

Applied Ballistics for Long Range Shooting

Second Edition

By Bryan Litz

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This book is dedicated to my Parents

To my Dad,
Who taught me how to shoot,
and that $2+2$ is *always* 4.

And to my Mom,
Who's always encouraged and supported
my pursuit of happiness.

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Introduction

There are a number of books on the subject of external ballistics. Most of them seem to fall into one of two categories: they're either too technical or they're not technical enough. The books in the *too technical* category are filled with equations and mathematical derivations intended to represent and advance the state of the art. In that respect, the books are a success; however few shooters are able to extract very much *practical* information that can be directly applied to improve their shooting. On the other end of the spectrum are the shooting books that aren't technical enough. The books I'm referring to usually talk about all aspects of shooting, with perhaps one chapter on exterior ballistics. Although well rounded and useful for teaching beginners about the many aspects of shooting, these books usually only scratch the surface of external ballistics.

This book is meant to bridge the gap between the rigorous mathematical treatment of external ballistics and the practical application of the subject. When I say *practical*, I'm talking about things that all shooters can understand and apply in order to achieve better performance. Some of the material is technical, but no more than it has to be.

The subject matter that fills these pages is inspired by years of experience and conversations with curious target shooters on the firing line and with long range hunters and tactical shooters. These are subjects that serious shooters care about and need to know in order to optimize the accuracy and precision of their shooting. I will try to avoid abstract, in depth explanations of things that won't help you shoot better! ***My objective is to help the average shooter improve their performance thru a better understanding of the science behind shooting.***

For years I pondered the notion of writing a book about ballistics because it is a subject that I enjoy learning and writing about. I felt there was a great need for a book that could explain the science of external ballistics to average shooters in layman's terms. However, it's not enough to just re-word information that's already available. I didn't feel it was worth the effort unless I could make an original contribution to the subject. After several years and a lot of effort and expense, I feel I have accomplished an original contribution. Part 3 of this book includes a catalogue of experimentally measured ballistic coefficient (BC) data for many popular bullets used for long range hunting and target shooting. As Chapter 2 will explain, the ballistic coefficient (BC) is the most important number for any kind of meaningful performance analysis including the calculation of accurate trajectories. A predicted trajectory is no more accurate than the information it's calculated with, and the BC is the input that characterizes the bullet. In the past, shooters have had to rely on the bullet manufacturer's advertised BC. For reasons that I'll explain later, the bullet manufacturers have historically advertised *inconsistent* and often *inaccurate* BCs. This situation has two major consequences. First of all, it prevents shooters from being able to make good comparisons of bullets from different makers. Secondly, shooters are unable to calculate the accurate trajectories that are required to hit targets at long range.

The accurate determination of a bullet's BC is not an easy task. The best way to determine BC is to instrument a range and perform carefully controlled test firings to *measure* the BC (vs predicting a BC with computer programs). This kind of testing is very expensive and complicated, but it's the only way to really know the BC of a

bullet for sure. Part 3 of this book contains the results of my BC testing of over 175 modern long range small arms bullets in 8 calibers from 6 major brands, and is the most extensive and accurate assembly of experimental BC data ever compiled. I consider the information compiled in Part 3 to be my original contribution to the shooting sports.

The chapters that fill this book address various subjects of long range shooting, many of which have to do with accurate and meaningful calculation of ballistic trajectories. Regardless of what methods are used, a trajectory prediction can't be any more accurate than its least accurate input. I feel that traditionally, BC has been the input that's prone to the highest degree of error, so I believe this makes my compilation of experimentally determined BCs a valuable asset to the shooting sports.

The state of the art

There have been several important advances in the science of external ballistics that have yet to make it into mainstream practice. With this book, I intend to make these advances understood and available to all shooters.

The application of precision rifle fire at long range is a challenge comprised of many variables. Some of these variables are easy to measure and account for; others involve more guess work. The idea is to move the variables into the *known* category, and minimize the number and effect of the *unknowns*. One area that this book will transform into a known variable is trajectory calculations.

State of the art ballistics solutions have been available to the sporting arms industry for quite some time. We don't have to re-invent the wheel; shooters only need to learn how to effectively employ the tools that are already available. This book will walk the reader thru these details.

The intent of this book is not to advance the state of the art in exterior ballistics. The intent is to help the average shooter understand and take full advantage of the existing state of the art by using accurate data, and employing the most appropriate tools available to solve the problem. Before you start to think this sounds like a sales pitch, I won't push the sale of any specific software. In fact, the only software you need is included with this book, and is available free on the internet. I will simply focus on demonstrating how to use the tools in the best possible way.

Modeling

Not all parameters involved with external ballistics can be accurately measured (as least not with my budget). For these more subtle details, I rely heavily on a background in modeling and simulation to illustrate the physics of what's happening. They say a picture is worth a thousand words. Oftentimes, a good model can be the picture that brings clarity to a situation. Digital computer models can be very misleading if the user doesn't understand their limitations. On the other hand, when models are used properly, they can be very powerful and educational tools.

Statistics

One problem with computer models and problem solutions in general is that they're inherently deterministic. In other words, if you feed it the same inputs, it will always return exactly the same outputs. Shooting, as we know, is not like that! Our objective as precision shooters is to minimize the uncertainties, and make our

shooting system perform as consistently as possible. However, there will always be some degree of uncertainty to deal with. The good news is; we have the means to deal with the uncertainty involved in shooting, with statistics. Statistics is a very powerful, important and often misunderstood subject area for shooters. Shooting is full of measurable uncertainties (muzzle velocity, range, wind, powder charge, case weight, case neck thickness, bullet dimensions, etc). It's obvious that the reason why shooters miss targets is entirely due to the uncertainties involved in shooting. ***Statistics is math's way of dealing with uncertainty.*** With just a few basic principles from statistics, shooters are empowered to make better informed decisions about their reloading and shooting. A systematic study of the uncertainties involved in shooting will be a common theme throughout this book. For many values that are given, the associated error bounds are given with them. Citing numbers in this way reflects the true non-deterministic nature of shooting. If I say the drop of some bullet is 55 inches, that number has value. But If I say the drop is 55 inches, +/- 5 inches based on the uncertainties involved, the shooter has better information to make a decision with.

The Big Picture

It's a good idea to take a step back once in a while and ask: ***What's the point?*** In this book, as we dive deep into the subjects within external ballistics, the big picture is always kept in the forefront. The material in this book is meant to help shooters achieve a deeper appreciation, understanding and enjoyment of shooting. Above all, the ***point is to achieve greater success!*** Whether you measure success in group size, points, or long range kills, the material in this book will help you do those things better.

Part 1: The Elements of Exterior Ballistics

Chapter 1: Fundamentals

There are many variables that come into play in long range shooting. To consider them all at once in their complexity would be overwhelming. In order to begin a systematic study of ballistics, we'll first break up the elements into 2 basic categories:

1. Deterministic variables
2. Non-deterministic variables

Deterministic variables are those variables that can be measured and accounted for. Most variables involved in long range shooting are deterministic. Gravity drop and spin drift are two examples of deterministic variables. Basically, deterministic variables are all those things that can be entered onto a predictive ballistics program and accounted for. If all the elements in long range shooting were related to *deterministic variables*, it would be quite easy to reliably hit targets at very long range. The most challenging elements of long range shooting are the *non-deterministic* variables.

Non-deterministic variables are those variables that cannot be directly measured, and affect the trajectory of the bullet. The most notorious and problematic non-deterministic variable in long range shooting is definitely the wind. Since the exact speed and direction of the wind cannot be determined at every point between the shooter and target, its effects cannot be precisely accounted for. Another non-deterministic variable is muzzle velocity variation. Ideally, every bullet leaves the rifle with the same muzzle velocity, and drops the same amount at a given range. The reality is that every shot leaves the barrel at a *different* velocity, and has a different amount of drop at long range. The goal is to handload ammunition that is as consistent as possible and produces the most uniform muzzle velocity, but there will always be some amount of *non-deterministic* variation. It's important to understand how to handle the uncertainties of shooting. Statistics is math's tool for doing just that.

This book has chapters on each of the most important elements of long range shooting. It's important to categorize the elements as deterministic or non-deterministic so you know how to manage them. Getting control of the sights should be a deterministic variable. With careful attention to detail and quality components, there should be no excuse for missing a target because of a misunderstanding of the

sights. The same goes for the rest of the deterministic variables. Everything affecting the flight of the bullet that can be measured should be measured and accounted for using predictive ballistics software. Chapter 8 will demonstrate the effective use of a ballistics program to account for all of the deterministic variables that affect a bullet on a long range trajectory. In reality, the only reasons (related to ballistics) for missing a target at long range are the non-deterministic variables. The non-deterministic variables are where you have to rely on statistics and imperfect human judgment. *After you have mastered the basic elements of long range shooting, the balance of your time spent training and improving will be with the non-deterministic variables.*

Accuracy and Precision

An important fundamental topic of shooting is accuracy vs. precision. In the context of shooting, accuracy is the measure of how close your shots are to the center of the target, and precision is how tightly the shots are grouped together (see Figure 1.1). It's important to distinguish between accuracy and precision because they're both important, but they're both influenced by different types of variables. For example, accuracy is more related to the elements involving the platform and the deterministic variables. For example, a problem with the sights will cause shots to miss the target *systematically*, meaning you may shoot a small group beside the intended point of impact.

In general, precision is determined by the non-deterministic variables. Group shooting (Benchrest competition) is only a contest of precision. It doesn't matter where the group is in relation to the center of the target; all that matters is how close the shots are to each other. Score shooting requires both accuracy and precision. The shots must hit near the center of the target *and* be tightly grouped to maximize score. Long range hunting and sniping also requires both accuracy and precision.

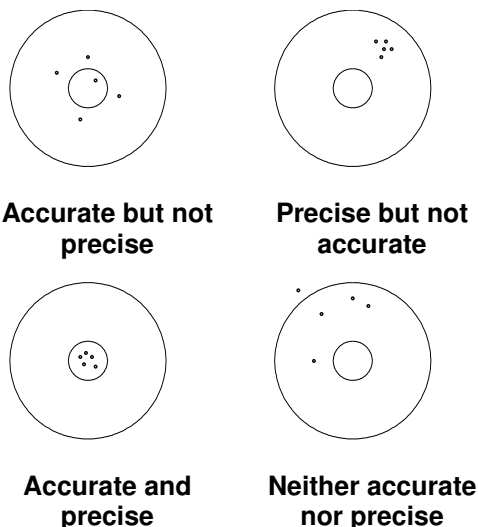


Figure 1.1. Examples of accuracy and precision.

Understanding the Shooting Objective

Serious shooters know how to consider the objective of their shooting. For example, if the shooting is being done on paper targets, then bullet impact energy is a non-issue. If the shooting is being done in uncertain wind conditions, then minimizing wind drift is paramount. Here's an example to illustrate the point. Consider a varmint hunter who has hunted groundhogs for many years without a rangefinder. This hunter favors cartridges like the .22-250 and .220 Swift because of the very flat trajectories. A flat trajectory is an asset to a shooter who has to deal with range uncertainty. Now, give this guy a laser rangefinder and you've changed the nature of his shooting. By removing the range uncertainty, a flat trajectory is no longer a valuable asset. Now the biggest uncertainty is wind deflection, and wind

deflection is minimized by a different type of shooting system than the *flat* shooting system. ***Selecting the proper shooting equipment is about minimizing the biggest sources of uncertainty.***

As long as the shooting objective is narrow and well defined as in target shooting, the task is easy. The challenge comes when you want to use one rifle for multiple objectives. When that's the case, some compromise is usually in order.

Understanding Measures of Ballistic Merit

Once the shooting objective is clearly defined, the next step is to consider the *measures of ballistic merit* that are relevant to the objective. A *measure of ballistic merit* is basically anything that relates to ballistic performance. The following subsections define some common measures of ballistic merit that are used to analyze the performance of shooting systems.

Muzzle velocity

For any bullet of any caliber, weight, and BC, elevated muzzle velocity will enhance all measures of external ballistic performance. Bear in mind that excessive muzzle velocity can have adverse effects on precision, accuracy and safety if taken to the extreme.

Muzzle velocity is typically measured in feet per second (fps) by shooting thru/over a chronograph. In addition to knowing the average muzzle velocity, shooters need to know and manage the variation in muzzle velocity for the shooting system under evaluation. The variation or uncertainty in muzzle velocity is typically quantified by two statistical parameters: Standard Deviation (SD) and/or Extreme Spread (ES). These statistical measures will be better defined in a later section. For now, the point is to understand the importance of measuring the average muzzle velocity, as well as the variation in muzzle velocity.

Ballistic Coefficient

In words, the Ballistic Coefficient (BC) determines how well a bullet can maintain velocity. Bullets with high BCs maintain velocity better. For long range small arms fire, downrange ballistic performance is largely dependent on how much velocity is retained by the bullet, which makes BC a very important measure of ballistic merit. BC will be the subject of much more discussion in this book.

Trajectory

As illustrated in the previous section about the shooting objective, there is great value in a flat trajectory for applications where range uncertainty exists. Small caliber rifles that fire light weight bullets at very high muzzle velocities (like the .22-250 and .220 swift) have the flattest short range trajectories. However, as Chapter 3 will demonstrate, a larger caliber, heavier bullet with a higher BC and slower muzzle velocity can have a superior (flatter) trajectory far downrange. For this measure of ballistic merit, superiority is determined by *danger space*. Danger space is similar to point blank range. The bigger the danger space is, the greater the chance of hitting a target, given a range or muzzle velocity uncertainty. Point blank range and danger space will be more completely explored in Chapter 3. For now, it's only important to get familiar with the concept of trajectory as a measure of ballistic merit that's related to range uncertainty.

Wind Deflection

Next to range uncertainty, wind uncertainty is usually the biggest problem to overcome for most long range shooting applications. All of Chapter 5 is devoted to the mechanics of wind deflection. The main idea to come to grips with is that the exact speed and direction of wind between the shooter and target in the field cannot be exactly measured and corrected for. We try to quantify wind the best we can, but in the end, there will always be some uncertainty. The shooting system that's best at hitting targets in the wind is the one that minimizes the magnitude, and with it, the uncertainty of wind deflection. For example, consider two rifles. Rifle A has 100" of wind drift at 1000 yards in a 10 MPH crosswind, and rifle B has 50" of wind drift in the same condition. If the wind speed changes or is misjudged by 2 MPH, rifle A misses the point of aim by 20", while rifle B only misses by 10". *The same wind uncertainty results in less miss distance for the bullet that has less wind deflection.* This principal applies to every long range shooting discipline. It doesn't matter if you'll only get one long shot at an elk, or if you're in the middle of a 20 shot string of target shooting and your last shot was 30 seconds ago. The less wind drift a bullet has, the less miss distance is incurred by uncertainties in the wind speed and direction. The fundamental measure of ballistic merit that quantifies wind deflection is *lag time*. Lag time is determined by a bullet's BC and muzzle velocity, and will be thoroughly explored in Chapter 5.

Kinetic Energy

Kinetic Energy (KE) is the measure of striking energy a bullet has as it travels downrange. KE is measured in foot-pounds, and is only relevant for certain applications where the shooter cares about the bullet's affect on the target. Hunting, military and law enforcement applications come to mind. Target shooters don't care about how much KE their bullets have, just so it's enough to put a hole in the paper. Also, varmint hunters usually aren't concerned with KE either, because most center fire rifles, even down to .17 caliber, are lethal enough to kill vermin.

KE is proportional to the bullet's mass and velocity. A common way to use KE is to determine how much KE is required to accomplish the shooting objective (humane kill of an animal or destruction of some material) and then calculate the range that the bullet falls below the required thresh hold. For example, let's say it takes 1,000 foot-pounds of KE to humanely kill a white tailed deer with a .30 caliber 165 grain Sierra Game King bullet. A .308 Winchester that can shoot the 165 grain bullet at 2700 fps has 2600 foot-pounds of KE at the muzzle, and drops below 1000 foot-pounds somewhere around 600 yards. Based on this measure of ballistic merit, we can say that the .308 loaded with 165 grain Game King bullets is *effective* on white tailed deer out to 600 yards. The actual effective range may be less if the accuracy of the rifle or other field variables prevents reliable hits at that range.

Measures of merit not related to external ballistics

It's important to realize that there are many variables related to long range shooting that are outside the scope of external ballistics and this book. Terminal bullet performance, quality of optics, the physical size of the rifle, shooting skills, and range estimation are all important factors that are not given much consideration

in this book, but are very important aspects of shooting. In other words, your choice of equipment shouldn't be made completely on ballistics alone, but ballistics is an important consideration. *The intent of this book is to help shooters understand ballistics so they can make decisions that are best for their application.*

The remaining Chapters in Part 1 of this book discuss the details and science of the important elements in external ballistics. Specifically, the most important forces that govern the flight dynamics of projectiles like gravity drop and wind drift are addressed. Part 2 is a collection of specific and general analysis for various types of target shooting and hunting applications. The idea is to provide the reader with enough fundamental information in Part 1, so they can perform the detailed and meaningful analysis as presented in Part 2. Part 3 presents the physical details of long range bullets including BCs to allow the reader to make accurate ballistic performance assessments.