The Evolution of Ballistic Calibration

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Abstract

When a modern precision shooter engages a long range target with a rifle shot, the ballistic trajectory is first computed, accounting for: distance, gravity, wind and other variables. For relatively short range shots on big targets, it's easy to achieve sufficiently accurate inputs for the ballistic profile. As the distance increases, there's more demand for the ballistic profile to be accurately characterized. At some range, the fire solution becomes so sensitive to errors in the ballistic profile, that it becomes necessary to incorporate some feedback from actual shooting. This feedback can be used to calibrate the ballistic profile, so the solver predicts the real world trajectory. There are several variables that can be calibrated, and the goal of this paper is to convey the thought process for determining which variable to calibrate within your ballistic profile.

Understanding ballistic calibration – background and common use

Ballistic calibration, aka *'truing'* is when you *calibrate* an input variable to your ballistic solver, so that the predicted fire solution matches the real world 'actual' trajectory as observed by the shooter. Below is a list of common culprits for error in fire solutions:

- Muzzle Velocity (MV) not correct for current string of fire.
- Ballistic Coefficient (BC) or Custom Drag Model (CDM) is not 100% correct for the bullet.
- Sight Scale Factor (SSF); sometimes the scope doesn't move the reticle accurately per click. For example, you could dial 10.0 MIL but the reticle may only move 9.8 MIL.
- Zero; it's common for a rifle/shooter to see a shift in zero due to a number of variables.

Any of the above problems will result in error between the calculated and actual trajectory. The shooters task, when faced with trajectory error, is to decide which of the above is the most likely cause of error, and fix it. Fortunately, a great deal of this work can be done at 100 yards (or meters). At 100 yards, you can: verify zero, do a 'tall target test' to verify correct sight adjustments, and measure your muzzle velocity with a chronograph. If you do all these things, you'll have the sighting variables locked down, as well as a measure of MV, which will set you up for success at long range, provided the BC or CDM for the bullet is accurate.

Suppose you've done all the above 100 yard work, and see your fire solutions are spot on out thru 800-900 yards, but you begin to see some error creeping in around 1000-1200 yards. Correctly calibrating that last remaining error out of your fire solution is what we'll be discussing.

Diagnosing trajectory error at long range, without the benefit of 100 yard work is impossible. You simply can't know which variable is the culprit, as your final fire solution is made up of all inputs. But, having done the 100 yard work, you'll isolate variables related to the sights, and an indication of MV. But remember, MV is a moving target, and can change due to: temperature, bore fouling, humidity, and other factors. There's also measurement error to consider with some legacy chronographs.

For the average long range shooter who's done the 100 yard work, they're approaching long range shots with: high confidence in their sighting system, an indication of MV from a chronograph, and a bullet model (BC or CDM) that's stipulated by a manufacturer or a third party. So if this shooter has trajectory error at long range, they can be assured it's not a problem with sights (unless it's possible something changed since the 100 yard work). So the culprit is likely either the MV or BC/CDM of the bullet.

Figure 1. Garmin Xero radar chronograph and others like it have changed the uncertainty landscape in ballistics and with it, options for ballistic calibration are evolving.

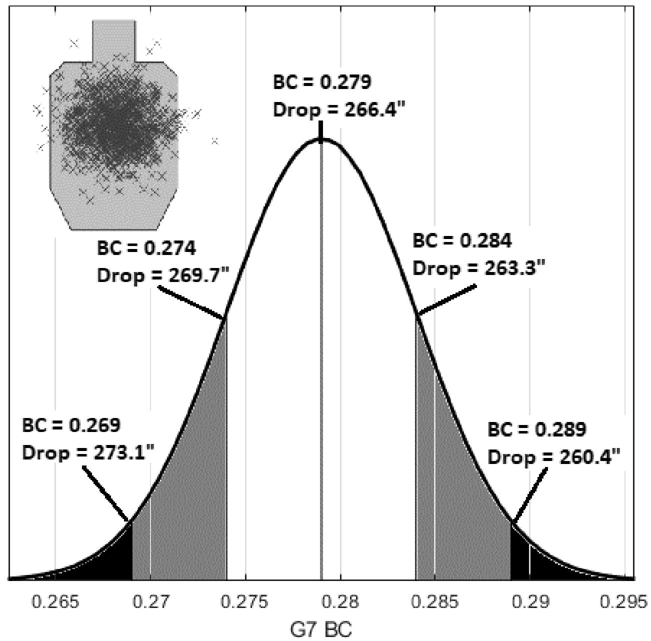
Until recently, it was not really common to have accurate chronographs to measure MV. Shooters either had no indication of MV, or a questionable measurement which meant that MV nearly always had more uncertainty than the BC/CDM data on the bullet. Because of this, ballistic software had built in means to calibrate the MV corresponding to the shooters observed trajectory. This 'built in' ability to calibrate only MV worked successfully for many years. Even in cases where trajectory error may be due to other variables, calibrating MV fixes it all, while doing limited damage to the solution at other ranges.

Recently, with the advent and proliferation of modern doppler chronographs such as the Garmin Xero, many shooters are now able to measure MV accurately, and more frequently, given how easy the device is to use. It's becoming more common to have the chronograph in use while shooting long range, which means that when you're diagnosing trajectory error, you can rule out MV error. This simple fact has changed the paradigm of uncertainty for diagnosing trajectory error, and this change has lead to further innovation of the ballistic solver itself.

Now that shooters have access to highly accurate MV data, and can nail down scope related error with 100 yard work, the only remaining culprit for error at long range is potential error in the bullets' BC/CDM model that was measured with Doppler radar. But how can there be error in the radar measurements? It's not that there's error in the measurement, but rather, different barrels can actually produce slightly different drag for the bullet. There are several ways individual barrels can affect the aerodynamic drag of bullets, such as: twist rate/bullet stability or barrel roughness translating to skin friction drag on the bullet. Of course there are also minor differences possible between production lots of bullets. For these reasons, the radar measured BC/CDM data my not actually be perfect for every rifle.

In the past, any small error in the BC/CDM model was overwhelmed by the much greater uncertainty in MV, and when you calibrated MV, it cleaned up any small error in drag modeling too. But now that MV can be nailed down, there's much less trajectory error, but it's possible that any remaining error is primarily in the BC/CDM. But how much error are you likely to see in your trajectory predictions due to error in drag modeling?

6mm 105 Berger Hybrid at 3000 fps



G7 BC Range	Portion of Samples	Miss Distance at 1000 yards
<= 0.269	2.5%	<= -6.7”
0.269 to 0.274	14%	-6.7” to -3.3”
0.274 to 0.284	67%	-3.3” to +3.3”
0.284 to 0.289	14%	+3.3” to +6.7”
>= 0.289 +	2.5%	>= 6.7”

Figure 2. Range of G7 BC’s and associated variation in drop at 1000 yards for 6mm 105 gr Hybrid.

In Figure 2, you can see a typical distribution of BC’s measured for the ubiquitous 6mm 105 Hybrid. This data was collected over several years of traveling the Applied Ballistics’ mobile laboratory with Doppler radar, and measuring performance of shooters’ equipment at major competitions. This data shows the range of BC’s that are possible for the same bullet fired from multiple barrels and being sampled from many different production lots.

In summary, 67% of bullet samples tested had a range in BC of 0.274 to 0.284. This range corresponds to a 6.6” difference in drop at 1000 yards. In other words, +/-3.3”, which is about 1 click. 95% of bullet samples tested fall within twice that range, so, +/- 6.7” of drop at 1000 yards, corresponding to +/- 2 clicks of elevation.

This is a real world example of how much spread there is in BC for the same bullet fired from multiple guns; it’s roughly within +/-2 clicks at 1000 yards. So if you’re seeing error about this magnitude or less, it’s reasonable that drag modeling error is the culprit. However, if you’re seeing much more error than this, the cause is likely to be something other than BC/CDM error.

How the paradigm has evolved to adapt

Now that we’re in a scenario in which not only the scope zero and adjustment can be verified, and also muzzle velocity can be measured accurately, the last remaining error that’s likely to affect your fire solution is the difference between how your rifle sends bullets vs. the average performance measured by Applied Ballistics’ for that bullet.

In order to deal with this new reality, Applied Ballistics has developed the Custom Drag Factor – CDF. The CDF is simply a percentage scale factor that applies to the bullet drag model. For example, if you’re modeling a BC of .279, but that prediction puts you 3.3” high at 1000 yards, your actual BC may be closer to .284. The CDF feature in Applied Ballistics works the same way as the MV calibration in which you input the observed drop at a range, and the solver finds the value of

CDF that corrects the trajectory to your observed impact. It can then automatically apply the CDF, which changes the prediction to match what you just shot.

The big advantage of having CDF as a potential calibration mode, is for those shooters who've verified all other inputs to a high degree of accuracy and are still observing a tiny bit of error which is likely due to small error in bullet drag modeling.

Before continuing, for completeness we should note that Drop Scale Factor – DSF – is another calibration option that's always been available with Applied Ballistics software. DSF doesn't affect MV or BC, rather, it's a straight DROP scale factor. It calculates the % error in trajectory, and applies the correction to the trajectory at the Mach number corresponding to the bullets terminal velocity at the target. DSF is most commonly used to correct for the effects of augmented aiming devices, such as adjustable scope bases, or prisms and periscopes that offset the image coming into the scope. Sometimes these augmentation devices aren't perfect, and DSF can be utilized to correct for the imperfections. A downrange DSF calibration can be appended to an existing CDF or MV calibration, giving you the ability to piecewise define the calibration to match your rifles ballistics.

Should I calibrate MV, DSF, or BC/CDM?

Given the option to calibrate three different variables, all of which will 100% fix your solution at the range you're calibrating, shooters may wonder how to choose. Since any choice of calibration will fix your solution at any single range, how should a shooter select the means of calibration?

DSF is different from the other calibration methods in that it can be 'piecewise defined', meaning, even if you've done an MV or CDF calibration out to some range, you can calibrate from that range to an even further range with DSF, pinning your trajectory in 2 or more points (you can define multiple DSF calibration points). The following list offers guidance as to which calibration method to choose.

- If you don't have any information (or low confidence information) on your bullets MV and BC, or you haven't verified your scope tracking on a tall target including augmenting devices like adjustable scope mounts and prisms/periscopes, use DSF calibration. This will only affect your drop prediction and won't affect the ballistic calculations in terms of wind drift or kinetic energy. You can also use DSF *after* using either MV or CDF calibration, to correct the trans/subsonic portion of the trajectory.
- If you have done a tall target test, but you don't have a chronograph, use MV calibration because muzzle velocity uncertainty is the most likely cause of big trajectory error.
- If you've done a tall target test, and you're using an accurate chronograph while shooting long range and you're still seeing error, select CDF calibration to true up any error in the bullet model.

Remember, you can 'add' DSF calibrations at multiple ranges beyond the initial MV, CDF or DSF calibration. However, MV and CDF calibrations if done, can only be done once and apply from muzzle to target.

Example of error in various calibrations

One can correct a ballistic trajectory with any of the 3 calibration methods, but if the wrong calibration method is selected, the error appears at ranges within, but mostly ranges beyond the calibration range. The first calibration range should be transonic for typical centerfire rifles. 'Transonic' refers to the range at which the bullet velocity slows to around Mach 1.2, or 1340 fps. For most cartridges, this is somewhere around 800m-1000m.

Suppose you're shooting a 6.5 Creedmoor at 1000m, and you're seeing 0.4 MILs of error in your trajectory vs. what was predicted. The numbers are shown in Table 1 for reference.

	MV	BC	1000m	1500m	
Start with	2720	0.322	10.0	22.0	
True MV	**2680**	0.322	10.4	22.9	-40 fps from MV
True BC	2720	**0.303**	10.4	23.5	-6% from BC

Table 1. Example of extrapolation error from calibrating the wrong variable

Beginning with the top row, this is the MV and BC we come into the string of fire with. It calls for 10.0 MILS at 1000m, but when we shoot, we find we actually need 10.4 MILS to hit the center of the target. Now if we've verified scope tracking on a tall target at 100m, we can rule out the error being due to anything scope related, so the error is likely MV or BC. It would take a 40 fps shift in MV, or a 6% change in BC to account for the 0.4 MIL trajectory error at 1000m.

Out to 1000m, there will be little trajectory error with either method because the solution is bounded. However, what happens to the solution accuracy beyond the range where you calibrated? That depends entirely on which variable you selected to calibrate.

Referring back to Table 1, both MV and BC calibration can get you to the same 10.4 MIL solution at 1000m, but because the effects of MV and BC are different at different ranges, these methods produce 1500m solutions of 22.9 MIL for MV truing, and 23.5 MIL for BC truing. Which is correct? You cannot know yet. You just know that based on your trajectory at 1000m, you had .4 MILs of error to correct. If you selected MV calibration, and MV really was the dominant error, you can expect your solution to be accurate at 1500m as well as 1000m. However, if you calibrated MV but it was really BC that was in error, you would predict 22.9 MIL for 1500m, but the real trajectory would be 23.5 MIL at that range, for an error of 0.6 MILs at 1500m. That potential 0.6 MILs of error at 500m beyond the calibration range is the cost of calibrating the wrong variable, if you were to do so.

Conclusion

Legacy ballistic calibration anchored on Muzzle Velocity (MV) as the most impactful variable to calibrate ballistic solutions because of the historic uncertainty with that variable. Recently, the state of the art in chronograph technology has improved, and it's now common for shooters to have real time accurate MV data while shooting long range. With MV being defined accurately, the next biggest error source is potentially with the bullet drag models in the software not matching the users specific equipment. Due to this shift, a new way of calibrating a ballistic solution was developed to alter the BC/CDM of the bullet so the predicted trajectory matches reality, when using MV data from an accurate chronograph. By enabling shooters to calibrate the right variables, ballistic solutions extrapolate more accurately to ranges beyond where the calibration was fired.