ARROW SPEED AND KINETIC ENERGY

FEEL THE NEED FOR SPEED?

Fast cars, fast computers, fast wide receivers, fast-drying paint, fast-acting weed-killer.....if it's fast, we love it. And when it comes to our archery equipment, it's no different. Show most guys a brand new bow, and their first question is likely to be "How fast does it shoot?" Right or wrong, speed is a major consideration for most archers. And it's great to see how advancements in materials and design technologies have made today's compound bows better, faster, and more fun to shoot than ever before.

Of course, there will always be a few dissenters in the crowd, those who'll loftily claim they don't care about speed. But the market trends don't lie. Archery consumers are taking advantage of these innovations, buying high-performance bows and speed-boosting gadgets by the trainload. And nothing yields such a predictable and significant increase in speed like a good set of lightweight carbon arrows. So let's examine the pro's and con's to shooting lightweight arrows. Let's find out where they help, where they hurt, and where they don't really make a difference.

THE EFFECT OF ARROW MASS ON SPEED

When all other variables are constant, arrow speed has an inverse relationship with arrow mass. Of course there is a point of diminishing returns, but as arrow mass increases, arrow speed decreases. As arrow mass decreases, arrow speed increases. Your bow will only generate a certain amount of energy (given its particular settings), and it uses that energy to get the arrow moving. The less the arrow weighs, the faster that energy can make the arrow accelerate. The heavier the arrow, the less acceleration is achieved. Interestingly, a bow transfers energy into a heavier arrow more efficiently than it does into a light arrow (more on this in a moment). Nonetheless. the rule still applies, lighter arrows go faster - heavier arrows go slower.

ARROW MASS VS VELOCITY CHRONO TEST

To illustrate this point, we prepared 9 arrows, ranging from 250 grains up to 650 grains in precisely 50 grain increments. Each arrow was fired from our test bow (60#/28" Bowtech Patriot) through the chronograph and the results were recorded (table below). Five trials were conducted for each arrow - to achieve a reliable speed measurement (average). Each arrow was fired from the same distance, from the same shooter, and without any modifications to the bow's settings during the test. The test was conducted at our indoor

range, where lighting and environmental conditions could be held constant throughout our test.

CHRONOGRAPH TEST RESULTS

FPS		Trial #1	Trial #2	Trial #3	Trial #4	Trial #5	Average
250gr Arrow	4.17 gr/lb.	294	294	295	294	294	294.2 FPS
300gr Arrow	5.00 gr/lb.	274	272	273	273	273	273.0 FPS
350gr Arrow	5.83gr/lb.	256	256	257	255	256	256.0 FPS
400gr Arrow	6.67gr/lb.	242	242	242	243	242	242.2 FPS
450gr Arrow	7.50 gr/lb.	231	231	231	230	231	230.8 FPS
500gr Arrow	8.33 gr/lb.	220	219	220	220	219	219.6 FPS
550gr Arrow	9.17 gr/lb.	211	210	209	210	209	209.8 FPS
600gr Arrow	10.00 gr/lb.	202	201	201	202	202	201.6 FPS
650gr Arrow	10.83 gr/lb.	196	195	195	195	194	195.0 FPS

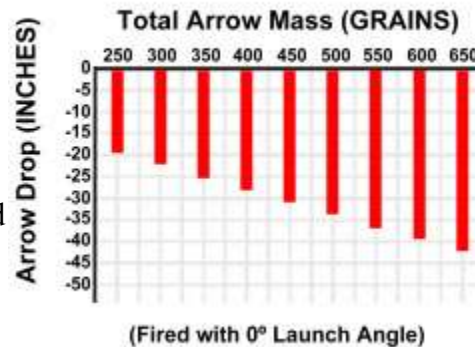Arrow Mass: Effects on Arrow Velocity — Bowtech Patriot 60# Peak - 28" Draw
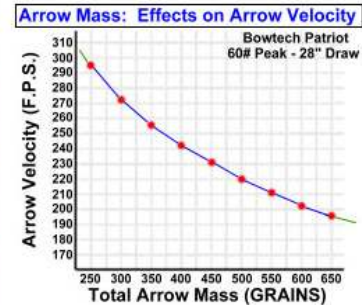
As you can see, as arrow mass increased - arrow velocity decreased. Mathematically, the inverse relationship isn't exactly linear, but close enough to illustrate the concept.

IS FASTER REALLY BETTER?

Maybe. From a standpoint of accuracy, you may find that lightweight arrows will yield some surprising benefits. From the moment your arrow is released from the bow, it begins to lose trajectory. As it succumbs to the effects of gravity and air resistance, it's flight path (trajectory) changes and the arrow eventually begins to drop back to earth. Arrows which fly more quickly hold their trajectory better than slower arrows. So archers who shoot lighter-faster arrows will have less need to adjust for distance - since the faster arrows will hold a "flatter" trajectory within a

Loss of Shot Trajectory at 30 Yards
(Fired with 0° Launch Angle)

given distance. In effect, the faster arrow allows you to make more mistakes in yardage estimation. If you mis-estimate a deer to be 25 yards away, and it is actually 30 yards away, the fast arrow still lands lower than expected, but it "misses" its mark by a smaller margin. Look at the trajectory chart on the right from our Bowtech Patriot experiment. The heavier arrows nosedive more quickly than the lighter faster arrows. So whether you're a hunter or competition 3D shooter, you may find that faster arrows actually add a little forgiveness into your shooting, allowing you to make an error in yardage estimation without paying such a heavy price.

Hunters may also find that a faster arrow gives game animals less opportunity move out of position. When you fire an arrow at a game animal, the sound of the bow travels much faster (about 1100 fps) than the arrow. So the game animal will certainly hear the sound of the bow before the arrow arrives. During that time, the animal has a brief opportunity to lunge, jump, squat, or otherwise get out of the way. For example, an alarmed deer will

often "crouch" in preparation to jump. This crouching motion makes it appear the deer has attempted to "duck" the arrow, when in fact the deer is just loading its muscles to jump and flee. As a result, many bowhunters tend to miss high, shooting the arrow over the deer's back or impacting above the kill-zone, resulting in an unfortunate wound. Of course, there are several factors that come into play (the alertness and athleticism of the deer, your distance and angle from the target, the amount of noise from your bow, etc.) which can affect how quickly a deer responds to the sound of your shot. But one thing is for sure. The faster your arrow arrives at the target, the less time the deer will have to react. So let's take a look at how quickly an arrow traverses it's flight path, given a known distance and launch speed.

APPROXIMATE TIME TO ARROW IMPACT

Distance--->	10 Yards	20 Yards	30 Yards	40 Yards	50 yards
150 fps	0.203	0.412	0.628	0.849	1.078
175 fps	0.174	0.353	0.538	0.728	0.924
200 fps	0.152	0.309	0.471	0.637	0.808
225 fps	0.135	0.275	0.418	0.566	0.718
250 fps	0.122	0.247	0.377	0.510	0.647
275 fps	0.111	0.225	0.342	0.463	0.588
300 fps	0.102	0.206	0.314	0.425	0.539
325 fps	0.094	0.190	0.290	0.392	0.497

MORE SPEED = MORE NOISE

Shooting a lightweight arrow may result in a notable increase in noise from your bow. It's to be expected, as the faster moving string makes a bigger disturbance in the surrounding air and bows transfer energy into lightweight arrows slightly less efficiently than with heavier arrows. On your particular bow, the difference may be subtle - or quite significant. If you shoot a high-quality modern bow that's already pretty quiet, the difference may be minor. But if your bow is already noisy even when shooting your heavyweight aluminum arrows, shooting ultra-light carbon arrows will guarantee you a virtual harmonic train-wreck.

As with any bow rig, maintaining your fastener torques, along with a compliment of string silencers, dampeners, and a good high quality stabilizer will all help, but be advised that added speed will still come with some added noise too. If you're a hunter, noise is an important issue, and you'll have to weigh the advantages of flatter trajectory against increased noise. For what it's worth, most modern equipment bowhunters tend not to choose the lightest shafts, but rather a mid-weighted shaft (Easton Axis, Gold Tip Hunter, Beman ICS Hunter, etc.) which yields a moderate finished arrow weight.
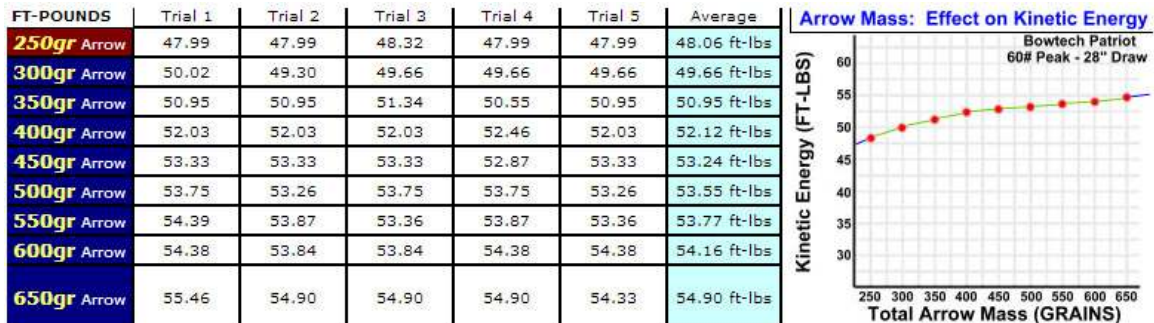
And while there is no single formula which fits every preference and bowhunting application, our average custom arrow order (for men's hunting bows anyway) yields a finished mass of around 400 grains. Now ... if you're not a hunter, bow noise isn't really a concern. For competition 3D shooting, where noise and penetration really don't make a difference, lighter arrows with flatter trajectories are definitely better. Most competition

shooters want arrows which are at the league minimums or speeds at the league maximums.

SPEED vs. KINETIC ENERGY

Here's where the debate gets heated. With all other variables constant, your bow will have more knock-down power when shooting heavier arrows. So some bowhunting enthusiasts will dismiss the benefits of faster arrow speeds and flatter trajectories, and claim that heavier and more deeply penetrating arrows are more responsible choices. But we have to keep this issue in perspective. Mathematically, there is a difference ... but how much? Does arrow mass affect knock-down power significantly? Does it actually make a difference in the field? Or is this debate just academic?

To understand this issue, let's look at the basic physics. How much penetration, or knock-down power, a projectile has in the shooting sports is generally expressed in ft-lbs of kinetic energy. Arrows which impact the target with more kinetic energy will penetrate the target more deeply than arrows with less kinetic energy. Kinetic energy is the energy of motion. Any object which has motion has kinetic energy. Total kinetic energy depends upon two variables: the mass of the object and the speed of the object. Since we had mass and speed data from our earlier chronograph test, we simply converted those numbers into Kinetic Energy in the table below. Notice that as the arrow gets heavier, the amount of kinetic energy increases.

FT-POUNDS	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
250gr Arrow	47.99	47.99	48.32	47.99	47.99	48.06 ft-lbs
300gr Arrow	50.02	49.30	49.66	49.66	49.66	49.66 ft-lbs
350gr Arrow	50.95	50.95	51.34	50.55	50.95	50.95 ft-lbs
400gr Arrow	52.03	52.03	52.03	52.46	52.03	52.12 ft-lbs
450gr Arrow	53.33	53.33	53.33	52.87	53.33	53.24 ft-lbs
500gr Arrow	53.75	53.26	53.75	53.75	53.26	53.55 ft-lbs
550gr Arrow	54.39	53.87	53.36	53.87	53.36	53.77 ft-lbs
600gr Arrow	54.38	53.84	53.84	54.38	54.38	54.16 ft-lbs
650gr Arrow	55.46	54.90	54.90	54.90	54.33	54.90 ft-lbs

Arrow Mass: Effect on Kinetic Energy
Bowtech Patriot
60# Peak - 28" Draw
Kinetic Energy (FT-LBS)
Total Arrow Mass (GRAINS)

In our example, the computed kinetic energy of the (5 gr/lb) 300 grain arrow was 49.66 ft-lbs. But when a 600 grain arrow was fired from the same bow, its computed kinetic energy was 54.16 ft-lbs. So doubling the arrow mass yielded another 9% in kinetic energy, or "knock down power." Obviously, all bows won't perform exactly as our test bow did, but you get the general idea - heavier arrows absorb more of the bow's energy (and carry more energy downrange). So if you want the added kinetic energy, you can shoot arrows at a heavy 10 gr/lb, just don't forget that to get the extra 9% in KE, you'll give up over 25% of your arrow velocity.

So before you make your decision in the speed vs. kinetic energy debate, you should consider your target - and the energy is takes to ethically harvest that animal with a bow. If you're hunting smaller athletic animals, say Pronghorn Antelope, which are particularly alert and skittish, a faster arrow would surely be best. Hunting smaller game doesn't

require as much knock-down power, so getting the arrow to the target quickly will increase your chances of success. Other the other hand, if you're pursuing a 600 lb. Elk, you'll be less concerned about the animal "jumping your string" and more concerned about getting optimal penetration. So if you hunt large heavy game, a heavier arrow may increase your chances of success.

Like many issues in archery, the speed vs. KE debate is one that may never end! Every hunter seems to have his own opinions on the proper techniques, strategies, and ethics of big game bowhunting - and what applies to one hunter may not necessarily apply to another. Ultimately, the choice is up to you.

HOW MUCH KE DO I NEED?

If you have a hot-rod modern compound bow producing 70+ ft-lbs of KE, and you only hunt Whitetail Deer, the speed vs. KE debate is just academic. No matter what arrow you shoot, you'll have practically twice the energy required to harvest your deer. In fact, at 70+ ft-lbs, you would have plenty of power for even the largest North American game species. But if your bow isn't such a hot-rod, or if you shoot low poundage and/or a short draw length, the KE issue may be a hair worth splitting.

According to Easton's field chart, the amount of KE you'll need varies by the species you intend to hunt. Obviously, the larger the game, the more KE you'll need. And regardless of the power of your bow, you'll still need to land your shots in the boilermaker. If you hit an animal in the shoulder, all bets are off. But assuming you do your part, Easton's recommendations gives us a place to start. Of course, these recommendations aren't absolutes, nor are they guarantees of success.

KINETIC ENERGY

Hunting Usage

< 25 ft. lbs.
Small Game (rabbit, groundhog, etc.)
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..)

To give this some perspective, refer back to our Bowtech Patriot test. Would our bow be capable of harvesting a Whitetail Deer? According to the chart, yes. A properly placed

arrow - impacting with 50+ ft-lbs of KE - has a very good chance of generating a clean pass-thru on a Whitetail Deer. So with respect to kinetic energy and Whitetail hunting, there may be no practical difference between the 300 grain arrow impacting with 49.66 ft-lbs of KE and a 600 grain arrow impacting with 54.16 ft-lbs (as in our experiment above). Assuming favorable conditions and a good shot, either arrow would provide sufficient energy to make a clean harvest on a deer. But if we decided to take our Bowtech Patriot out for some Minnesota Black Bear or Rocky Mountain Elk ... we just might come up short on power. So in that case, the extra KE might come in handy.

HOW DO I COMPUTE KINETIC ENERGY?

Kinetic energy of an arrow can be found by using the formula KE=(mv²)/450,240 where m is the mass of the arrow in grains and v is the velocity of the arrow in fps. The 450,240 just sorts out all the units and converts things from fps & grains to ft-lbs. So if your new bow setup ultimately shoots a 400 grain arrow at a respectable 250 fps, your actual kinetic energy or "knock down power" will be:

KE=(mv²)/450,240
KE=[(400)(250²)]/450,240 KE=25,000,000/450,240
KE=55.53 ft-lbs

Before we move on, we should mention that KE and Momentum aren't the same thing. We received an email several seasons ago from a gentleman who emphatically insisted that Kinetic Energy was NOT the best mathematical predictor of hunting penetration with a bow and arrow. He said that the industry standard expression of Kinetic Energy was "short-sighted" since the benefit of speed is exaggerated by squaring velocity in the equation (we didn't make up the equation BTW) and that the KE model applies better to high-speed projectiles like bullets. He explained (at some length) that Momentum was the better model for archery. With over 10 years in the archery industry, we have yet to see an archery product rated for slug/fps. But in the interest of leaving no stone unturned ...

MOMENTUM vs. KINETIC ENERGY:

Should you have an unquenchable interest in ballistic physics, you may find it interesting that a few sporting enthusiasts will even dispute the convention that KE is the best measurement for predicting hunting penetration with a bow and arrow. A number of enthusiasts will debate that MOMENTUM is the better mathematical model. Of course, KE and Momentum aren't the same thing.....

----> **Kinetic Energy = Weight X Velocity Squared /2 X Acceleration of Gravity**
----> **Momentum = Weight X Velocity / Acceleration of Gravity**

Since velocity isn't squared in the momentum formula, arrow mass and velocity play more equivalent roles. The kinetic energy of a moving body increases as the square of the velocity whereas the momentum increases directly as velocity increases. So if you

recomputed our chart to show momentum, then the graph would look much different. The heavier arrows would show a significant improvement in overall momentum, and you could therefore conclude that heavier arrows would indeed yield dramatically better penetration.

Right or wrong, the shooting sports have a number of traditions and conventions regarding technical measurement. And the lethality of a projectile (whether from a firearm or bow) is traditionally expressed as a function of KE (ft-lbs). As such, most sporting enthusiasts have some comprehension of this measurement. Unfortunately, a momentum rating in Slug Feet-per-Second would surely leave many of us scratching our heads. Given the dramatic difference in the two methodologies, it seems unlikely that KE has remained the "standard" for so long if it's entirely incorrect. There are a lot of talented engineers in the archery industry. So either they have ALL missed it, or perhaps the momentum theory has a glitch (not to worry - our team of physicists are working on it now).

PERSPECTIVE ON HUNTING MATH

Regardless of how you crunch your numbers during pre-season, you can't avoid the elements of chance during the actual hunt. Shooting a live animal in the woods is quite different than shooting a block of ballistics gel in a laboratory. In the field you'll encounter unpredictable and complex variables that limit any mathematical model to just a "best guess." If you consider that your arrow must arrive on target then pass through layers of hair, hide, muscles, bones (perhaps), and a host of other tissues.....AND that all of this is happening in an uncontrolled outdoor environment, it's pretty clear that the issue of hunting penetration cannot truly be distilled into a mathematical puzzle. As many experienced bowhunters can attest, just as it's possible to make mistakes and get lucky, it's also possible to do everything right and come-up empty handed. That's just part of the sport. However, with good equipment, good technique, smart planning, and some good-old common sense, you can surely tip the scales in your favor and maximize your chances of success in the field.