BROADHEAD PERFORMANCE

BY

Dr. Ed Ashby

Most often little attention is paid to what broadhead one selects to hunt with. Often the choice is predicated on what the local sporting goods store has in stock, what one's hunting buddies use, what worked on Uncle Joe's deer last year, or on that tried and true axiom "If it cost more it must be better". Volumes of data on terminal ballistics (what happens from the moment of impact) have been written for every conceivable rifle / bullet combination in existence. Virtually no such information exist for archery equipment.

In the summer of 1985, I had the unique opportunity to conduct a field research project to evaluate, at least on a limited basis, the effectiveness of various types of broadheads. The project was conducted at Mkuzi Game Reserve in the Province of Natal, Republic of South Africa. Tony Tomkinson, Chief Ranger at Mkuzi, was the moving force behind the research. He has also been the person primarily responsible for the opening of Natal to legalized bowhunting. Tony deserves the thanks of all archers for his dedication and Herculean efforts towards the opening of Africa to bowhunters.

THE PLAN

We set out to evaluate the effectiveness of as many types of broadheads as possible on a wide variety of game from the size of bushbuck to zebra. We had hoped to evaluate the effectiveness of the bow against Cape buffalo, but no buffalo were listed for herd reduction and no animals were available for testing. Still, the variety of animals tested is most applicable to selection of broadheads for North American game. The animals in the test included impala and bushbuck (average weight from 106 to 143 pounds), warthogs (154 - 220 pounds), nyala (198 - 299 pounds), wildebeest (473 - 550 pounds), and the zebra (700 - 1000 pounds). Some testing was also conducted on giraffe and white rhino, but the data from these animals was not included in the performance analysis. The size of these animals places them outside the practical realm for all but the very most experienced of archers. I found that hunting the rhino, besides experience and skill, also required nerves of steel and the ability to run like hell!

THE EQUIPMENT

All testing to evaluate broadhead performance was done with heavy draw weight bows. This was done to negate bow weight as a limiting factor. Tony used a 80# Martin Warthog compound for all his shooting, and I used a 94# longbow. The average total mass of the arrows used with the longbow was 698.5 grains; the average velocity was 182 FPS. The mass and velocity, of necessity, varied with the different broadheads. Tony's compound was not available to me to chronograph prior to the trip, and the average velocity is unknown, but I would expect it to be comparable.

Thirty two varieties of broadheads were tested. These included most popular fixed and replaceable blade heads, and a number of limited production semi-custom heads.

METHODS

The data was accumulated using two different sources. One was animals hunted and taken solely with a bow. This method was employed to the maximum extent possible. Where more detailed evaluation of a particular shot was desired, the animal was taken with a rifle (being careful not to damage any tissue even remotely near the site for the test shot) then positioned and shot with the arrow. These "simulated" test shots were taken immediately to minimize the effects of tissue change. Each shot was evaluated by wound channel examination and by dissection. All field evaluations were tape recorded and later transferred to written shot evaluation forms. Where field evaluation was not complete enough, such as shots into the spine, the animal was returned to the slaughter house for dissection and detailed shot evaluation. The data was transferred to a computer data base program for analysis. Shots taken on animals previously culled with a rifle were rated as lethal if: (1) a major nerve center was penetrated, (2) a major blood vessel was severed, (3) the thorax was penetrated and a vital organ hit, (4) a major visceral organ was hit, i.e.: kidney, liver, etc.

All usable meat from animals taken was salvaged. Non-usable parts were used in the predator feeding program at Mkuzi.

THE DATA

Data from 154 shot records was included in the data base for evaluation of broadhead performance. The accompanying tables and graphs present a representation of a small portion of the data. Some of the questions that we proposed to address were: (1) what are the most lethal shot angles; (2) what shot angles offer the least chance of a lethal hit; (3) which style of head gives the greatest portion of lethal hits on the most difficult shot angles; (4) is there a significant difference in penetration among the types of heads and, if so, which penetrates best when soft (muscle, connective tissue, etc,) and hard (bone) tissue is hit; and (5) would a restriction on what types of heads could be used on what class of animal be appropriate.

THE ANALYSIS

Any analysis based upon such a limited number of test reports certainly is open to criticism. This study is, however, the most extensive uniform methodology analysis of broadhead performance ever performed to date on actual game animals. The results, and most definitely my conclusions from those results, will most assuredly be controversial. The analysis itself, however, was performed as uniformly and unbiased as possible.

One of the striking features noted during the testing was that a large number of the broadheads tested were very fragile, often bending or breaking whether bone was hit or not. Table I and Graph I reflect an evaluation of the different types of broadheads and the percentage damaged during testing. The rigid 2 blade (or more accurately, single blade with two cutting edges) broadheads proved to be significantly more resistant to damage than either the rigid multiblades or the replaceable blade type of broadheads.

Table II and Graph II are the result of the evaluation of the probability of a hit being lethal based upon the hit location. Hits from directly in front, into the brisket, and shots from a forward quartering angle that hit back of the shoulder blade (to differentiate from shots taken into the very tough neck-shoulder junction area) were 100% lethal, but this was based upon a very limited number of shots. There were 25 shots quartering from the rear forward, with 24 of these being lethal hits. It is of little surprise that this shot is generally regarded by experienced bowhunters as the very best. Not only does it position the hunter so that he may move freely to position for the shot, but also gives a great probability of a quickly lethal hit.

It is somewhat disturbing that almost 30% of the broadside shots into the chest-shoulder area were non-lethal. This has long been considered the "classic" shot. The rump hit proved fatal just over half the time. Its lethality proved dependent on (1) whether the femur is hit, (2) whether the head can break the femur to reach the femoral artery and iliac vessels just deep of the femur, or (3) whether the hit is medial to the femur and penetration is deep enough to reach the vessels (significant penetration is required on a large animal such as a zebra). As had been expected from past experiences, the toughest shot on which to make a kill was into the area of the neck-shoulder junction.

Table III and Graphs III - VI reflect a further analysis of broadhead shots when single blade heads are compared to multiblade heads. It addresses four scenarios: (1) the percent of hits that are lethal when single blade heads are compared to all multiblades, regardless of hit location; (2) when only shots that hit heavy shoulder blades are considered; (3) when a rib is hit on entrance; and (4) when the hit is in the area of the neck-shoulder junction.

Among the 16 scapula hits with single blade broadheads, 12 penetrated the scapula (shoulder blade) and rib cage to enter the thorax to be lethal hits. Four failed to reach the thorax: an Anderson 245 shot as a single blade (penetration was 3/8" into the scapula); a Black Diamond which, according to the field notes "bent into a long curve" on impact with a zebra scapula; a Premium I which hit a warthog scapula and "bent at a 90 degree angle, arrow deflected, head destroyed"; and a Grizzly which penetrated the thickest part of a zebra scapula and a rib, but did not enter the thorax sufficiently to be lethal.

Only three of the three blade heads hit a scapula: 2 Rocky Mountain Razors (one on a zebra, one on a wildebeest) and a Bodkin (zebra). None penetrated the scapula.

Among the 4, 5, and 6 blade heads, there were 8 hits on the scapula. Only two of these penetrated the bone; an Interceptor which penetrated a zebra scapula, and a Kolpin 6 used on a warthog. The Kolpin 6 achieved 10" of penetration, but most of the blades (5 of 6) were sheared off and left in the scapula.

If the analysis of the effect of hitting bone on entrance is carried one step further, in order to see the effect of hitting a rib on entrance, all hits with single blade heads were lethal (100%). They averaged 19.1" penetration (Table IV and Graph VII). There were ten shots in this group. Among three blade heads, only three shots hit ribs on entrance and only one of these, a Snuffer that chipped a rib on entrance on a warthog, penetrated to be a lethal hit (33.3%). Penetration on this shot was 14". The 2 non-lethal hits were both with 150 gr. Rocky Mountain Razors (one on an nyala, and one on a wildebeest). With the other multiblade heads, 7 of 12 hits encountering a rib on entrance penetrated to be lethal (58.3%). Five failed to penetrate the rib.

To me, the last section of Table III was the most striking result. If one considers only the most difficult of all shots, with the animal quartering toward the archer and the arrow striking in the area of the neck-shoulder junction, only 51.5% of all the hits were lethal (Table II). But when the type of broadhead enters the equation (Table III and Graph VI), the results are starkly revealing. When single blade broadheads were used, 85% of all the hits in the neck-shoulder junction were lethal (17 of 20 hits). None of the hits with multiblade heads were lethal (zero of 16). The three single blade heads that failed to penetrate were a Howard Hill, a Black Diamond, and a Timberwolf. All three of these heads bent on impact with bone and failed to penetrate. The bulk of these lethal shots (8 of 17) with the single blade heads were on the animal we judged to have the heaviest bone structure of all the test animals, the wildebeest. The wildebeest also has an average skin thickness of 8mm. Most shots with the multiblade heads were taken on lighter built animals (all but 2 were on "light" animals, i.e.: warthogs, nyala, and impala).

A glance at Table IV and Graph VII reveals that when a bone of any type is hit, the single blade head offers vastly superior penetration. Even when only soft tissue is hit, the single blade heads penetrated substantially better than the multiblade heads. If the thorax is entered, the superior penetration of the single blade would be offset, to some degree, by the greater cutting area of the multiblade heads. But, there is a significant reduction in the percentage of the shots reaching the lethal area with multiblade heads.

The strongest point of the rigid single blade head is the vastly superior penetration. Nowhere was this more evident than when analysis was completed on shots that hit the vertebral column. There were 12 hits in the vertebral column with single blade heads, with ten of these penetrating sufficiently to sever the spinal cord (83.3%). **Of these ten hits, six penetrated the scapula before hitting the spine!** One hit penetrated a rib before hitting the spine. Nine multiblade heads hit the spine. None penetrated enough to reach the spinal cord.

COMMENTS, OBSERVATIONS, OPINIONS

A number of items were observed as our testing progressed. Some of these we had not kept track of sufficiently to analyze fully, and some could not be quantified.

Since we had planned to test a large quantity of broadheads, most heads with tapered ferrules had been mounted on the "screw-in" type broadhead adapters. Most replaceable blade heads have this screw-in type mounting system integral with the broadhead. This appears to be a weak link in the arrow/broadhead system. A large number of the adapters bent on both soft and hard tissue hits. It appears that it would be advantageous to use a fixed broadhead taper mounting system, especially for medium and large animals.

Several shots were tried with the free rotating type broadhead adapters. Claimed benefits are truer flight (less tendency to wind plane) and deeper penetration (head can rotate freely away from a bone when one is hit). Sufficient shots were not recorded to verify or refute these claims. These adapters appear to be at least as strong and bend resistant as conventional screw-in adapters (which, as noted, left something to be desired). No increase in penetration was apparent.

Some testing was also done with various arrow shaft materials. During analysis it was determined that there was not sufficient data with the other variables remaining constant for definitive conclusions to be drawn. It did appear the there was a definite lower limit to arrow mass, regardless of shaft material, for adequate penetration, even with the best of broadheads. Adequate penetration appeared to require a total arrow mass of at least of 650 grains if any bones at all were encountered. There also appears to be a marked increase in penetration occurring when the total mass was in the 800 to 900+ grain range. These "super heavy" arrows would appear to be ideal in a controlled shot situation for heavy animals, such as bear over bait.

It has long been claimed that multiblade broadheads leave a better blood trail than single blade heads. There appears to be no way to quantify this factor in a field situation. From observations, it appears that the degree of blood trail is dependent on (1) where the animal is hit and (2) is there an exit wound. In the testing, there were 77 shots with single blade heads and 77 shots with multiblade heads (Graph VIII). With roughly equal hit locations and the absence of an exit wound, I was unable to distinguish any difference in the quantity and quality of the blood trail left by hits with single and multiblade heads. With an exit wound the blood trail is greatly increased, especially when the shot is taken at a downward angle, such as from a tree stand. Single blade heads achieved total penetration (exit wound) on 22.1% of the hits. Multiblade heads had total penetration on only 10.4% of the hits. Single blade heads were more than twice as likely to leave an exit wound (Graph IX). They were also able to immobilize the animal over 80% of the time when the spine was hit (as opposed for zero percent for multiblades). The claim of increased trailing ease with the use of multiblade heads appears ill founded.

Based on the test results, no responsible bowhunter using a multiblade head should take a shot at even a deer sized animal that is facing him or angling toward him. The chance of a hit into the non-lethal neck-shoulder area is too great. Conversely, with a heavy draw weight bow, a strong single blade broadhead, and good arrow mass, this becomes an effective shot even on relatively large animals.

To this point, I have refrained from recommending specific broadheads. Now I will stick my neck out and give everyone a chop at it. How did the specific broadheads compare? Four broadheads tied for title of "Worst Performance". Each head was totally destroyed on each shot - several of which did not hit any bones. They were: the Kolpin 6, Razorbak 5, Bear stainless steel Super Razorhead (conversely, the old standard Razorhead performed quiet well), and the Viper (which was a failure in all categories). Almost every Magnum II 4-blade broadhead shattered on impact, even with soft tissue. It is suspected that this was the result of faulty tempering of the steel (too brittle). No such problem was encountered with the Magnum I, which is identical except for the shape of the trailing edge. The Premium I broadhead also failed in every instance where a bone was encountered, but performed well in soft tissue.

All replaceable blade type broadheads proved fragile and gave inadequate penetration, particularly when bone was encountered. The best performer of this group was the Muzzy.

Among rigid multiblade broadheads, those offering the best performance were the Catclaw and the Interceptor. If one feels compelled to use a multiblade broadhead, it would be difficult to find one that out performs the Interceptor. A semi-custom head, the Interceptor may also be used as a single blade head without the bleeder blade insert. In our testing, the Martin Brute was used only as a single blade head, but it also accepts the Bear type bleeder blade insert and may well be a good choice as a multiblade broadhead for whitetail size animals.

Once one leaves the deer class animals (and even for large mule deer) a tough single blade is clearly the choice. Most of the tougher single blade heads performed well, but most also occasionally failed when heavy bone was encountered at an oblique angle. The Howard Hill and Black Diamond (both of which had long been favorites of mine for large animals) demonstrated a disturbing tendency to bend on this type of hit, as did the Timberwolf and the Martin Brute.

Three broadheads took all we could throw at them and finished all test undamaged. Each gave outstanding performance. All were fairly heavy rigid single blade broadheads. These were the "Best of the Best". One was the old Ben Pearson Deadhead. No longer in production, it performed flawlessly. A second excellent performer was the Maxi-Head. A semi-custom head, it features a long, slightly concave, cutting edge with serrations. My own personal choice for the award of the best broadhead tested is the Grizzly.

The Grizzly, also a semi-custom head, is a large, long, extremely tough broadhead. It has a length three times its width. This broadhead is available in two hardness, Rockwell 44 and 55, and in several weights. Only the heaviest, at 190 grains, was tested. Only one shot was taken with the "softer" (44 hardness) head, and the tip was slightly flattened after penetrating a wildebeest shoulder blade on a neck-shoulder junction shot. Penetration was 12 inches.

Only one non-lethal shot was recorded with the Grizzly head. This was on a large (approximately 1000 lb.) zebra stallion. To quote the field notes, this shot went "through the thickest part of the scapula (1" of bone), into a rib, did not reach into the thorax". The 55 hardness Grizzly was not damaged on any of the shots. And what shots! For example: "zebra, through scapula, into spine, cut spinal cord, head penetrated 3" into spine..."; "nyala, through scapula into spine, cut spinal cord..."; wildebeest, neck-shoulder shot, "through scapula, through thorax, cut rib on opposite side..."; "bushbuck, hit right gut, cut left femur below ball joint, exited left hip...".

Progressively more difficult shots were taken with the Grizzly broadhead in an attempt to find the limits of its performance. I found myself actually looking for shots that I felt would not be lethal. It recorded a remarkable 95.8% lethal hits on the toughest shots that I could devise. It was 100% lethal on those tough neck-shoulder shots (and 75% of those neck-shoulder shots were on the toughest animal tested, the wildebeest).

CLOSING REMARKS

I would like to express my deepest appreciation to the Natal Parks Board for making this test possible, and to thank Tony Tomkinson personally for all he has done to advance bowhunting in Africa. It is encouraging to know that there exist game departments willing to do research and find answers before proposing laws that may prove detrimental and/or difficult to change once in place.

One of the goals of our testing was to determine recommendations on what type of broadhead should be used on what class of animal. My recommendation is that, even with careful shot selection, multiblade heads should not be used on animals larger than nyala (large mule deer size game). Certainly larger animals can be taken cleanly with multiblade broadheads when everything goes perfect, but if your bowhunting goes like mine, well..., I need all the help I can get.

As long as the very fastest arrows travel not much over 250 fps, and most less than 200 fps, and animals move faster than the arrow, no archer can guarantee where his shot will hit. We each owe it to the animals we hunt to use equipment capable of making a clean kill when things don't go just as we planned. To me that means a combination which includes a bow of adequate weight, an arrow of heavy mass, and a tough, rigid, well sharpened, single blade broadhead.

TABLE I

BROADHEADS DAMAGED OR DESTROYED BY SHOT	
Rigid single blade broadheads	15.5%
Rigid multiblade broadheads	50.0%
Replacement blade type broadheads	64.0%

TABLE II

PERCENT LETHAL HITS BY SHOT ANGLE (ALL BROADHEADS)	
Quartering from front (hits back of shoulder blade)	100.0%
Frontal hits	100.0%
Quartering from rear	96.0%
Broadside	71.8%
Rear (rump)	54.5%
Area of neck-shoulder junction	51.5%

TABLE III

PERCENT LETHAL BY TYPE OF SHOT AND TYPE OF BROADHEAD	
Broadside, single blade broadheads	81.8%
Broadside, multiblade broadheads	64.9%
Broadside, single blade broadheads, scapula hit	75.0%
Broadside, three blade broadheads, scapula hit	0.0%
Broadside, 4, 5, & 6 blade broadheads, scapula hit	25.0%
Single blade broadheads, rib hit on entrance	100.0%
Three blade broadheads, rib hit on entrance	33.3%
Other multiblade broadheads, rib hit on entrance	58.3%
Single blade broadheads, hit in neck-shoulder junction	85.0%
Multiblade broadheads, hit in neck-shoulder junction	0.0%

TABLE IV

AVERAGE PENETRATION BY TYPE OF SHOT AND TYPE OF BROADHEAD

Scapula hit, single blade broadheads	8.5"
Scapula hit, three blade broadheads	3.0"
Scapula hit, four blade broadheads	4.1"
Rib hit on entrance, single blade broadheads	19.1"
Rib hit on entrance, three blade broadheads	8.3"
Rib hit on entrance, four blade broadheads	11.9"
All soft tissue hit, single blade broadheads	24.9"
All soft tissue hit, three blade broadheads	20.5"
All soft tissue hit, 4, 5, & 6 blade broadheads	16.6"

COLLATERAL RESEARCH DATA

Wounding Rate:

R. W. Aho -

Michigan Dept. of Natural Resources: 1.4 wounded deer for each deer killed.

Horace Gore-

Whitetail Project Director, Texas Parks and Wildlife Department: One deer wounded for each deer killed.

Survey by Deer & Deer Hunting Magazine:

(N = 2,103): 1.13 deer wounded for each deer killed.

Gayle Wescott-

Michigan State University: Observed one deer wounded for each deer killed (N=51 wounded, N=51 Killed).

"Wounded Deer Behavior", Deer & Deer Hunting, August, 1990:

- "This 1:1 ratio for wounded deer to deer killed continues to surface in the hunting literature".

Associated Data:

Horace Gore:

- "unless a relatively low exit wound in thorax hits exist, most bleeding is internal, resulting in a poor blood trail".

- Gore argues that "little data exist with regard to broadhead penetration on a live deer. We know how broadheads penetrate non-organic material such as ethafoam, styrofoam, and wood, but not wild animals in real hunting situations".

Deer Search, Inc.:

- "chest hits in which an arrow only penetrates one lung presents very difficult tracking problems".
- "High lung-shots are difficult to track even with a dog, especially if no exit wound exist".

Shot Placement

Gayle Wescott:

- "56% of hits on broadside shots resulted in unrecovered deer".
- "81% of quartering away shots resulted in retrieval of the animal".

Researchers in Wisconsin:

- "71% to 82% of all shots taken missed".

In Michigan:

- "78% of all shots taken missed".

Horace Gore:

- concluded that "shot placement is, for all practical purposes, random".

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Historical Wounding Rate

de Boer: Waste in the Woods, Wisconsin Conservation Bullitin #22, 1957 - 7% wounding rate for bowhunted whitetails.

Stormer, et al Hunter Inflicted Wounding on White Tailed Deer, Wildlife Society Bullitin #7 (1), 1979 - 17% to 32% wounding rate for bowhunted deer over a four year study period in Indiana.

POSTULATES BASED ON ARROW PENETRATION TEST OF GAME ANIMALS

1. Many broadheads are to fragile, bending or breaking on impact, thus limiting penetration.

2. Rigid single blade broadheads are the least prone to damage on impact.

3. The most lethal shot angle is with the animal quartering away from the archer.

4. The least lethal shot angle is with the animal quartering towards the archer and the shot hitting in the neck-shoulder junction area.

5. All multiblade broadheads offer insufficient penetration when heavy bone is encountered.

6. Single blade broadheads penetrate significantly better than multiblade broadheads in both soft and hard animal tissue.

7. Four and five blade heads penetrate better than three blade heads.

8. When a rib is hit on entrance, a single blade broadhead is almost twice as likely to be lethal as 4, 5, and 6 blade heads and three times as likely as three blade heads.

9. When heavy bone is encountered, a total arrow mass of at least 650 grains, as well as a tough single blade broadhead, is required to achieve adequate penetration.

10. A single blade broadhead is more than twice as likely to produce an exit wound as a multiblade broadhead.

11. The degree of blood trail is dependent on the location of the hit and the presence/absence of an exit wound, not the number of blades on the broadhead.

12. When all shots are considered, the degree of wound inflicted (depth of wound channel times the number of blades) by single blade broadheads is equal to or greater than that inflicted by any multiblade broadheads.

13. No multiblade broadhead can reasonably be expected to penetrate

even a deer size animal when the hit is from the forward quartering angle and in the area of the neck-shoulder junction.

14. The most important factor in achieving adequate penetration is a well constructed single blade broadhead.

15. The second most important factor in achieving adequate penetration is adequate arrow mass (a minimum mass of 650 grains is recommended).

16. Game animals have reflexes faster than even the very fastest of arrows. No archer can guarantee where his arrow will strike an animal. I concur with Horace Gore. In bowhunting, shot placement is, for practical purposes, random.

BROADHEADS TESTED

1. MUZZY
2. ANDERSON 245
3. HOWARD HILL
4. PREMIUM I & 2
5. BLACK DIAMOND (ESKIMO)
6. BEAR SUPRER STAINLESS STEEL
7. (OLD) BEAR RAZORHEAD
8. ALASKAN
9. PSE BRUTE (3 VERSIONS)
10. KOLPIN 6
11. CATCLAW
12. INTERCEPTOR
13. ROCKY MT. RAZOR (3 BLADE - 2 VERSIONS)
14. ROCKY MT. SUPREME (4 BLADE)
15. BLACK COPERHEAD
16. RIPPER (BLACK COPPERHEAD SERRATED)
17. GRIZZLY
18. BODKIN
19. MAGNUM I
20. SNUFFER
21. (OLD) BEN PEARSON DEADHEAD
22. TIMBERWOLF
23. VIPER
24. SATALITE
25. WASP
26. MAXI-HEAD
27. RAZORBACH
28. THUNDERHEAD (2 VERSIONS)
29. WASP
30. REDD HEAD
31. MA-3
32. MAGNUM II

Kinetic Energy, Momentum, Mechanical Advantage
and
Broadhead Performance

Kinetic energy, momentum, and mechanical advantage are a part of the basic terminology of physics. All are used, and often misused, in attempts to predict terminal performance of various bow, arrow and broadhead combinations. Much of the misuse originates from a lack of understanding of what, by definition, these terms mean and what it is they measure.

In the terms of physics, all broadheads are classes as a "simple machine". As such, all broadheads are no more than a series of inclined planes. The mechanical advantage (M.A.) of a "simple machine" is the ratio of the resistance to the effort. The mechanical advantage of an inclined plane is equal to the length of the plane divided by the height of the plane. A single blade broadhead, with a straight taper, 1" wide by 3" long can be viewed as 2 inclined planes, each of which has a mechanical advantage of 6.0 (3" divided by 1/2"). The mechanical advantage of the two planes combined would be 3.0 because the height would be doubled while the length remains the same. What this means is that with an exerted force (effort) of 1 pound, a weight of 3 pounds can be lifted from the tip of the broadhead to the back edge of the broadhead. The higher the M.A. the more work a broadhead can do with the force available.

To determine the mechanical of any broadhead with a straight taper to the cutting edge, divide the length of the one cutting blade by 1/2 the width of the broadhead (or, more precisely, the distance from the central axis of the arrow to the highest point on the plane) multiplied by the number of blades. In an equation this would be expressed as:

$$\text{M.A.} = \frac{\text{Length of cutting edge}}{(\text{1/2 width of head}) \times (\text{number of blades})}$$

Example #1

As stated above, a single blade broadhead 3" long by 1" wide has a mechanical advantage of 3.0. If that same head has three blades, the M.A. would be 2.0, i.e.: (3" length/.5" lift distance X 3 blades). If it had four blades, the M.A. would be 1.5; or one half that of the single blade.

Example #2

In a broadhead with a cutting edge length that is 2.25" long and with each blade .75" high (a common dimension) the M.A.'s work out as follows:

Single blade head	=> M.A. = 1.5	(Note: this is 1/2 the M.A. of the 1" X 3" single blade broadhead)
Three blade head	=> M.A. = 1.0	
Four blade head	=> M.A. = 0.75	
Five blade head	=> M.A. = 0.6	
Six blade head	=> M.A. = 0.5	

In example #2, a single blade head would be able to 50% more work than a three blade broadhead with the same applied force. It does 100% more than the four blade, 150% more than the five blade and 200% more than the six blade broadhead.

The mechanical advantage equation dictates that the greater the length of a broadhead relative to the width, and the fewer the number of blades, the more efficiently it will be able to utilize the force applied to it.

KINETIC ENERGY vs. MOMENTUM

As a base point for a discussion of momentum and kinetic energy, one must understand that the laws of physics dictate that energy can never be manufactured or destroyed but only transformed or directed in its flow. The equations for these two measurements are:

$$\text{Kinetic Energy} = \frac{\text{Weight X Velocity Squared}}{\text{2 X Acceleration of Gravity}}$$

$$\text{Momentum} = \frac{\text{Weight X Velocity}}{\text{Acceleration of Gravity}}$$

The kinetic energy (K.E.) of a moving body increases as the square of the velocity whereas the momentum increases directly as velocity increases.

With the advent of compound bows and overdraw setups, with their higher velocity capability, it has become common to see kinetic energy figures cited as a supposed measure of the penetration capability of a particular bow-arrow-broadhead combination. This use of kinetic energy reflects a misunderstanding of these basic principles of physics.

By definition, kinetic energy is the capacity to do work. It is the **TOTAL ENERGY** of a body in motion. **K.E. is scalar, or nondirectional, in**

<u>nature</u>. As applied to an arrow in motion, K.E. includes such things as: radial energy due to arrow flexion, rotational energy due to arrow spin, sonic energy due to vibration, heat energy due to friction, and potential energy (all other remaining energy). (Simple use of K.E. alone, also fails to take into consideration the mechanical advantage of the broadhead.) The kinetic energy of an arrow, by definition, is not a direct indicator of the penetration capability of the bow-arrow-broadhead combination.

Momentum is the measure used in physics to quantify the "impulse"; the force exerted over a period of time **IN ONE SPECIFIC DIRECTION**. **<u>Momentum is a unidirectional force vector</u>**. Another of those basic laws of physics states that "in cases of collision, whether the bodies are elastic or inelastic, the momentum before collision is equal to the momentum after impact". This means that momentum is the measure of how much energy, due solely to the weight and velocity of an arrow, which must be transferred to whatever it impacts before the arrow comes to rest. (Again, momentum alone will not fully predict the penetration capability of an arrow, and the mechanical advantage of the broadhead must also be considered.)

Assuming there is no bending of broadhead or arrow shaft, how far into the target an arrow will go before all available energy is lost (the amount of penetration) depends on three MAIN factors: the resistance of the object impacted (target), the momentum of the arrow, and the efficiency with which the arrow (broadhead) utilizes the force available to it. The resistance of the target we have little control over. Arrow and broadhead selection we do have control over. Use of a broadhead with a high mechanical advantage and use of heavier arrows with high levels of arrow momentum maximizes the penetration of hunting arrows, regardless of what target resistance is encountered.

The following page gives the calculated momentum of the best performing combination tested and compares it with the momentum of common rifle and handgun loads. It also demonstrates the measured effect on the momentum of increased arrow mass. An arrow used on big game clearly must maximize the use of its very limited energy. There is no excess to spare!

Graph XIV is intended to allow the reader to calculate various arrow mass (weight) and velocity combinations that will give a momentum equal to the best of those used in the broadhead performance study. It will be noted that, with current equipment, it is impossible to generate this amount of momentum with light weight arrows. Even at an arrow mass of 520 grains, the velocity needs to be near 250 feet per second, yet a heavy arrow of 740 grains need only be traveling a little over 160 feet per second to reach this level of momentum (a velocity fully within the capability of most conventional and compound bows).

MOMENTUM AND MASS

$$\text{MOMENTUM} = \frac{\text{MASS IN LBS. X VELOCITY IN FT./SEC}}{\text{32 FT./SEC./SEC}} \Rightarrow \text{POUND SECONDS}$$

2419 w/190 gr. Grizzly (710 gr.) at 180.5 Ft./Sec. => .57 Lb-Sec

22 Hornet 45 Grain at 2690 Ft./Sec. => .537 Pound-Seconds

.38 Special 158 Grain at 755 Ft./Sec. => .529 Pound-Seconds

.357 Magnum 158 Grain at 1250 Ft./Sec. => .88 Pound-Seconds

TO ACHIEVE .57 POUND SECONDS OF MOMENTUM: (The momentum of the "Best" performing arrow/broadhead combinations in study, all of which had broadheads with a 3.0 mechanical advantage):

A 740 Grain Arrow must reach a velocity of 161 Ft./Sec.

A 550 Grain Arrow must reach a velocity of 234 Ft./Sec.

A 450 Grain Arrow must reach a velocity of 285 Ft./Sec.

A 350 Grain Arrow must reach a velocity of 367 Ft./Sec.

EFFECT OF INCREASED ARROW MASS:

With 94# longbow:

> Arrow of 650 grains has 184.5 FPS velocity and Momentum = .54 Pound Seconds (Approximately the same as a .38 Special factory load).
>
> When arrow mass is increased to 1286 Grains velocity is 154 FPS and Momentum = .88 (equal to a .357 magnum factory load).

In this example an increase in arrow mass of 98% results in a velocity decrease of 16.6% and a momentum increase of 63%.

Of historical note, Art Young and Saxon Pope used 75# longbows and 3/8" birch shafts with broadheads 1" wide by 3" long (arrow mass of approximately 800 grains). With these they were able to completely penetrate (with arrow exit) Alaska Brown Bears, and Young successfully took many of the larger Africa species, including several lion and buffalo, with the same equipment.