

# Applied Ballistics for Long Range Shooting

Second Edition

By Bryan Litz

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## Table of Contents

Acknowledgments.....	xi
Introduction.....	1
<b>PART 1: THE ELEMENTS OF EXTERIOR BALLISTICS .....</b>	<b>2</b>
Chapter 1: Fundamentals .....	7
Chapter 2: The Ballistic Coefficient .....	13
Chapter 3: Gravity Drop .....	37
Chapter 4: Uphill/Downhill Shooting.....	47
Chapter 5: Wind Deflection.....	53
Chapter 6: Gyroscopic Drift.....	85
Chapter 7: The Coriolis Effect.....	97
Chapter 8: Using Ballistics Programs .....	103
Chapter 9: Getting Control of Sights .....	123
Chapter 10: Bullet Stability .....	135
Chapter 11: Extended Long Range Shooting.....	149
Summary of the Elements.....	165
<b>PART 2: BALLISTIC PERFORMANCE ANALYSIS .....</b>	<b>142</b>
Chapter 12: Interesting Facts and Trends .....	171
Chapter 13: Example Performance Analysis .....	189
Chapter 14: Generalized Score Shooting Analysis.....	201
Chapter 15: Lethality of Long Range Hunting Bullets.....	215
Chapter 16: Hit Probability for Hunting .....	243
<b>PART 3: PROPERTIES OF LONG RANGE BULLETS.....</b>	<b>234</b>
Chapter 17: Anatomy of a Bullet.....	253
Chapter 18: Monolithic Bullets.....	263
Chapter 19: Using the Experimental Data .....	271
.224 Caliber (5.56 mm).....	317
Berger .224 cal 70 grain VLD .....	318
Berger .224 cal 73 grain BT .....	319
Berger .224 cal 75 grain VLD .....	320
Berger .224 cal 77 grain BT .....	321
Berger .224 cal 80 grain VLD .....	322



Berger .224 cal 82 grain BT .....	323
Berger .224 cal 90 grain VLD .....	324
Berger .224 cal 90 grain BT .....	325
Sierra .224 cal 52 grain MatchKing .....	326
Sierra .224 cal 55 grain FMJ.....	327
Sierra .224 cal 69 grain MatchKing .....	328
Sierra .224 cal 77 grain MatchKing .....	329
Sierra .224 cal 80 grain MatchKing .....	330
Sierra .224 cal 90 grain MatchKing .....	331
Nosler .224 cal 52 grain CC.....	332
Nosler .224 cal 55 grain Ballistic Tip.....	333
Nosler .224 cal 77 grain CC.....	334
Hornady .224 cal 40 grain Vmax .....	335
Hornady .224 cal 50 grain Vmax .....	336
Hornady .224 cal 55 grain Vmax .....	337
Hornady .224 cal 52 grain Amax .....	338
Hornady .224 cal 75 grain Amax .....	339
Hornady .224 cal 80 grain Amax .....	340
Hornady .224 cal 68 grain BTHP .....	341
Hornady .224 cal 75 grain BTHP .....	342
Lapua .224 caliber 69 grain Scenar.....	343
Lapua .224 caliber 77 grain Scenar.....	344
JLK .224 caliber 80 grain VLD .....	345
DRT .224 caliber 79 grain Frangible.....	346
Lake City .224 cal 62 grain FMJBT.....	347
.243Caliber (6mm).....	348
Berger .243 cal 87 grain VLD .....	349
Berger .243 cal 90 grain BT .....	350
Berger .243 cal 95 grain VLD .....	351
Berger .243 cal 100 grain BT.....	352
Berger .243 cal 105 grain BT.....	353
Berger .243 cal 105 grain VLD .....	354
Berger .243 cal 108 grain BT.....	355
Berger .243 cal 115 grain VLD .....	356
Sierra .243 cal 70 grain MatchKing .....	357
Sierra .243 cal 80 grain Blitz.....	358
Sierra .243 cal 95 grain MatchKing .....	359

Sierra .243 cal 107 grain MatchKing .....	360
DTAC .243 caliber 115 grain BTHP .....	361
DTAC .243 caliber 117 grain .....	362
Nosler .243 cal 70 grain Ballistic Tip.....	363
Nosler .243 cal 80 grain Ballistic Tip.....	364
Nosler .243 cal 95 grain Partition.....	365
Hornady .243 caliber 58 grain Vmax .....	366
Hornady .243 caliber 65 grain Vmax .....	367
Hornady .243 caliber 75 grain Vmax .....	368
Hornady .243 caliber 87 grain Vmax .....	369
Hornady .243 caliber 85 grain Interbond .....	370
Hornady .243 caliber 87 grain BTHP .....	371
Hornady .243 caliber 100 grain BTSP .....	372
Hornady .243 caliber 105 grain Amax .....	373
Precision Ballistics .243 caliber 103 grain VLD .....	374
Precision Ballistics .243 caliber 105 grain VLD .....	375
Precision Ballistics .243 caliber 108 grain VLD .....	376
Precision Ballistics .243 caliber 113 grain VLD .....	377
Precision Ballistics .243 caliber 115 grain VLD .....	378
Lapua .243 caliber 90 grain FMJBT .....	379
Lapua .243 caliber 90 grain Scenar.....	380
Lapua .243 caliber 105 grain Scenar.....	381
JLK .243 caliber 105 grain VLD .....	382
Matrix .243 caliber 107 grain VLD .....	383
25 Caliber (.257" diameter) .....	384
Berger 25 caliber 115 grain VLD .....	385
Sierra 25 caliber 100 grain Match King .....	386
Sierra 25 caliber 117 grain Pro Hunter .....	387
Nosler 25 caliber 115 grain Ballistic Tip .....	388
Hornady 25 caliber 87 grain Spitzer .....	389
Hornady 25 caliber 110 grain Interbond .....	390
Hornady 25 caliber 117 grain SST.....	391
Barnes 25 caliber 115 grain TTSX FB.....	392
.264 Caliber (6.5mm).....	393
Berger .264 caliber 120 grain BT.....	394
Berger .264 caliber 130 grain VLD .....	395
Berger .264 caliber 140 grain VLD .....	396

Berger .264 caliber 140 grain short BT .....	397
Berger .264 caliber 140 grain Long Range BT .....	398
Berger .264 caliber 140 grain BT .....	399
Sierra .264 caliber 120 grain Pro Hunter .....	400
Sierra .264 caliber 107 grain MatchKing .....	401
Sierra .264 caliber 123 grain MatchKing .....	402
Sierra .264 caliber 142 grain MatchKing .....	403
Nosler .264 caliber 120 grain Ballistic Tip .....	404
Nosler .264 caliber 140 grain Accubond.....	405
Nosler .264 cal 140 grain Custom Competition .....	406
Hornady .264 caliber 95 grain Vmax .....	407
Hornady .264 caliber 129 grain SST .....	408
Hornady .264 caliber 140 grain Amax .....	409
Lapua .264 caliber 108 grain Scenar.....	410
Lapua .264 caliber 123 grain Scenar.....	411
Lapua .264 caliber 139 grain Scenar.....	412
Lapua .264 caliber 144 grain FMJBT .....	413
JLK .264 caliber 140 grain VLD .....	414
Cauterucio .264 caliber 119 grain 10-ogive.....	415
Cauterucio .264 caliber 119 grain 15-ogive.....	416
Cauterucio .264 caliber 131 grain VLD.....	417
Hoover .264 caliber 136 grain.....	418
Norma .264 caliber 130 grain Diamond.....	419
Swift .264 caliber 130 grain Scirocco .....	420
.270Caliber (.277") .....	421
Berger 270 caliber 130 grain VLD .....	422
Berger 270 caliber 140 grain VLD .....	423
Berger 270 caliber 150 grain VLD .....	424
Sierra 270 caliber 115 grain MatchKing .....	425
Sierra 270 caliber 135 grain MatchKing .....	426
Sierra 270 caliber 150 grain Game King .....	427
Nosler 270 caliber 140 grain Ballistic Tip .....	428
Nosler 270 caliber 140 grain Nosler Partition .....	429
Hornady 270 caliber 110 grain Vmax .....	430
Hornady 270 caliber 130 grain Interbond .....	431
Hornady 270 caliber 140 grain BTSP Interlock .....	432
Hornady 270 caliber 150 grain SP Interlock.....	433

Matrix 270 caliber 150 grain RBT .....	434
Cutting Edge 270 caliber 120 grain HPBT .....	435
Cutting Edge 270 caliber 130 grain HPBT .....	436
.284 Caliber (7mm) .....	437
Berger .284 caliber 140 grain VLD .....	438
Berger .284 caliber 168 grain VLD .....	439
Berger .284 caliber 175 grain XLD .....	440
Berger .284 caliber 180 grain VLD .....	441
Berger .284 caliber 180 grain Hybrid .....	442
Berger .284 caliber 180 grain BT .....	443
Sierra .284 caliber 150 grain Game King .....	444
Sierra .284 caliber 175 grain Game King .....	445
Sierra .284 caliber 168 grain MatchKing .....	446
Sierra .284 caliber 175 grain MatchKing .....	447
Nosler .284 caliber 120 grain Ballistic Tip .....	448
Nosler .284 caliber 150 grain Ballistic Tip .....	449
Nosler .284 caliber 150 grain Partition .....	450
Nosler .284 caliber 175 grain Partition .....	451
Hornady .284 caliber 120 grain Vmax .....	452
Hornady .284 caliber 139 grain SP Interlock .....	453
Hornady .284 caliber 139 grain BTSP Interlock .....	454
Hornady .284 caliber 154 grain SP Interlock .....	455
Hornady .284 caliber 154 grain SST .....	456
Hornady .284 caliber 162 grain Amax .....	457
Hornady .284 caliber 175 Interlock .....	458
JLK .284 caliber 180 grain BTHP .....	459
Barnes .284 caliber 175 TSX .....	460
Wildcat .284 caliber 200 grain ULD .....	461
Cauterucio .284 caliber 177 grain VLD .....	462
Cauterucio .284 caliber 189 grain VLD .....	463
Matrix .284 caliber 168 grain VLD .....	464
Matrix .284 caliber 175 grain RBT .....	465
Matrix .284 caliber 190 grain VLD .....	466
.308 Caliber (7.62mm) .....	467
Berger .308 caliber 155 grain BT .....	468
Berger .308 caliber 155 grain VLD .....	469
Berger 155.5 grain BT FULLBORE .....	470

Berger .308 caliber 155 grain Hybrid .....	471
Berger .308 caliber 168 grain BT .....	472
Berger .308 caliber 168 grain VLD .....	473
Berger .308 caliber 168 grain Hybrid .....	474
Berger .308 caliber 175 grain Long Range BT .....	475
Berger .308 caliber 175 grain VLD .....	476
Berger .308 caliber 175 grain Tactical .....	477
Berger .308 caliber 185 grain VLD .....	478
Berger .308 caliber 185 grain Long Range BT .....	479
Berger .308 caliber 185 grain Hybrid .....	480
Berger .308 caliber 190 grain VLD .....	481
Berger .308 caliber 200 grain Hybrid .....	482
Berger .308 caliber 210 grain VLD .....	483
Berger .308 caliber 210 grain Long Range BT .....	484
Sierra .308 caliber 155 grain Palma (2155) .....	485
Sierra .308 caliber 155 grain Palma (2156) .....	486
Sierra .308 caliber 168 grain MatchKing .....	487
Sierra .308 caliber 173 grain FMJBT .....	488
Sierra .308 caliber 175 grain MatchKing .....	489
Sierra .308 caliber 180 grain MatchKing .....	490
Sierra .308 caliber 190 grain MatchKing .....	491
Sierra .308 caliber 200 grain MatchKing .....	492
Sierra .308 caliber 210 grain MatchKing .....	493
Sierra .308 caliber 220 grain MatchKing .....	494
Sierra .308 caliber 240 grain MatchKing .....	495
Sierra .308 caliber 165 grain Game King .....	496
Sierra .308 caliber 180 grain Game King .....	497
Sierra .308 caliber 200 grain Game King .....	498
Nosler .308 caliber 125 grain Ballistic Tip .....	499
Nosler .308 caliber 150 grain Ballistic Tip .....	500
Nosler .308 caliber 165 grain Ballistic Tip .....	501
Nosler .308 caliber 180 grain Ballistic Tip .....	502
Nosler 155 grain Custom Competition .....	503
Nosler .308 cal 168 grain Custom Competition .....	504
Nosler .308 caliber 165 grain Partition .....	505
Nosler .308 caliber 180 grain Partition .....	506
Nosler .308 caliber 200 grain Partition .....	507

Nosler .308 caliber 165 grain Accubond.....	508
Nosler .308 caliber 180 grain Accubond.....	509
Nosler .308 caliber 200 grain Accubond.....	510
Hornady .308 caliber 155 grain Amax .....	511
Hornady .308 caliber 168 grain Amax .....	512
Hornady .308 caliber 178 grain Amax .....	513
Hornady .308 caliber 208 grain Amax .....	514
Hornady .308 caliber 150 grain SST .....	515
Hornady .308 caliber 165 grain SST .....	516
Hornady .308 caliber 150 grain BTSP .....	517
Hornady .308 caliber 190 grain BTSP .....	518
Hornady .308 caliber 168 grain HPBT .....	519
Hornady .308 caliber 178 grain HPBT Match .....	520
Dietlein .308 caliber 155.5 grain ULD .....	521
Dietlein .308 caliber 168 grain ULD .....	522
Dietlein .308 caliber 173 grain ULD .....	523
Dietlein .308 caliber 175 grain ULD .....	524
Dietlein .308 caliber 185 grain ULD .....	525
Dietlein .308 caliber 190 grain ULD .....	526
Lapua .308 caliber 155 grain Scenar.....	527
Lapua .308 caliber 167 grain Scenar.....	528
Lapua .308 caliber 185 grain Scenar.....	529
Lapua .308 caliber 185 grain FMJBT (D46) .....	530
Lapua .308 caliber 200 grain FMJBT .....	531
Barnes .308 caliber 168 grain TSX BT .....	532
Barnes .308 caliber 168 grain TTSX BT .....	533
Barnes .308 caliber 180 grain TSX BT .....	534
JLK .308 caliber 155 grain VLD .....	535
JLK .308 caliber 210 grain VLD .....	536
JLK .308 caliber 210 grain VLD LBT .....	537
Matrix .308 caliber 168 grain RBT .....	538
Matrix .308 caliber 210 grain VLD .....	539
Cutting Edge .308 caliber 180 grain HPBT.....	540
.308 caliber 155 grain HBC (Australia) .....	541
PMP .308 caliber 155 grain HPBT (S. Africa).....	542
DRT .308 caliber 175 grain Frangible.....	543
DRT .308 caliber 200 grain Frangible.....	544



GS Custom .308 caliber 137 grain SP ..... 545

.338 Caliber ..... 546

Berger 338 caliber 300 grain Hybrid ..... 547

Sierra 338 caliber 250 grain Match King ..... 548

Sierra 338 caliber 300 grain Match King ..... 549

Sierra 338 caliber 250 grain Game King ..... 550

Hornady 338 caliber 225 grain SST ..... 551

Hornady 338 caliber 250 grain BTHP Match ..... 552

Hornady 338 caliber 285 grain BTHP Match ..... 553

Nosler 338 caliber 225 grain Accubond ..... 554

Nosler 338 caliber 250 grain Accubond ..... 555

Lapua 338 caliber 250 grain Scenar ..... 556

Lapua 338 caliber 300 grain Scenar ..... 557

Barnes 338 caliber 225 grain TTSX BT ..... 558

Lehigh 338 caliber 230 grain brass solid ..... 559

GS Custom 338 caliber 232 grain SP ..... 560

**REFERENCES ..... 561**

**APPENDIX ..... 562**

Equation 2.1: The Ballistic Coefficient ..... 563

Equation 2.2: The Form Factor ..... 564

Equation 5.1: Lag Time ..... 565

Equation 5.2: Wind Deflection ..... 566

Equation 5.3: Velocity ..... 567

Equation 5.4: Aerodynamic Jump ..... 568

Equation 6.1: Spin Drift ..... 569

Equation 9.1: Aperture Sight Calibration ..... 570

Equation 12.1: Kinetic Energy ..... 571

Equation 15.1: Matunas' Optimal Game Weight Formula ..... 572

Equation 19.1: G7 form factor prediction ..... 573

The Miller Stability Formula ..... 574

The Miller Stability Formula: Velocity Correction ..... 575

The Miller Stability Formula: Atmospheric Correction ..... 576

ICAO Standard Atmosphere ..... 577

Definition of Speed of Sound ..... 578





*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.*

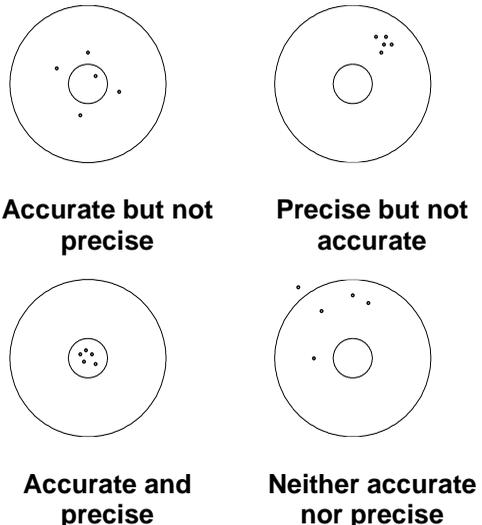
### Accuracy and Precision

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.

### 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



**Figure 1.1. Examples of accuracy and precision.**

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.