Understanding FoC

By Dr. Ed Ashby
with David Petersen

Given the relatively recent popularization and use of the term FoC, it's natural to see some misunderstanding among bowhunters regarding just what arrow FoC is, how it works and how it's measured. In the following, necessarily superficial discussion, I hope to clarify these points and more.

The acronym FoC stands for "weight forward of center," and refers to the distance forward of an arrow's measured linear midpoint where gravitational balance occurs. Normal FoC is defined as up to 12% forward balance. From 13% to 19% is high FoC, while 20% upwards is extreme FoC.

And here's the meat of the entire matter as it relates to bowhunting: Extreme FoC (EFoC) is among the most important penetration factors thus revealed in my decades of arrow lethality research ("the Study"), substantially affecting the amount of tissue penetration a hunting arrow can achieve. While I was prepared for the FoC test results to show increasing penetration benefits as the balance point was moved forward, I was unprepared for the *profound* implications the results revealed, especially for those using lighter draw-weight hunting bows.

Sidebar 1

The AMO Standard Formula for measuring relative FoC

1. Measure shaft length from the bottom of the nock's throat to the back of the head.
2. With head mounted on shaft, determine the balance point by balancing the arrow on a knife edge. Mark this point.
3. Measure balance point distance from the bottom of the nock'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 a percentage by multiplying by 100 (or simply moving the decimal point two places to the right) to arrive at the percent of FoC.

Or … for the less mathematically inclined like my friend Elkheart, simply use the "FoC for Dummies" chart provided in Sidebar 2.

How is "weight forward of center" determined?

The standard AMO formula for calculating FoC is detailed in Sidebar 1. Additionally, an "FoC for Dummies" calculation chart is provided in Sidebar 2. Since FoC is a relative measurement, it's perfectly legitimate to do the calculations based on the midpoint of an arrow's *total* length, head included. Yet for purposes of the Study and this article I use the more common method of measuring the midpoint of the *shaft* only, from bottom of nock to back of ferrule. Rather than an absolute measurement, FoC is expressed *relatively*, as a percentage ratio of the location of the shaft or arrow's weight balance point forward of its measured mid-point.

Without getting into cumbersome detail, be aware that FoC numbers merely allow us to make relative comparisons between arrow set-ups, nothing more. By way of analogy, static spine measures the relative stiffness of a shaft: how much it flexes when a specified weight is suspended midway between two supporting points located a specified distance apart (commonly 28"). Everything about spine measurement is *relative*; nothing is *absolute*. Commonly used FoC measurements are also *relative*. Thus, for practical applications, either of the two commonly used FoC formulas (shaft length or full arrow length) works so long as the method you choose to use is stated, so that everyone is measuring the same thing when making comparisons or trying to duplicate your results.

Why do we need to know an arrow's FoC? How can it benefit us?

High FoC benefits the hunting archer in two distinct ways: enhanced accuracy and increased penetration. Let's look at accuracy first.

Think of FoC as indicating an arrow's fulcrum point — that is, the point around which, if pinned there precisely, an arrow will rotate up, down, left, right or obliquely when a force is applied on either end — then return to neutral balance when the force is removed. The farther forward the fulcrum point is located on a shaft, the longer the rearward fulcrum or lever arm. There's also a *forward* lever arm, of course, and we'll talk more about it shortly, as it becomes critically important from the time of arrow impact onward.

The necessary concept to understand at this point is that the longer one lever arm is in relation to the other, the less pressure you have to apply on the longer arm to exert a given amount of force or cause a given amount of movement at the opposite, short-arm end. Conversely, it takes more pressure on the short-arm end to generate a given amount of force or movement at the longer arm's end.

For example, think of a big kid

named, A, and a smaller kid named B, sitting on opposite ends of a teeter-totter. The closer the bar supporting the board is moved toward big kid A, effectively shortening his lever arm, the longer becomes little kid B's fulcrum arm and, consequently, the easier it becomes for little B to lift big A off the ground. In archery terms, the longer the rear lever arm of an arrow, the more pressure a given amount of fletching exerts on the arrow's flight, enhancing stabilization. A useful corollary is that the longer the rear lever-arm of an arrow (that is, the higher the FoC), the less fletching is required to exert a given amount of stabilizing force.

In sum, a higher FoC makes the fletching's job easier, resulting in greater stability during flight for a given surface area of feathers.

How much FoC does an arrow need to have?

That depends on the purpose for which the arrow is being set up. The range of FoC traditionally recommended varies for different forms of archery. In its charts, Easton shows the following FoC guidelines, which have been around for many years, with calculations based on the AMO Standard formula:

3-D archery 6% to 12%
Field archery 10% to 15%
Hunting 10% to 15%
FITA (Olympic style) archery 11% to 16% FoC

Why do FITA shooters need a higher amount of FoC than hunters and other target archers? Because they are seeking *long-range* accuracy. To obtain this, FITA arrows must be exceptionally stable in flight. As mentioned, a distinct advantage of higher FoC is that it provides the level of stabilization required from relatively smaller fletching. Smaller fletching, in turn, offers less drag and is less subject to the effects of crosswinds than larger fletching. These details all become significant at the extreme ranges at which FITA shooters compete.

By way of analogy, consider how FoC affects an airplane's handling. An airplane with high FoC demonstrates high stability in flight. By lowering FoC (that is, moving the weight distribution rearward), the plane becomes increasingly maneuverable — but at the cost of becoming less stable and more difficult to control. This principle becomes even more important with arrows, where maneuverability counts for nothing and stability in flight is essential.

FoC balance measurements have been around in archery for a long time, although until recently their major or only application was in determining the amount of fletching required to achieve adequate arrow stability in flight. There is much historical precedence for this application. However, those historic precedents, including the relatively low FoC values recommended for hunting arrows in the Easton chart, were limited by the amount of FoC easily achievable with arrow materials commonly available at the time. While EFoC *can* be achieved with wood and aluminum shafting, the recent advent of carbon shafting creates an abundance of new possibilities insofar as carbon offers greater stiffness at lower mass and more forgiving flexional characteristics. Consequently, carbon shafting permits unprecedented amounts of FoC and exceptional flight, easily achieved.

Hunting arrows need an amount of FoC notably higher than what's required to achieve stable flight in target arrows. Why? Because a broadhead exerts a steering effect on an arrow in flight, via wind-shear (think of little wings). Fletching must overcome these wind-plane forces. If you want to see how substantial a broadhead's "steering" force is, try a few bare-shaft shots with broadheads — but do so in a safe area with a *huge* backstop! In general, the larger a broadhead, the greater its "wing" influence on arrow flight. Consequently, a hunting arrow's fletching has a lot more work to do than a target arrow's. This presents two basic choices: (1) increase the surface area of fletching, or (b) increase the FoC.

We should also note that the shorter a hunting arrow, the higher its FoC will need to be (or the greater the surface-area of fletching) in order to assure stability in flight. Shorter arrows are inherently less stable in flight than longer arrows because of the shorter rear steering/lever/fulcrum arm. With a given amount of FoC and fletching, the greater rear lever arm of longer arrows allows the fletching to exert more pressure. A finger release also adds to arrow instability, especially in initial flight, adding even more need for high FoC with shorter arrows.

How does high FoC work to increase tissue penetration?

At some point in the past, I noticed that a number of archers who had gone to extreme FoC arrows for flight stability were reporting impressive penetration increases as well. Consequently, I added FoC as a factor for evaluation in the Study, to see if it really did have any effect on tissue penetration. Subsequently, the Study has confirmed those early anecdotal reports, in spades. Extreme FoC arrows show *significantly* greater tissue penetration, all else being equal. This is so in large part because EFoC arrows encounter lower resistance due to less shaft-flex on impact. Shaft flex increases shaft drag, and shaft drag is a *major* resistance factor influencing tissue penetration.

Extreme FoC, as we have seen, means an arrow has a short forward lever arm. And the shorter the forward lever arm, the less a shaft flexes when a

Forward of Center (FoC) Chart

By Dr. Ed. Ashby

Inches the balance point is located forward of the shaft's center

	Shaft Overall Length												
	28.0	**28.5**	**29.0**	**29.5**	**30.0**	**30.5**	**31.0**	**31.5**	**32.0**	**32.5**	**33.0**	**33.5**	**34.0**
1.00	3.57%	3.51%	3.45%	3.39%	3.33%	3.28%	3.23%	3.17%	3.13%	3.08%	3.03%	2.99%	2.94%
1.25	4.46%	4.39%	4.31%	4.24%	4.17%	4.10%	4.03%	3.97%	3.91%	3.85%	3.79%	3.73%	3.68%
1.50	5.36%	5.26%	5.17%	5.08%	5.00%	4.92%	4.84%	4.76%	4.69%	4.62%	4.55%	4.48%	4.41%
1.75	6.25%	6.14%	6.03%	5.93%	5.83%	5.74%	5.65%	5.56%	5.47%	5.38%	5.30%	5.22%	5.15%
2.00	7.14%	7.02%	6.90%	6.78%	6.67%	6.56%	6.45%	6.35%	6.25%	6.15%	6.06%	5.97%	5.88%
2.25	8.04%	7.89%	7.76%	7.63%	7.50%	7.38%	7.26%	7.14%	7.03%	6.92%	6.82%	6.72%	6.62%
2.50	8.93%	8.77%	8.62%	8.47%	8.33%	8.20%	8.06%	7.94%	7.81%	7.69%	7.58%	7.46%	7.35%
2.75	9.82%	9.65%	9.48%	9.32%	9.17%	9.02%	8.87%	8.73%	8.59%	8.46%	8.33%	8.21%	8.09%
3.00	10.71%	10.53%	10.34%	10.17%	10.00%	9.84%	9.68%	9.52%	9.38%	9.23%	9.09%	8.96%	8.82%
3.25	11.61%	11.40%	11.21%	11.02%	10.83%	10.66%	10.48%	10.32%	10.16%	10.00%	9.85%	9.70%	9.56%
3.50	12.50%	12.28%	12.07%	11.86%	11.67%	11.48%	11.29%	11.11%	10.94%	10.77%	10.61%	10.45%	10.29%
3.75	13.39%	13.16%	12.93%	12.71%	12.50%	12.30%	12.10%	11.90%	11.72%	11.54%	11.36%	11.19%	11.03%
4.00	14.29%	14.04%	13.79%	13.56%	13.33%	13.11%	12.90%	12.70%	12.50%	12.31%	12.12%	11.94%	11.76%
4.25	15.18%	14.91%	14.66%	14.41%	14.17%	13.93%	13.71%	13.49%	13.28%	13.08%	12.88%	12.69%	12.50%
4.50	16.07%	15.79%	15.52%	15.25%	15.00%	14.75%	14.52%	14.29%	14.06%	13.85%	13.64%	13.43%	13.24%
4.75	16.96%	16.67%	16.38%	16.10%	15.83%	15.57%	15.32%	15.08%	14.84%	14.62%	14.39%	14.18%	13.97%
5.00	17.86%	17.54%	17.24%	16.95%	16.67%	16.39%	16.13%	15.87%	15.63%	15.38%	15.15%	14.93%	14.71%
5.25	18.75%	18.42%	18.10%	17.80%	17.50%	17.21%	16.94%	16.67%	16.41%	16.15%	15.91%	15.67%	15.44%
5.50	19.64%	19.30%	18.97%	18.64%	18.33%	18.03%	17.74%	17.46%	17.19%	16.92%	16.67%	16.42%	16.18%
5.75	20.54%	20.18%	19.83%	19.49%	19.17%	18.85%	18.55%	18.25%	17.97%	17.69%	17.42%	17.16%	16.91%
6.00	21.43%	21.05%	20.69%	20.34%	20.00%	19.67%	19.35%	19.05%	18.75%	18.46%	18.18%	17.91%	17.65%
6.25	22.32%	21.93%	21.55%	21.19%	20.83%	20.49%	20.16%	19.84%	19.53%	19.23%	18.94%	18.66%	18.38%
6.50	23.21%	22.81%	22.41%	22.03%	21.67%	21.31%	20.97%	20.63%	20.31%	20.00%	19.70%	19.40%	19.12%
6.75	24.11%	23.68%	23.28%	22.88%	22.50%	22.13%	21.77%	21.43%	21.09%	20.77%	20.45%	20.15%	19.85%
7.00	25.00%	24.56%	24.14%	23.73%	23.33%	22.95%	22.58%	22.22%	21.88%	21.54%	21.21%	20.90%	20.59%
7.25	25.89%	25.44%	25.00%	24.58%	24.17%	23.77%	23.39%	23.02%	22.66%	22.31%	21.97%	21.64%	21.32%
7.50	26.79%	26.32%	25.86%	25.42%	25.00%	24.59%	24.19%	23.81%	23.44%	23.08%	22.73%	22.39%	22.06%
7.75	27.68%	27.19%	26.72%	26.27%	25.83%	25.41%	25.00%	24.60%	24.22%	23.85%	23.48%	23.13%	22.79%
8.00	28.57%	28.07%	27.59%	27.12%	26.67%	26.23%	25.81%	25.40%	25.00%	24.62%	24.24%	23.88%	23.53%
8.25	29.46%	28.95%	28.45%	27.97%	27.50%	27.05%	26.61%	26.19%	25.78%	25.38%	25.00%	24.63%	24.26%
8.50	30.36%	29.82%	29.31%	28.81%	28.33%	27.87%	27.42%	26.98%	26.56%	26.15%	25.76%	25.37%	25.00%
8.75	31.25%	30.70%	30.17%	29.66%	29.17%	28.69%	28.23%	27.78%	27.34%	26.92%	26.52%	26.12%	25.74%
9.00	32.14%	31.58%	31.03%	30.51%	30.00%	29.51%	29.03%	28.57%	28.13%	27.69%	27.27%	26.87%	26.47%
9.25	33.04%	32.46%	31.90%	31.36%	30.83%	30.33%	29.84%	29.37%	28.91%	28.46%	28.03%	27.61%	27.21%
9.50	33.93%	33.33%	32.76%	32.20%	31.67%	31.15%	30.65%	30.16%	29.69%	29.23%	28.79%	28.36%	27.94%
9.75	34.82%	34.21%	33.62%	33.05%	32.50%	31.97%	31.45%	30.95%	30.47%	30.00%	29.55%	29.10%	28.68%
10.00	35.71%	35.09%	34.48%	33.90%	33.33%	32.79%	32.26%	31.75%	31.25%	30.77%	30.30%	29.85%	29.41%
10.25	36.61%	35.96%	35.34%	34.75%	34.17%	33.61%	33.06%	32.54%	32.03%	31.54%	31.06%	30.60%	30.15%
10.50	37.50%	36.84%	36.21%	35.59%	35.00%	34.43%	33.87%	33.33%	32.81%	32.31%	31.82%	31.34%	30.88%
10.75	38.39%	37.72%	37.07%	36.44%	35.83%	35.25%	34.68%	34.13%	33.59%	33.08%	32.58%	32.09%	31.62%
11.00	39.29%	38.60%	37.93%	37.29%	36.67%	36.07%	35.48%	34.92%	34.38%	33.85%	33.33%	32.84%	32.35%
11.25	40.18%	39.47%	38.79%	38.14%	37.50%	36.89%	36.29%	35.71%	35.16%	34.62%	34.09%	33.58%	33.09%
11.50		40.35%	39.66%	38.98%	38.33%	37.70%	37.10%	36.51%	35.94%	35.38%	34.85%	34.33%	33.82%
11.75			40.52%	39.83%	39.17%	38.52%	37.90%	37.30%	36.72%	36.15%	35.61%	35.07%	34.56%
12.00					40.00%	39.34%	38.71%	38.10%	37.50%	36.92%	36.36%	35.82%	35.29%
12.25						40.16%	39.52%	38.89%	38.28%	37.69%	37.12%	36.57%	36.03%
12.50							40.32%	39.68%	39.06%	38.46%	37.88%	37.31%	36.76%
12.75								40.48%	39.84%	39.23%	38.64%	38.06%	37.50%
13.00									40.63%	40.00%	39.39%	38.81%	38.24%
13.25											40.15%	39.55%	38.97%
13.50												40.30%	39.71%

given level of resistance force (impact) is applied at the arrow's tip. Two primary characteristics of EFoC combine to greatly reduce the amount of shaft flex on impact:

First, with EFoC there is less arrow mass, or weight, toward the rear, thereby reducing the force with which the arrow's rear "pushes" forward on the shaft at impact. To see this clearly, take a slender arrow shaft and securely glue a brick to one end, using a big glob of something like JB Weld. Now place the other end of the shaft on the floor. Unless you keep the shaft absolutely perpendicular to the floor, it bends and flexes under the top weight. Next, bump the shaft against the floor and note that even if held absolutely perpendicular, the shaft flexes at impact. The collision forces *have* to go somewhere. The resultant force vectors — between floor-impact and the "push" exerted by the mass at the shaft's top end — must either compress the shaft linearly, or be redirected outward, causing shaft flex. 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 scarce to none, regardless of how hard the impact.

A second way EFoC works to reduce the amount of shaft flex on impact is by concentrating arrow mass far forward. The resulting short forward lever arm means, in turn, that the dynamic center of flexing pressure exerted on the shaft at impact is also far forward, where the EFoC shaft is stiffest. This is important on all impacts, and becomes especially important when an arrow's impact on bone is at any angle other than perpendicular.

Restated in summary: The shorter an arrow's forward lever arm, the less shaft flex it will experience on impact. This means less of the arrow's force is used up needlessly in flexing and more is retained for penetration ... even as the reduced shaft vibration lowers resistance as the arrow passes through tissues.

High FoC has other advantages for the bowhunter as well. When all else is equal, higher FoC means faster recovery from paradox. That means the arrow is flying straight within a shorter distance after its departure from the bow. On close-range shots, this means less shaft flex at impact, and more penetration. The influence of paradox on arrow penetration is easy to see. All you need to do is shoot a few arrows into a target at very close range and compare the penetration against what those same arrows show at a somewhat longer range. The greater the arrow's paradox at impact, the less its penetration. The difference can be huge.

Finally, recalling our earlier discussion of fulcrum physics and arrow accuracy, we saw that the higher an arrow's FoC, the less affected it is by a broadhead's wind-sheer influence. For bowhunters, this means we can use less fletching to stabilize EFoC broadhead-tipped arrows. Less fletching means less drag as the arrow flies downrange. This, in turn, means a bit more retained force at impact. Having less fletching on hunting arrows also means less cross-wind steerage effect on the arrow, just as it does for flight and FITA shooters. That can be important when hunting windy, open country. If you've bowhunted much in such natural wind-tunnels as eastern Wyoming, North Dakota, West Texas or the Arctic tundra, you know exactly what I mean!

Author's Note

Stay tuned for additional reports and interpretations of Dr. Ed Ashby's groundbreaking research into arrow lethality in future issues of **Traditional Bowhunter**. Dave Petersen's role in this series is as an editorial crash-test dummy: "If we can get all of this into terms simple enough for Dave to understand," Ed quips, "then anyone can understand it!"