Prologue to the 2007 Updates

Understanding FOC

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In the aftermath of the last series of Study Updates many questions were received regarding arrow FOC. There's no doubt significant interest in FOC exist, as well as much confusion. What is FOC; what does FOC do; how much FOC is needed; how and why does FOC affect tissue penetration; and what method of measuring FOC is “correct”? Questions regarding the FOC testing have become too numerous to answer individually. About here, I must point out that I'm far from a definitive source on the precise technicalities of FOC aerodynamics – but I have learned a bit about what it is and what it does to arrow flight and, as you'll see in the upcoming Updates, *a lot* about how, why and how-much it affects a hunting arrow's penetration in tissues.

Hopefully this prologue will provide sufficient introduction to FOC to assist those interested in understanding the upcoming Update information. Extreme FOC has turned out to be one of the most important penetration factors; one substantially affecting the amount of tissue penetration your hunting arrow can achieve. The first two 2007 Updates address areas not directly related to FOC, but from Part 3 onward understanding what FOC is, and how it works, becomes important. You may find it helpful to reread this prologue at that point.

Though earlier testing had indicated Extreme FOC was very important, the exact degree of that effect could not be quantified because of the measurement constraints of the off-side rib penetration-barrier and the limits of measurable penetration. In the more recent testing a bow of lesser draw weight was employed. I was prepared for FOC test results to show a marked penetration benefit, but I was not prepared for the profound implications they would have, especially for those using lighter draw-weight bows for their hunting.

Though the Study's definitions for the different degrees of FOC have been stated previously, I'll reiterate them. "Normal FOC" is defined as any amount up to 12%. From 12% to 19% is Study-defined as "High FOC". FOC from 19% upwards is defined as "Extreme FOC".

Now let's set the stage for the new Updates by taking a look at what FOC is all about.

FOC Doesn't Mean the Same Thing to Everyone

What Does FOC stand for? It's an abbreviation for “Forward of Center”, but archers commonly use it as a total replacement for the entire phrase “weight forward of center”.

What does weight forward of center mean? The routinely encountered answer among archers is: FOC represents how far forward an arrow’s balance point is from the midpoint of the shaft … or the mid-point of the arrow's total length; and we'll discuss that definition-difference a bit later. In archery, FOC is specified as a ratio of the location of the arrow's balance-point to the shaft's (or arrow's) mid-point, expressed as a percentage.

The above definition is sufficiently correct for the common uses archers apply FOC to. However, for the discussions that follow we also need to state the true, precise definition of FOC: *For projectiles in flight, FOC represents what percent a projectile's gravitational balance point is forward of the projectile's <u>center of pressure (CP)</u>*.

What the heck is the CP? The CP is that exact point where the maximum 'bending force' is exerted upon a projectile during its flight. Note that this true FOC definition relates only *to a projectile in flight,* and expresses a relationship between the gravitational balance point and the resultant *<u>center of pressure</u>* of *<u>all forces</u>* acting on the projectile as it flies through any given medium. Also note that there's no mention of any projectile 'length' in this definition. Additionally, keep in mind that your arrow is still 'flying' during penetration; all that's changed is the density of the medium(s) it's 'flying through'.

The CP of an object in flight is *<u>dynamic</u>*, and is constantly changing as propulsion forces, resistance forces and forces exerted by moving air currents change. For convenience, the 'practical purpose' formula(s) we archers use merely *<u>assumes</u>* the CP to be at the shaft's (or arrow's) mid-point. Why we do that is coming up shortly.

Note very carefully that the CP (and the genuine amount of FOC) does not - in any manner whatsoever - reflect the point of greatest projectile flex. It indicates the point upon which the greatest *flexional force* is exerted, not the point of greatest flex. The point of greatest flex depends not only upon the forces encountered in flight (and launch) but also on the projectile's structural design and the material(s) from which the projectile is made.

The design (profile) of your arrow shaft and the material it's made from affects both CP location *and* where the shaft will flex most; which *are not* necessarily the same point. For example, take two cedar shafts of equal mass and stiffness; one parallel and one tapered. Mount identical points on each and each will show a different CP and a different point of maximum-flex when shot from the same bow.

Similarly, shafts having identical profiles can be made of different materials. When shot by that same shooter from that same bow, each will again show a different CP and point of maximum-flex; and this is most pronounced during launch and while the arrow is in paradox. During launch and paradox the flexional characteristics of the material becomes a major factor in the location of the arrow's CP and point of maximum flex at any given instant; as do several other influencing factors, like the amount of your bow's center-shot and the quality of your release. For a given bow and shooter, the design of the arrow and material(s) its made from determines both the arrow's CP *and* where, and to what degree, the arrow shaft flexes during the shot-sequence and ensuing flight … *and also during impact and penetration*.

Is precise FOC measurement critical? Well, yes; if you're trying to calculate a trajectory to guide a missile to a pinpoint target from 2000 miles away, or design an F22 Raptor that can change directions on a dime and darned near fly laterally! For archers, no, precise measurement is not all that critical. All we require is a *relative reference point*. However, in order to understand Extreme FOC's affects on both arrow flight and arrow penetration you do need to know and understand that an arrow's true FOC is not the same as the 'relative FOC' archers normally discuss; and you need to know what the difference between the two is.

Why do we need a FOC reference point? What does it do for us? Think of FOC as indicating the arrow’s fulcrum point; the point around which it rotates up, down, left, right or obliquely when a force is applied on either end of the arrow. The further forward the fulcrum point is, the longer the fletching's fulcrum arm (lever). Note that this represents the '*rearward* lever arm'. There's also a forward lever arm, and we'll talk more about it shortly - because it's the one that's most important from time of arrow impact onwards.

The most important concept for you to understand is that, as with any lever system, the longer one lever arm is in relation to the other, the less pressure you have to apply on the 'long arm' to exert a given amount of force - or cause a given amount of movement - at the short-arm end. Conversely, it takes more pressure on the short arm's end to generate either a given amount of force or movement at the long arm's end.

The longer the rear lever arm, the more pressure a given amount of fletching can exert on your arrow; increasing fletching's control (its degree of stabilizing effect). You can also think of this the other way around; the longer the rear lever-arm, the less fletching you need to exert a given amount of stabilizing force on your arrow. The bottom line is the same: Having higher FOC makes fletching’s job easier, and results in greater stability during flight with any given amount of fletching.

Don't confuse the point of lateral, vertical and oblique rotation with the rotational rate of your arrow; they're two distinctly different things. You can change the point of lateral, vertical and oblique rotation without affecting the rate the arrow revolves around its lengthwise axis during flight. Changing FOC won't alter how fast your arrow revolves as if flies downrange.

Using archery's 'common definition' for FOC gives us an easy way to 'rank' the amount of fletching's rear-leaver. If, for any reason, you wish or need to alter your arrow's steering arm, FOC provided a *reference point* telling you 'where you are', 'which direction you're going', and 'how much change you've made'. For eons this has been the major application to which arrow FOC has been applied. To understand FOC's effect on arrow penetration requires we expand how we think of FOC, but there's more to discuss before we get to that.

What's the “correct way" to measure my arrow's FOC? The AMO Standard FOC measurement uses shaft-length; ignoring insert, taper and tip (broadhead) length. The other commonly used formula employs the arrow's overall length; including the insert, taper and tip. Which is “correct”? Neither. *True* FOC is based on the center of pressure. We merely *simulate* the CP location in both formulas. The AMO formula was adopted as 'standard' merely because, between the two commonly used formulas it uses a *simulation point* nearer the actual CP location for *most commonly used target arrows* during flight through air.

Just as it is with static spine, the FOC 'number' we use is definitive of *absolutely nothing* about our arrow's flight. The commonly used static spine and FOC 'numbers' merely allow us to make a *relative* comparison of one arrow to another; nothing more. For example, static spine measures *relative stiffness* of a shaft; how much it flexes when a weight of *specified* mass is suspended mid-way between two shaft-supporting points; which are located a *specified* distance apart. Everything about the measurement is *relative*, not *absolute*.

Static spine tells you nothing at all about an arrow’s dynamic spine – how it will react when *you* shoot it off *your* individual bow. If you doubt that, perfectly tune an arrow from a true center-shot bow and then measure its static spine on your spine tester. Now take that same arrow and shoot it from a non-center-shot bow (one with a peg rest – no arrow shelf at all) of equal draw weight. What happens? The arrow will shoot massively strong-spine. The arrow hasn't changed; the launch-force and power stroke are the same; and the shaft's static spine hasn't changed. However, the shaft's dynamic spine is now no longer anywhere close to correct, and it no longer shoots where you're aiming.

All static-spine indicates is the *relative stiffness* of the shaft. What it *does* do is provide you a *reference point.* This helps whenever you need to find a stiffer or softer spine in order to get *your* arrow to shoot well from *your* bow. This is *all* it does; nothing else. It merely allows you to compare shafts *relative to each other*, so you can tell which one is 'stiffer' and which one is 'weaker'. Static spine's 'relativity' is precisely why it's necessary to tune *your* arrow to *your* bow in order to get correct arrow flight.

No static measurement or calculation contends with the myriad variables encountered when you shoot an arrow from your bow. This is why, besides charts, Easton publishes 35 instructional pages on selecting 'the right arrow' *after you've used their 'static-spine' charts to find a 'starting place'*. No chart provides a magic number saying, “Pick me. I’m the right one!”

Commonly used FOC measurements are exactly the same; they are *relative*. Neither formula is “correct”, nor is either “wrong”. Each serves its purpose equally well; providing a reference point. As long as you know which formula was applied to a given arrow to determine its 'relative FOC', you can duplicate results. If you prefer, you can re-measure and state the arrow's FOC in the other format; that’s perfectly alright. It still provides you a 'relative reference'.

For practical applications, either commonly used FOC formula works equally well. Just remain aware that neither genuinely tells you anything at all that's 'precise' about an arrow's true FOC. However, for a given arrow design, when our 'commonly measured' FOC goes up the true FOC also goes up; but the amount we've 'measured' won't indicate the *actual amount of change in true FOC*. The single most important thing to remember is that the 'relative measurement' method you use should always be stated, so everyone is “reading off the same page” when making comparisons, or trying to duplicate results.

How much FOC does my arrow need to have? The range of FOC *classically recommended* for different forms of archery varies. In their charts Easton shows the following recommended FOC guidelines; which have been around for many, many years. The calculations are based on the AMO Standard formula:

o	FITA (Olympic Style) Archery	11% to 16%
o	3-D Archery	6% to 12%
o	Field Archery	10% to 15%
o	Hunting	10% to 15%

FITA shooters, who compete at the longest ranges, use the highest average amount of FOC; 3-D shooters the lowest; with field archers and hunters in-between.

Why do FITA shooters prefer a higher amount of FOC than most other target archers? They are seeking precision long range accuracy. To obtain this their arrows must be very stable in flight. High FOC allows them to achieve the level of stabilization they require from relative smaller fletching. Smaller fletching offers a lower drag factor, and is less subject to the effects of cross-winds than larger fletching. These factors all become important at the extreme ranges at which FITA shooters compete.

It's also relevant to note how FOC affects an airplane's 'handling'. An airplane with high FOC flies very stable; the lower the FOC, the more maneuverable the plane, but the harder it is to control. Indeed, as a plane's FOC gets very low (such as that of the F22) it becomes incredibly maneuverable, but so difficult to control that no pilot can fly it without computer assistance.

Now relate FOC effects on an airplane's handling to your arrow. You want your hunting arrow to be as stable as possible in flight. High mobility; easily achieved changes in direction of flight; is precisely what you *don't want* in your arrows. This implies that you want as much 'true FOC' as possible; within the limits allowed by design and materials.

If high FOC is desirable why are the recommended amounts of arrow FOC not simply "as much as you can get"? FOC measurements have been around in archery a long, long time and, as noted, their major application has been in determining how much fletching you're required to have in order to get adequate arrow stability in flight. There is much historical precedence for this application. However, those historic precedents were limited by the amount of FOC easily achievable *with the materials commonly available*. The availability of carbon shafting, in particular, has created an abundance of new possibilities. Carbon behaves differently than other shaft materials.

Carbon shafts offer great stiffness at low mass, with forgiving flexional characteristics. They permit unprecedented amounts of FOC, with exceptional flight; and it's easily achieved. Possibilities in arrow design have changed, and the 'common knowledge' rules aren't nearly as simple or clear-cut as they once were; but 'common knowledge' dies harder than a frog in mud.

What's the lowest FOC usable? It's possible to use arrows with slight amounts of negative FOC, and some flight shooters use these. Negative FOC can be made to work whenever drag force is sufficient to prevent the arrow swapping-ends in flight, but the flight of such arrows is very sensitive to all factors affecting their flight; just like that F22, they are 'highly maneuverable'.

Currently, most flight shooters still lean towards use of neutral to very low amounts of FOC. They feel low FOC arrows maintain a 'nose up' attitude longer, providing longer flight; but contrast this with the staggering number of flight records that are currently being systematically demolished by O. L. and Juli Adcock using very high FOC flight arrows. The 'common knowledge' concepts of flight arrow FOC, which have also existed for many, many decades, are being very successfully dismantled.

A hands-on look at flight shooting also provides some interesting insights into FOC's characteristics. Go to any flight shoot and watch what's happening. You'll see an extreme dispersion of impact (distance wise) among the shooters using very low or negative FOC arrows. This is often as much as sixty to a hundred yards, from shot to shot. Compare that with the consistency of distance the shooters using high FOC flight arrows are getting, shooting under the same conditions. Their arrows will be tightly nestled, often within a ten yard spread … and they're smashing existing distance records with that same degree of consistency!

For those who content that arrows with high amounts of FOC 'nose over' faster, and show more drop than matching arrows having 'normal' amounts of FOC, there are a few points about these clearly observable distance and consistency 'outcomes' worth pondering. If Extreme FOC arrows 'drop faster', why are they shooting farther than the neutral and low FOC arrows?

My experience has been that the Extreme FOC test arrows *appear* to shoot somewhat flatter than the precisely matching mass and profile normal FOC arrows I've set up for comparison penetration testing; at least across distances that are more that double that of my self-imposed animal-shooting distance. This, *I think*, is because the Extreme FOC arrows are recovering from paradox faster; conserving arrow energy otherwise wasted during paradox - which also means they are flying-straight sooner, dropping arrow-drag to its 'normal level' faster and conserving even more arrow energy.

FOC and the Hunting Arrow

What does all this have to do with hunting arrows? At the very minimum hunters need a fair amount of arrow FOC; higher than that *required* to reach the minimum level of stability needed to achieve constant flight from any target arrow. Why? Because broadheads exert a steering effect upon the arrow, due to wind-shear. Fletching must overcome these 'wind-plane' forces. If you want to see how substantial a broadhead's wind-sheer effect is, try a few bare-shaft shots with broadheads; but do so in a very safe area, and with a HUGE backstop! Your hunting arrow's fletching has a lot of 'deviating forces' to overcome, and high amounts of FOC means fletching has a longer 'lever', giving it more steering control; a very desirable hunting arrow feature.

You should also consider that the shorter the arrow you shoot, the higher the FOC of your hunting arrow should be – or the greater the surface-area of fletching you'll need. Shorter arrows are inherently less stable in flight than longer arrows, simply because of their physically shorter rear 'steering arm'. With any given amount of FOC and fletching, the greater rear lever of longer arrows allows the fletching to exert more pressure. A finger release also adds to arrow instability, especially in initial flight. Here too high FOC is beneficial (as is 'more fletching'); and it becomes of greater importance the shorter your arrow is.

OK, so FOC's longer lever arm allows fletching to exert more stabilizing effect, but what led to FOC's inclusion as a tissue penetration factor? Many folks hunting with Extreme FOC arrows reported conspicuous penetration increases, and this deserved formal evaluation. Extreme FOC was added as a factor for evaluation to see if it really did have any effect on tissue penetration and, if so, how great an influence it showed. Field test have confirmed the reports. Extreme FOC arrows do show *significantly greater* tissue penetration, when all else is equal. The frequency, consistency and magnitude of test results are far too extensive for one to conclude otherwise.

Why do Extreme FOC arrows give more tissue penetration? They encounter lower resistance. The reduced resistance results from less shaft-flex on impact. Prior testing has shown shaft flex increases shaft-drag, and shaft-drag has been shown to be a *major* resistance factor influencing tissue penetration.

How do Extreme FOC arrows achieve this reduction in shaft flex? Shaft flex is related to CP location, relative to the arrow’s center of mass. Extreme FOC means your arrow now has a very short *forward* lever arm. The shorter this lever arm, the less the shaft flexes when any given level of resistance force is applied at the arrow’s tip.

Now let's look at exactly how FOC achieves its effect on hunting arrow penetration. High arrow FOC has at least two characteristics which greatly reduce the amount of shaft flex on impact. These are:

(1) Less arrow mass is towards the rear, reducing the force with which the arrow’s rear 'pushes' on the shaft.

To see this clearly, take a slender shaft and securely glue a brick to one end; with a big glob of something like JB Weld. Now place the other end of the shaft (the one without the brick) on the floor. Unless you keep the shaft absolutely perpendicular to the floor, the shaft flexes.

Next, bump the shaft against the floor. Even when it is held perpendicular to the floor the shaft flexes at impact. The collision forces are *required* to go somewhere. The resultant force-vectors between floor-impact and the 'push' exerted by whatever mass (weight) is at the shaft's rear must either compress the shaft linearly or be redirected, causing shaft-flex. Shafts don't show much linear compression. On forceful frontal impacts they crack, split or break before compressing any significant amount.

Now reverse the shaft, placing the brick on the floor. The shaft does not flex. Bump it up and down as forcefully as you like. Shaft flex is scarcely visible, regardless of how hard the impact. This is a drastic example of one effect high FOC has on shaft-flex during direct impact, and clearly demonstrates what happens.

(2) Extreme FOC arrows concentrate arrow mass far forward. The *forward* lever arm is short. This means the dynamic center of pressure at impact is also far forward. This is important on all impacts, and becomes especially important whenever your arrow's impact is at any angle other than perpendicular.

To understand how this short forward lever affects shaft-flex, think of the distance from arrow tip to CP as being a short section of shaft; the shorter the section, the stiffer the shaft. The stiffer it is, the less it flexes.

To observe this effect, let's use the same slender shaft and brick. Hold the shaft near mid-point and turn it so that the shaft is not vertical. Note the amount the shaft bends. Without changing the angle at which the shaft is held, shorten the 'forward lever' by holding the shaft closer to the brick. This moves the CP closer to the front; where the greatest mass is located. The shaft flexes less. The closer you move your hand to the brick, the less the brick’s 'given force' flexes the shaft.

We all know that a shaft becomes stiffer as it gets shorter, but why? It gets 'stiffer' simply because we've moved the center of pressure closer to the center of mass. Where's the major force exerted on our hunting arrow during impact and penetration? It's located between the point of resistance (our broadhead) and the position of the arrow's center of mass. The further forward that mass, the shorter the shaft section between the two.

The shorter your arrow's forward lever arm, the less shaft flex you'll have on any impact. This means less of your arrow's force is used up needlessly in flexing the shaft *and* the reduced shaft vibration also lowers resistance as the shaft passes through the tissues. Both of these factors conserve arrow force, providing more 'useful' arrow force (momentum) that can be applied to arrow penetration.

Another, and perhaps simpler, way to visualize this effect is to lay a piece of string on a table and stretch it out straight. Put your finger somewhere near the middle of the string. The string represents your arrow shaft and your finger represents the arrow's center of mass. Now try *pushing* the string. What happens? The portion of string that's forward of your finger 'bends'; it flexes. Why? Because the 'stiffness' of the string forward of your finger is not sufficient to overcome the resistance between the string and resistance force; in this case, the string's friction against table's surface.

Next, move your finger 'forward', placing it very near - but not immediately at - the end of the string. Again push the string. Now the string's 'forward lever' is shorter, and the string 'bends' a lesser amount.

Now put your finger at the string's very front end and move the string forward. What happens? The string follows quietly along behind the 'center of mass' that's now pulling it. By placing your finger on the very front of the string you've reduced the forward lever arm to zero, and there's no 'shaft flex' at all. The only difference between the string's flexion and that the shaft of your hunting arrow will show on impact - and during penetration - is the *degree* of flex.

Having high amounts of arrow FOC has other advantages for the bowhunter too. When all else is equal, it means faster recovery from paradox. That, in turn, means the arrow is 'flying straight' in a shorter time; closer to its departure from the bow. On close-range shots this means less shaft-flex at impact, and more penetration. The affect of paradox on arrow penetration is easy to see. All you need to do is shoot a few arrows into your broadhead target at very close range and compare the penetration to that they show at a somewhat longer range. The greater the arrow's paradox at impact the less the penetration, and difference can be huge!

Do you remember what was said earlier; that it takes more pressure on the end of the fulcrum's short arm to generate any given amount of force or movement at the end of the fulcrum's long-arm? This means that the higher your arrow's FOC the less affected it is by your broadhead's wind-sheer effect. That makes getting perfect flight with broadheads easier because, regardless of the broadhead's shape, the effect of whatever sheer effect it exhibits is now lessened in degree. It's harder for the broadhead to steer the arrow's rear end.

Another closely related advantage is, just as for the FITA shooters, having very high amounts of arrow FOC means a longer steering arm for the fletching. For the hunter, this means he can use less fletching to stabilize his broadhead tipped arrow equally well; *with any given broadhead*. Less fletching means less drag as the arrow flies downrange. This means a bit more retained force (momentum) at impact.

Having less fletching on your hunting arrow also means less crosswind effect on the arrow; just as it does for the FITA shooters. That's *sometimes* important when hunting windy, open-country. If you've hunted much in eastern Wyoming, North Dakota, West Texas or the artic tundra, you'll KNOW exactly what I mean!

Less fletching also means a slight reduction in arrow noise during flight; but I doubt it is significant. Fletching shape has much more effect on arrow noise than does its surface area. (As an aside, I worked on American Indian Reservations for eleven years. A centenarian Sioux once told me that owl feathers made arrows fly quieter than any other feather and were always the preferred choice for deer and elk arrows. I've never had a chance to check that out!)

The effects of Extreme FOC on arrow penetration represent the major portion of the Study Updates which follow. Though this prologue doesn't come close to covering everything about FOC, it is hoped the forgoing will help clarify FOC; how it is used and some of the major benefits it offers the bowhunter. I fervently hope it will help the reader understand the 'why' behind many of the test results; and I think most will be surprised by just how important Extreme FOC's penetration effects can be for bowhunters.

For those interested, here’s the AMO Standard Formula for measuring an arrow's *relative* FOC:

(1) Measure shaft length; bottom of the nock's throat to the most rearward portion of the broadhead taper.

(2) With tip mounted, determine the balance point by balancing the arrow on a knife edge. Mark this balance point.

(3) Measure balance point distance; from the bottom of the knock's throat to the balance point.

(4) Divide balance point distance by shaft length. This gives the decimal equivalent of the balance point's percentage relative to shaft length.

(5) From this quotient subtract 0.50, the decimal equivalent of 50%.

(6) Convert the resultant decimal fraction to percent by multiplying by 100 (or simply moving the decimal point two places to the right). This gives the percent FOC.

In formula format:

$$\%FOC = \left(\left(\frac{\text{Dist. knock throat to Balance Point}}{\text{Shaft Length}}\right) \text{minus } 0.50\right) \text{X } 100$$

If you wish to use the alternate common method for measuring your arrow's *relative FOC*, merely substitute total arrow length for shaft length. The answer will be different; but the arrow will still be the same! If, however, you wish to compare the FOC of your arrows to those in the *Arrow Lethality Study Updates* you'll need to use the AMO Standard formula – merely because that's the one I used to get the 'relative measurements' shown.

As is the case with most arrow design factors, the measurement methods we all use are nothing more than 'numbers'. They are relative values having little real meaning other than when comparing one arrow to another. It's all part of the language of archery. Just so long as you know which definition from 'archery's dictionary' is being used, all will work out well!