Practical Ballistics

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Introduction

External ballistics is the science of bullet flight, and is part of the diverse skill set required to hit targets at long range. When science is applied in the real world, especially in a field environment, compromises are a necessary evil; perfect data just isn't available. How much the compromise affects your ability to hit targets will depend on your tools, and more importantly, your ***knowledge of how to use them properly.*** *This article will explore the application of external ballistics to tactical shooting scenarios, focusing on how to close the gap between pure science, and practical application*.

Tools of the trade

There are 3 primary *classes* of tools that you'll use when applying ballistics in the field:

1. Tools for raw data collection. These are things like: rangefinders (LRF's, maps, ranging reticles), Kestrel or other weather measuring tools, angle cosine indicators, etc. Basically they're the measurement tools you need to gather the information required to support a scientific calculation. The more refined and accurate your measurements are, the more accurate your ballistic solutions will be.
2. The ballistic solver. The purpose of this tool is to bridge the gap between raw data and useful fire solutions. These come in many forms including PDA's, smartphones, nomograms (like the Accuracy 1st Whiz Wheel), and basic range-cards. It's important to note that some solvers are inherently more accurate than others, but *no solver is more accurate than the raw data supplied to it.*
3. The riflescope. In terms of ballistics, the purpose of the scope is to enable the shooter to apply the calculated fire solution via dials or reticle with as little error as possible. This is a demanding task that's often taken for granted.

You can think of these 3 classes of tools as links in a chain. Raw data supports a calculation, and the riflescope applies that calculation. As with any chain, it's no stronger than its weakest link. In a perfect world, raw data measurements would be complete and perfect every time. That perfect data would drive a perfect ballistic calculation, and the scope would allow the shooter to apply the fire solution with no error. Obviously we don't live in a perfect world. What we can do is learn how to do the most with what we have and close the gap as much as possible.

Great amounts could be (and have been) written on each of the 3 classes of tools. From how to refine your use of a ranging reticle, to verifying your scope dials are producing the desired corrections; it's a lot of information. The remainder of this article will focus on the ballistic solver.

The ballistic solver: From raw data to a useful fire solution

Essentially the ballistic solver is applying the equations of projectile motion to simulate a ballistic trajectory. This requires accurate models of the: target, atmosphere, projectile, as well as the initial conditions. Of the variables required to predict bullet drop, there are only a couple that are difficult to nail down with certainty; the *muzzle velocity and BC*.

Muzzle velocity is difficult to know because you need a chronograph to measure it directly. Even then, most chronographs are not as accurate as they're thought to be. Furthermore, access to chronographs for military snipers is not always assured. Due to these challenges, it's common to have a degree of uncertainty related to muzzle velocity. You can make an intelligent assumption about your muzzle velocity by shooting at a distant target, observing your drop, and adjusting the velocity input to your ballistic solver until the prediction matches the observed drop. Some programs even have built in functions that automatically find the MV based on observed drop. ***Caution is advised when conducting this exercise though, as any error or uncertainty in the observation will bias the calibration, and your future predictions will be off as a result***. Best practice is to shoot to the supersonic extent of your weapon system to determine MV, as this will minimize (but not eliminate) experimental error (more on this later).

Having an accurate BC is even more challenging and as we'll see shortly, even the most *accurate* BC may not be an adequate model at transonic speed.

Modeling the Projectile: G1 vs. G7 Standards

A bullet's Ballistic Coefficient (BC) is a measure of how well a bullet retains velocity. There's lots of smoke and mirrors surrounding the actual meaning of the BC, but it's actually quite simple to understand. Mathematically, the BC is the Sectional Density (SD) divided by a form factor. SD is a familiar term, and is easy to calculate: SD = bullet weight/7000/caliber squared. For example, a 175 grain .308 bullet has a SD of: $175/7000/.308^2 = 0.264$. BC is simply the SD divided by a *form factor*. Form factor is simply a comparison of a particular bullets drag to the drag of a *standard projectile.* There are many standard projectiles; G1 and G7 are the ones in most common use. Suppose you compared the drag of a bullet to the G1 standard and found your bullet had 55.6% the drag of that standard projectile. That means your bullet has a G1 form factor of 0.556. If we're talking about the .30 cal 175 grain SMK which has a SD of .264, that bullet would have a G1 BC of .264/.556 = .475. In fact this is the measured form factor and BC for that bullet between 3000 and 1500 fps.

The G7 BC is the same math, only referring to the G7 curve instead of G1. The G7 form factor of the 175 SMK is 1.086, so the G7 BC is: .264/1.086 = .243.

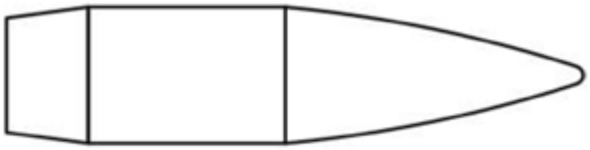
G1 Standard Projectile	G7 Standard Projectile
	

Figure 1: Comparison of the standard projectiles.

The form factors are so different because the G1 and G7 projectiles and drag curves are dramatically different (see Figures 1 and 2).

The drag curves depicted in Figure 2 are representing the drag coefficient as a function of Mach number. There's a lot of science behind this plot that we don't need to get into. For our purposes, simply note that these models are scaled to represent drag in a ballistics program, when using G1 or G7 BC's. ***How well your bullet matches the drag model will affect how accurately the ballistic solver can predict that bullets trajectory***.

Notice that at supersonic speeds, the G1 and G7 drag curves are very similar in shape. That means that ***if an accurate form factor is used, both the G1 and G7 BC's can model very accurate trajectories for bullets in their supersonic range of flight***.

However, look at how the drag curves compare in the transonic range of flight. The G7 drag model has proportionally more drag at transonic speed compared to the G1 drag curve, and by a significant margin. *In fact, transonic speed is where drag models diverge the most*. ***As a result of the divergence in drag models at transonic speed, ballistic solvers can calculate different transonic trajectories for G1 vs. G7 BC models.***

175 SMK @ 2550 fps Sea Level conditions

Range meters	G1 BC 0.475	G7 BC 0.243	Diff
	Trajectory (MILS)		
100	0	0	0
200	-0.61	-0.61	0
300	-1.57	-1.56	0.01
400	-2.73	-2.72	0.01
500	-4.08	-4.05	0.03
600	-5.64	-5.6	0.04
700	-7.43	-7.38	0.05
800	-9.49	-9.46	0.03
900	-11.86	-11.9	-0.04
1000	-14.56	-14.74	-0.18
1100	-17.6	-17.99	-0.39
1200	-20.99	-21.62	-0.63
1300	-24.74	-25.6	-0.86
1400	-28.83	-29.93	-1.1
1500	-33.26	-34.6	-1.34

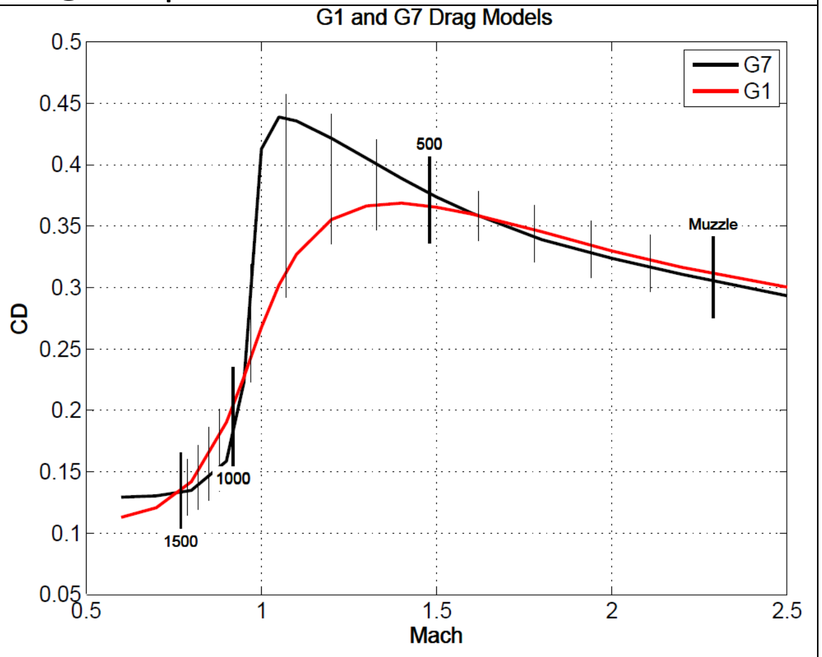


Figure 2: The drag models begin separating around Mach 1.5, but the G1 vs. G7 trajectory predictions don't show major divergence until hundreds of meters later.

There are several interesting things to see in Figure 2. Note how smooth and parallel the G1 and G7 curves are from the muzzle to about 500 meters. Over this range, the G1 vs. G7 predicted trajectories are very similar, within 0.1 MIL. From the muzzle to 400 meters, the G1 BC is modeling drag a little bit higher than the G7 BC. As a result, the G1 BC is predicting slightly more drop, but not much. Due to the higher drag modeled early in the G1 trajectory, the bullet is predicted to have more drop, even 100's of yards beyond where the curves cross. In other words, ***since G1 modeled more drag early in the flight, and less drag later, the cumulative drop is not very different compared to the G7 based prediction from zero to about 800 meters***. After 800 meters, the higher transonic drag of the G7 model results in much more drop than the G1 trajectory.

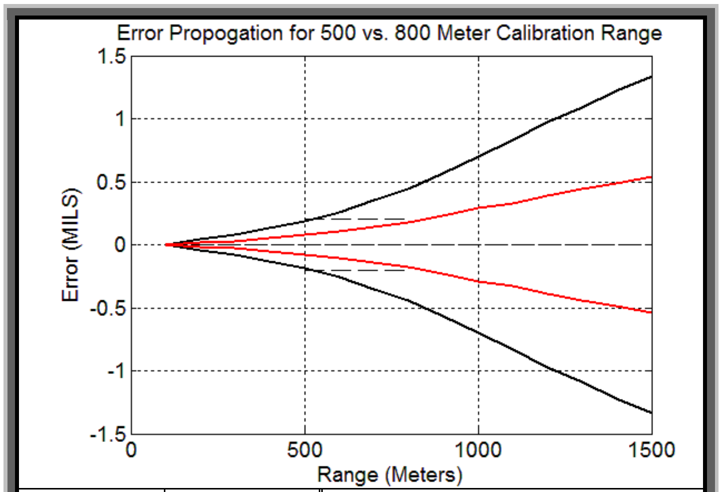
So what's this mean in terms of practical application? For one, it means that ***you could true your ballistic solver for MV at 800 meters, and see essentially zero error in trajectory prediction due to the different drag curves from the muzzle to transonic*** . But after transonic (800 meters in this case), the divergence of the drag curves results in increasing separation between the G1 and G7 based trajectories.

In reality, the .30 cal 175 grain SMK has a unique drag curve that doesn't perfectly match either the G1 or the G7 curve. In fact, *the custom drag model for the 175 SMK is about 1/2 way between the G1 and G7 model*. As a result, the *actual drop of that bullet would be about 1/2 way between that predicted by G1 and G7* tables above.

When shooting into the transonic range of your bullet's trajectory, you have to account for the transonic effects on drag. The most common sense way is to ***true BC in a similar way that MV is***

trued over supersonic range. Procedures for truing BC in trans/subsonic vary by application, and we won't get into that here. Basically you're observing the bullets actual drop, and using that information to modify the drag curve for future calculations. ***The closer the drag model (G1 or G7) matches your bullet, the less truing, or correction will be required***. Of course the best approach is to start off by modeling the actual custom drag curve for your bullet if your software allows. Truing may still be required, but there will be much less error to true if you start with a more accurate drag model.

In both the supersonic, and transonic portions of the trajectory, it's important to extend the distance between truing points as much as possible to minimize experimental error. Figure 3 demonstrates this concept visually.



		0.2 MIL Calibration error at:			
	Actual MV	**800 meters**		**500 meters**	
Range (m)	**2550**	**2570**	**error**	**2600**	**error**
100	0.00	0.00	0.00	0.00	0.00
200	-0.61	-0.59	0.02	-0.57	0.04
300	-1.56	-1.53	0.03	-1.48	0.08
400	-2.71	-2.66	0.05	-2.58	0.13
500	-4.05	-3.97	0.08	**-3.86**	**0.19**
600	-5.59	-5.48	0.11	-5.33	0.26
700	-7.37	-7.23	0.14	-7.02	0.35
800	-9.44	**-9.26**	**0.19**	-9.00	0.44
900	-11.88	-11.65	0.23	-11.31	0.57
1000	-14.72	-14.43	0.29	-14.02	0.70
1100	-17.96	-17.63	0.33	-17.13	0.83
1200	-21.59	-21.20	0.39	-20.62	0.97
1300	-25.56	-25.12	0.44	-24.47	1.09
1400	-29.89	-29.40	0.49	-28.67	1.22
1500	-34.55	-34.01	0.54	-33.21	1.34

Figure 3. A 0.2 MIL calibration error at 500 yards results in velocity being modeled with 50 fps error, whereas the same 0.2 MIL error at 800 meters only results in a 20 fps error in MV.

Summary

This article began by putting ballistic predictions into context as one of the many tasks a long range shooter has to master for success. Even when isolated, trajectory prediction is still a vast subject area and we've only focused on one very narrow portion of it; *error management*.

To review; the modern (properly written) ballistic solver can predict trajectories as accurate as the data supplied to it. Given perfect data, ballistic solvers can predict equally accurate trajectories. Any imperfections in predictions stem from inaccuracies in describing your projectile, environment, or target. The field environment is far from the *perfect world* scenario, so many of the ballistic inputs are estimates and intelligent assumptions which compromise the accuracy of trajectory predictions. The well educated sniper knows how to manage these uncertainties with field expedient methods that bring the predictions closer to reality.

Muzzle velocity is a fundamentally important variable which you probably won't know with perfect accuracy. One field expedient approach to correcting this variable is to shoot to the supersonic limit of the trajectory, observe the bullet drop, and use it to correct the MV input.

Over the supersonic range of the bullet, MV is the biggest uncertainty, and differences in drag modeling (G1 vs. G7) are minor. It's important that you choose a range at the supersonic extent of the trajectory to minimize experimental error.

When the bullet slows to transonic speed, the drag modeling can become an issue. This can be *field corrected (trued)* in much the same way as the MV input. For best results, care must be taken to choose the truing ranges in terms of the transonic zone. Any error that's incurred in the process of truing the ballistic solver will become a permanent, built in bias to all future calculations. Remember, truing is a calibration exercise, and such, must be done with extreme discretion.

References

1. Bryan Litz: "Applied Ballistics for Long Range Shooting", Second Edition, Applied Ballistics, LLC, Cedar Springs, MI, 2011

2. Bryan Litz: "Accuracy and Precision for Long Range Shooting", Applied Ballistics, LLC, Cedar Springs, MI, 2012