CHAPTER 1

ARROW BALLISTICS
FROM SINGLE SHOT TO COURSE REQUIREMENTS

ARROW FLIGHT - BALLISTICS

The Oxford Dictionary defines ballistics as "the science of projectiles." Unfortunately, this leads to thoughts of energies, velocities and scads of equations which never actually seem to answer our questions. Ballistics does define the movement of arrows (as well as bullets and missiles) and must be considered to help define safety limits for arrow flight. Throughout the Guide I will keep numbers to a minimum and relegate formulas to the very back of the book. The formulae I used and some tables developed from them can be found at Annex B, Formulae and Tables.

The safety of an archery course depends on how well the course designer has figured out where arrows might fly (including misses and those fired in error) and on keeping people out of those areas. I will repeatedly dwell on missed arrows, we can plan for them, arrows which hit their targets are safe enough and those shot negligently can never be fully guarded against. The area needed for an entire course can be built up from understanding the area needed to fire one arrow safely. When data must be presented, I will give three sets of figures (*sorry*) to describe the actions of bows firing 180 ft/s for longbows and recurves, 240 ft/s for compounds and 300 ft/s for extreme cam compounds. I feel it is important to do this to show the different capabilities and safety requirements of each type of bow. Also, I will present data based on the maximum target range of 50 yards given in the Federation of Canadian Archers (FCA) 3-D Round Rules. This approach will describe the requirements to allow even the fastest bows to compete on the designer's course. The rules for the Canadian 3-D Round are given at Annex A.

Note: Throughout the Guide units of measure will be in Imperial units (feet, yards, feet per second, etc.). I have decided to do this as I feel that most of the archers I've met are still more comfortable with these units. I've never heard an archer speak of his or her bow firing in meters per second. Those who prefer metric, are welcome to convert the presented figures.

ARROW FLIGHT - THE SINGLE SHOT

How Far Can One Arrow Go? - Range. First of all, to decide how large an area must be kept safe for the flight of an arrow, we will consider how far that arrow can fly. How far an arrow will fly is dependent upon the arrow's velocity and the upward angle at which it is fired.

Any projectile will fly to its maximum range if launched at an angle of 45 degrees. Although practical experience tells us that we seldom shoot at such an extreme angle unless we have shots sited up the bank of a ravine or simulating a treed raccoon. Keep in mind that my calculations disregard the effects of air resistance, a very difficult aspect of ballistics to calculate. Therefore, my range calculations should err slightly on the side of caution. Anyway, at 45 degrees the theoretical maximum ranges, for the example bows are;

- 180 ft/s - 334 yards,
- 240 ft/s - 595 yards, and
- 300 ft/s - 931 yards.

These figures, however, are extreme and not very realistic for range design requirements. In this guide the calculations for realistic safety measures are based on an arrow shot at a target 50 yards away over level ground with the arrow missing high. In this situation, the arrow will strike the ground at about the following ranges from the archer;

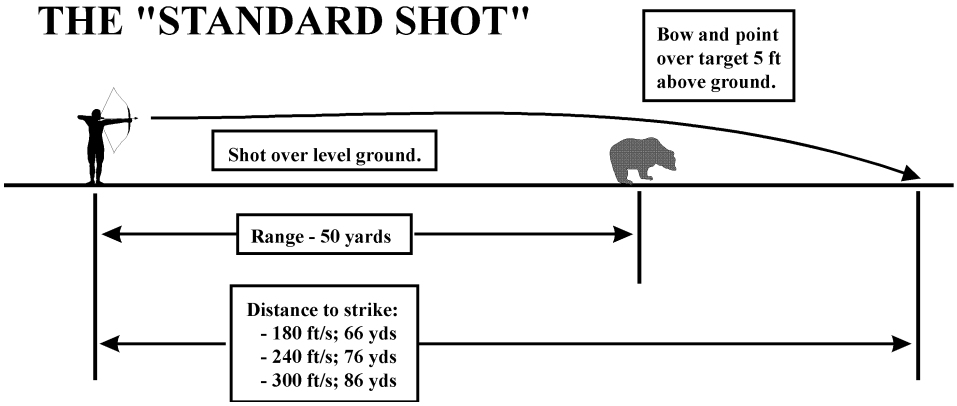
- 180 ft/s - 66 yards,
- 240 ft/s - 76 yards, and

NOTE: These ranges are developed from what will be considered the standard shot for range data in this Guide. Figure 1 illustrates the conditions for the "standard shot" and a detailed examination of equations and variables is at Annex B - Formulae and Tables.

- 300 ft/s - 86 yards.

The presumed conditions for the standard shot are:

- A target range of 50 yards;
- A bow height of 5 feet above ground;
- An arrow missing high which passes over the target at a height of 5 feet above the ground; and,
- The archer, target and the point at which the arrow strikes the ground are all level with each other.



The second set of numbers (above) gives us a more realistic set of ranges from which to develop our safety requirements. At an open shoot, where bows up to 300 ft/s may be allowed, a target set at a range of fifty yards over level ground will need a safety area behind it about 50 yards long. This area cannot contain other targets or trails. It cannot even overlap the "safety area" behind neighbouring targets. Most of our ranges are set up so that archers do not walk behind targets this closely. Keep in mind that these safety distances also apply to any shots toward areas where people (or animals) not involved in the archery event may wander. There are no extra points for shooting a neighbouring farmer's prize bull or somebody's pickup truck in the parking lot.

Range Factors - Shot Angle. We've already seen the difference in range between missing a target at 50 yards and firing at a 45-degree angle for maximum distance. This increase (from five to eleven times as far) highlights the need to very carefully consider any shot that requires archers to fire at an upward angle, however slight. To look at these figures from a perspective of shot angle, consider our missed arrows for the

fifty-yard target. The angles above horizontal they were fired at are:

- 180 ft/s - 4 1/2 degrees,
- 240 ft/s - 2 1/2 degrees, and
- 300 ft/s - 1 1/2 degrees.

ARROW BALLISTICS

Range in yards based on Velocity and Angle of Departure

Angle of Departure	Velocity		
	180 ft/s	240 ft/s	300 ft/s
5 degrees	73	120	183
10 degrees	123	213	328
15 degrees	173	304	472
30 degrees	292	518	809
45 degrees	334	595	931

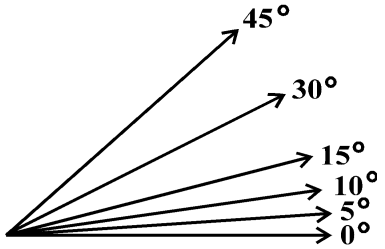


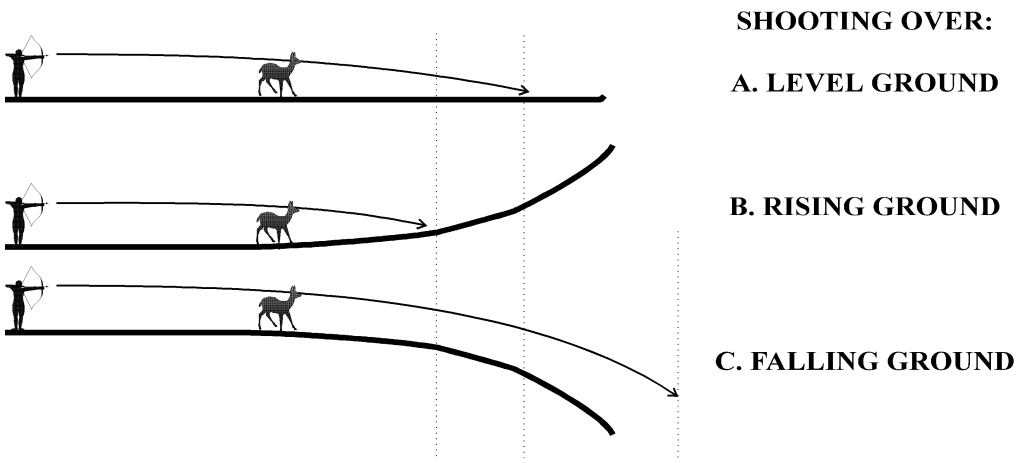
Figure 2 presents a table which compares possible ranges based on varying angles of departure and our standard arrow speeds. Any shooting stations which require archers to fire upwards (even slightly) should be laid out with a backstop that will stop all misses (however wide or high). This backstop could be natural, like a hillside, or artificial. A shoot I attended in Ontario had a treed raccoon target, behind the target the club had hung a large heavy fabric stop which halted and dropped missed arrows. Shooting at a downward angle obviously presents a significantly lower danger with the ground around the target catching the arrows. Figure 3 illustrates potential arrow trajectories when firing upwards and downwards.

Range Factors - Lay of the Land. Another consideration for designing an archery course is the lay of the land around each shooting station and target area. If we think about the arcing path of an arrow, we can see that the arrow will fly farther if the ground drops away behind the target and not fly as far if the ground rises behind the target. Figure 4 shows the relative effects of firing over ground which remains level, rises or falls behind the target. We can see that rising ground behind the target makes a natural backstop for missed arrows. Depending on how steeply the ground starts to rise, the additional distance behind the target needed for safety will vary accordingly. The steeper the ground, the shorter the distance. Remember, this applies to ground which rises behind the target, if the target is higher than the shooting station, go back to the paragraphs on Shot Angle. Next, we will look at what happens to our missed fifty yard shots if the ground level behind the target drops? How much farther will our arrows fly? If the ground behind the target drops 5 yards and continues on a level plane, how far from the archer will the arrow strike?:

- 180 ft/s - 95 yards,
- 240 ft/s - 117 yards, and
- 300 ft/s - 138 yards.

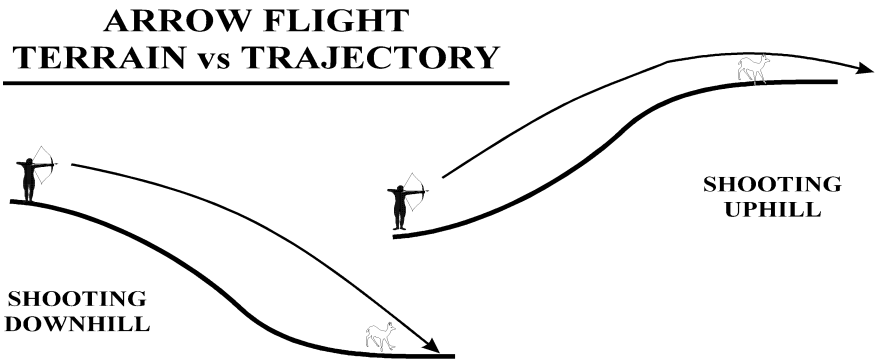
From this we can see that our open shoot target lane now needs to be 140 yards long to be safe for all three bow groups. Siting targets and shooting stations to make maximum use of natural backdrops certainly becomes more attractive.

Ricochets - Lane Width. We have looked at the distance an arrow may travel for our standard



shot, and considered the effects of the angle of fire and the lay of the land. Now what happens with those arrows that, heaven forbid, strike an intervening branch and decide to change direction? Or perhaps a beginning archer will not successfully thread the needle's eye to strike the vitals of one of ***those*** targets we've all seen. These arrows are ricochets. The existence of trees and other obstacles to sight and/or the line of fire (except, of course on that three-inch diameter heart circle) make it essential to consider them when estimating the dangerous area for a shooting lane. The possibility of the arrow ricocheting from trees, other objects or even the edge of the target itself means that the space in which an arrow may cause injury has width as well as length. Remember, a clear shot for the range designer may not be as clear for another archer less experienced or six inches shorter or taller. Obstacles will appear where you least expect them. The likelihood of ricochets is only truly reduced when a shot is over completely open ground.

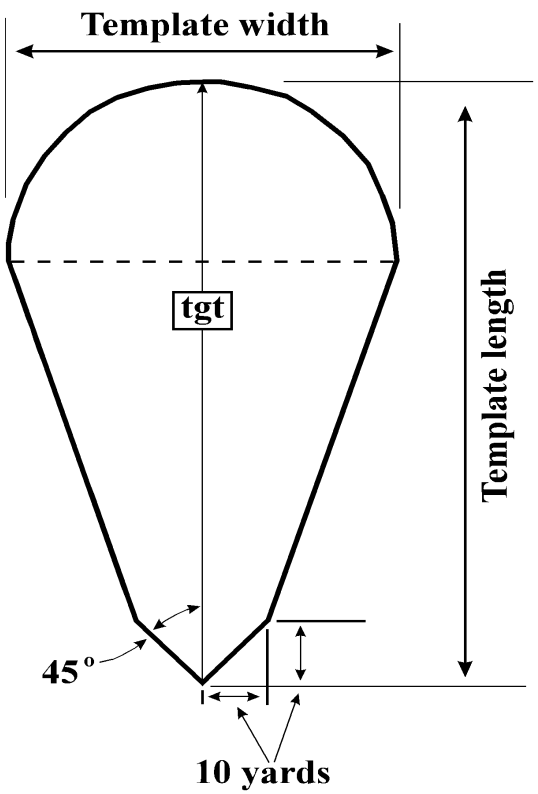
How Wide Could it Go? It is very difficult to estimate the "average" change of direction, velocity and angle of flight for a bouncing arrow. Experience shows that small changes of direction are more likely (less than 30 degrees), that arrows quickly lose energy and velocity on ricocheting and that the loss of speed



usually limits the distance gained from an upward bounce. This experience, unfortunately more often from watching my own arrows rather than someone else's, has allowed me to estimate that the general shape of the area we need to keep clear for a single shooting lane is something like the diagram at figure 5. A ratio of 60 per cent of the standard shot distance past the target seems to be an appropriate width either side of the target. For some additional safety, remember, this is not an exact science, I have rounded the template size up to 100 yards long and 60 yards wide.

The Template. I call the diagram of this danger area the Archery Template. It describes the "danger" area for one shot and can be reproduced to design a complete course. In practice, the concept of the template helps a course designer keep in mind the fact that a shooting lane required depth and width around

the target for safety. Missed arrows and ricochets affect where trails can run and what areas may or may not be considered safe when a shooting lane is in use. Admittedly, the shape and general dimensions of this template are based on experience rather than calculation. Additionally, each target lane must be subjected to an assessment based on target range, the lay of the land, and the presence of obstructions which may cause ricochets. The safety area must then be adjusted accordingly. For this template and all subsequent work I will use dimensions based on 300 ft/s bows. I recommend this be applied to all courses unless firm decisions are



made (and strictly enforced) to restrict faster bows.

ARCHERY TEMPLATE

For general planning purposes a template sized for 300 ft/s bows should be used.

Examination of the terrain for each shooting lane will require adjustment of the template based on the course designer's assessment.

The 300 ft/s template is:
100 yards long, and
60 yards wide.