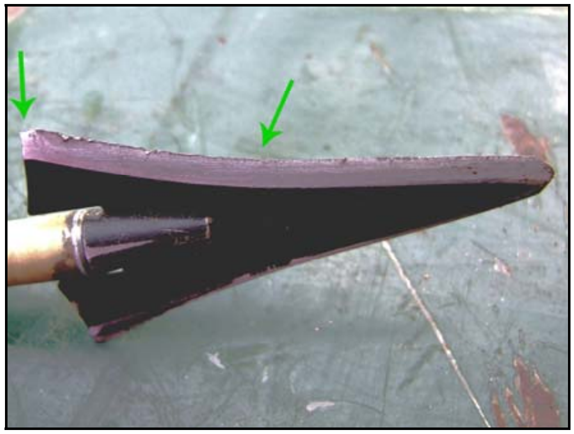
These modified broadheads were mounted on left-wing fletched Cabela's shafts with aluminum inserts. The shafts were internally weighted with two pieces of 2.7mm (0.105") weed-eater line for testing. Finished total mass was 732 grains, and FOC was 11.1%. Impact force on the shots was .473 Slug Ft/Second.

Only two shots were taken with the single-bevel Shark, using the 82# bow. Both were on a large buffalo bull. From broadside, both impacted back of the shoulder, giving rib-only bone impacts. There was a small shaft split on one shot, at the abutment of the aluminum insert. The shot managed to penetrate the rib, giving a penetration was 9.5". The second shot penetrated the rib, giving 13.5" penetration and a modest degree of second-lung hit.

Three broadside, similarly placed shots with the modified double-bevel Sharks were taken on the same animal. One shaft split at the insert-shaft abutment. It failed to penetrate the rib and gave 5" of penetration. One shot showed no shaft damage but also stopped in the on-side rib, giving 5.375" of penetration. The third shot penetrated the on-side rib, giving 11.625" of penetration, and a one-lung hit. This arrow was undamaged.

Additional testing of these modified broadheads on Extreme FOC arrows was planned, but testing was suspended after the first series. The single-bevel Sharks suffered severe edge damage on both hits. On each, the edge damage first appears at the point where the blade's upsweep commences and continues to the upsweep's termination. This represents the blade's area where a marked resistance spike would be encountered, as the blade's angle of attack to the tissues abruptly increases. The damage, and the area of its occurrence, is shown in the accompanying photo. Though outcomes are *suggestive* that a single bevel *might* be an advantage for concave profile blades, such edge damage rendered this particular broadhead's single-bevel ineffective for use during heavy bone impact. Harder steel is required.

It should be noted that broadhead MA has a marked effect on the level of peak resistance-force the entire arrow system will be subjected to. Higher MA means the broadhead can accomplish the same amount of work with less force; which also means the peak level of resistance-force encountered will be less. This places less stress on both the broadhead and the arrow system; ergo, higher MA means the broadhead/arrow-system does not *require* as much structural strength as it would with a broadhead having lower MA.



Area of severely rolled-edge along the single-beveled Shark's 'upsweep' (arrows). Note direction of roll; opposite that of bevel-induced rotation.

Testing a Single-Bevel Snuffer

An attempt to evaluate the effects of a single bevel on a three-blade broadhead was made by modifying some Snuffer broadheads. The process was the same as for the Sharks, ending up with matching single and double-bevel Snuffers as close to identical as possible, excepting only the type of bevel.

For testing, these were mounted on Purple Heart shafts, giving a total mass of 938 grains and FOC of 6.5%. Impact force was .537 Slug-Ft/Second. Only two test shots were taken with the single-bevel Sharks. Both were from broadside, with back of the shoulder rib-bone impacts, on a large buffalo bull. One shot stopped with the broadhead stuck in the rib, giving 5.75" of penetration. One penetrated the rib, giving 8.75" of penetration. On both shots, there was collapse of one of the three blades (presumably, the weakest of the three) along the area of the blade's vent. It was surmised that, in order to remove the original double bevel and regrind a single bevel, so much metal had to be removed from the blades that it fatally weakened them.

Collapsed blade on single-bevel Snuffer

Only a single shot was taken with the matching double beveled Snuffer. The shot had a shoulder impact, missing the shoulder bones. It stopped against the on-side rib, without entering the bone. Overall penetration was 8", with broadhead and shaft undamaged.

Testing of this particular single-bevel variation was terminated because of the repeat blade collapses. No valid comparisons can be made, due to the structural-failures.

Starting with the next Update we'll look at more broadhead testing, beginning with a most perplexing outcome.