Ballistic Coefficients - Explained

The Beginning

It started back around 1850 when ballisticians of many countries began experiments in an effort to improve the accuracy of artillery shells and the measurements of the drag(1) or air resistance they encountered during flight. Basically, the necessities of war meant everyone wanted more accuracy.

There were no computers back in those days, so all of the mathematical solutions to these very complex equations were hand written. These took months and years to complete. Between 1875 and 1898, German, French, Russian and English ballisticians worked feverishly to quantify air drag resistance of artillery shells and finally came up with a standard model of projectile to which further calculations could be based.

This was to make it a little easier to calculate the trajectories of new shaped projectiles by lessening the time required for new calculations. This standard reference projectile shape is known as the G_1 Standard bullet. "G" stands for the Gâvre(1) Commission of the French Naval Artillery. This commission conducted many air resistance firings at the Gâvre Proving Ground utilising a Belgian chronograph manufactured in 1864. Figure 1 below illustrates the shape and measurement of this projectile in "calibres". One calibre is the width of the projectile.

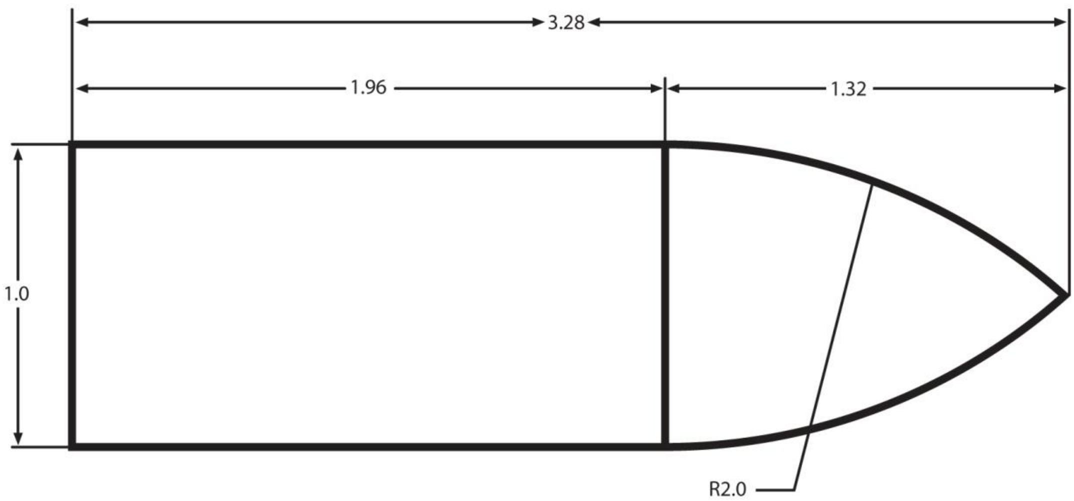

Figure 1 G_1 Standard reference bullet

The G_1 projectile was one pound in weight (lead), and was one inch in diameter. This hefty 7000 grain (1lb) projectile is basically what most small-arms projectiles today are measured against for their ballistic coefficient reference numbers.

Between the First and the Second World Wars, again, out of necessity, further projectile shapes were designed, calculated and mapped for air drag resistance. Different projectile shapes emerged now with angled bases called "Boattails" and pointed tips. These pointed tips were constructed by making the radius of the projectile curve at the front called the "ogive", larger. The Ogive radius of the Type 1 projectile in Figure 1 is 2.00 calibres. The radii of the new projectile types were now between 6 and 10 calibres. These projectile types were numbered G_2, G_3, G_5, G_6, G_7 and G_8. They ranged from flat based more rounded nosed ones, to classic spitzer shaped projectiles with angled boattails as seen in today's long range small arms ammunition.

There are many projectiles we use today that closely match these reference models. For instance, the .30-cal Berger 210gn VLD very closely resembles the G_7 model, although it is not actually a G_7. The .30-cal Nosler 150gn Ballistic Tip very closely resembles the G6.

The exact model of the G_7 projectile is illustrated in Figure 2. If another projectile has all the same measurements except that the boattail angle is 8° instead of 7.5°, it is not a G_7.

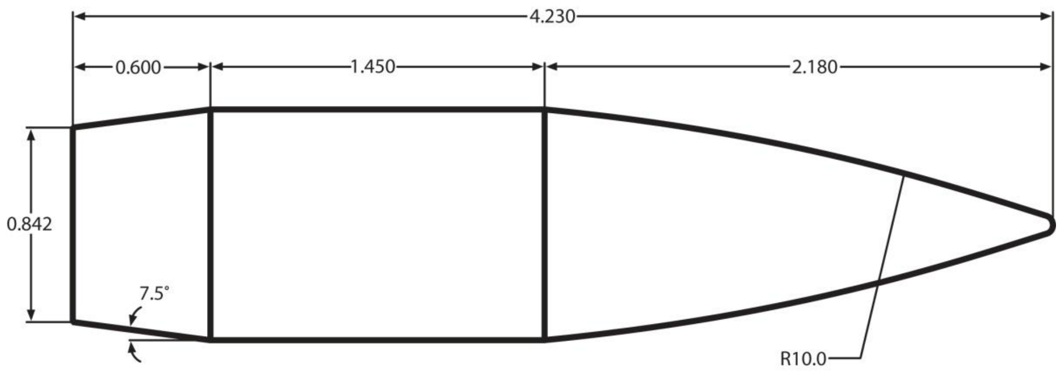

Figure 2 G_7 Standard reference bullet

Drag and Form Factors of Projectiles

The amount of drag that a projectile experiences in supersonic flight heavily depends on it's shape and velocity. The speed of sound at sea level at a 15° C, and 78% RH, may be around 1116 fps (340m/s). This can be referred to as Mach 1. A projectile travelling at this speed is travelling at the same speeds that sound travels in the same atmosphere. A projectile travelling in this same atmosphere at 2232 fps will be doing Mach 2. Mach 2.5 would be approximately 2790 fps and so on.

A projectile travelling at these speeds has shock waves(2) of compressed air attached to the front and rear which tends to draw a large amount of energy from it, thus slowing it down aggressively. These shock waves are attached at certain angles to the projectile which change at different speeds and as a result, draw different amounts of energy from the projectile. What this means is that the amount of drag or resistance on the projectile varies at different speeds .

The two main factors that affect drag (air resistance) on a spin-stabilised free-flight projectile are, shape and velocity.

The blunt-nosed G_1 projectile will be less efficient through the air than the G_7 as it is simply not as streamlined. The relationship of a projectiles weight and it's cross sectional area is called the "sectional density". An example that may shed some light on this can be explained with arrows and crossbow bolts.

If an arrow is fired from a bow made with an aluminium shaft, a broad head tip and 3 plastic flights at a speed of 380 fps, it will only travel so far before hitting the ground. If a crossbow bolt made of the same width aluminium shaft but only 1/3 the length, the same broad head tip and plastic flights and was fired at the same velocity of 380fps, it would hit the ground earlier. Why? It has the same frontal area exposed to the oncoming air flow but it is lighter due to only being 1/3 the length. The crossbow bolt had a lower sectional density than the arrow. Projectiles of the same calibre, but different weights, have different sectional densities.

However, this crossbow bolt that has a lower sectional density will travel further if launched at a higher velocity. This is usually the case with crossbows anyway. All things being equal, the higher the sectional density, the longer the flight or range.

The "form factor" of a projectile is a numerical figure that compares a projectile's unique drag to that of a standard bullet or reference bullet such as the G_1 or G_7 projectile. The lower the form factor (FF) of the test projectile, the more efficient it is. Let's compare the G_1 projectile to the G_7 projectile.

At a velocity of 2792 fps the amount of drag on the G_1 projectile can be quantified into a numerical figure of say 0.540. At the same velocity, the G_7 projectile may have a *drag coefficient(3)* of 0.270. The lower the drag coefficient the more efficient it is through the air. Compare these two by dividing the G_7 by the G_1 figures and you have the G_1 FF of 0.5. If the figure is below 1.0 the projectile is more efficient than the reference projectile. In Figure 3 below you can see that the G_7 is twice as efficient in air when compared to the G_1.

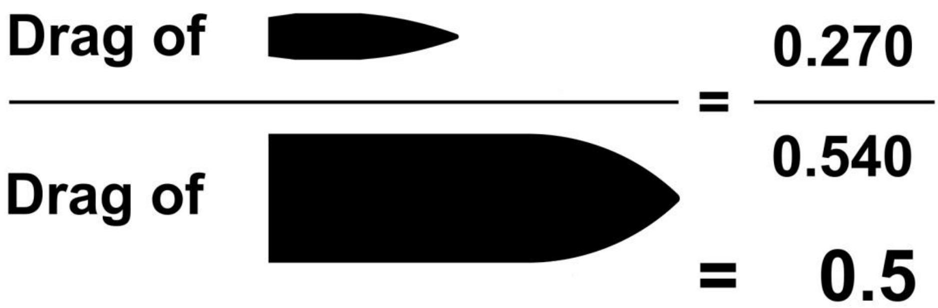

Figure 3 Drag Coefficient of the G7 bullet compared to or divided by the G1 reference bullet. The G7 is twice as efficient through the air.

Ballistic Coefficients(4)

A Ballistic coefficient is a numerical figure usually between 0 and 1 than allows you to see basically how well it penetrates through the air. The closer more accurate description would be *"a numerical factor that describes the rate of velocity degradation of a particular projectile when compared with the rate of velocity degradation of a standard projectile".* This figure is determined by two attributes of the projectile, sectional density and form factor.

The Sectional Density of a of a 210gn Berger VLD would be as follows;

Sectional Density (SD) = $\frac{\text{Bullet weight in pounds (lb)}}{\text{Bullet calibre x Bullet calibre}}$

or

Sectional Density (SD) = $\frac{\text{Weight in Grains (210) / 7000 (1 lb)}}{.308 \text{ x} .308}$

= 0.316

Divide this number by the G_1 Form factor ($\boldsymbol{i_1}$**)**, and you have the G_1 Ballistic Coefficient.

This would read as; $$\mathbf{BC} = \frac{SD}{i}$$

SD = Sectional Density

$\boldsymbol{i}$ = Form Factor

Therefore; $\frac{0.316}{0.489 \ (\boldsymbol{i_1} \text{ form factor})}$

G_1BC = **0.646** (at 2790 fps only)

If this projectile was travelling at a lower velocity then the G_1 Ballistic Coefficient would change. At 2000 fps the form factor may be around .496. This would mean the G_1 BC would be;

$\frac{0.316}{0.496 \ (\boldsymbol{i_1} \text{ form factor})}$

G_1BC = **0.637** (at 2000fps only)

And again at 1500 fps

$\frac{0.316}{0.532 \ (\boldsymbol{i_1} \text{ form factor})}$

G_1BC = **0.593** (at 1500fps only)

You can see what is happening here, the $\boldsymbol{i}_1$ FF is changing at different speeds because the Form Factor is made from the drag coefficient. The drag coefficient is changing at the velocity is changing (slowing down). The G_1 BC given to us by Berger is the average G_1 BC experienced throughout the entire supersonic flight of the projectile. In this instance the average G_1 BC of this Berger 210gn projectile is 0.631. BC's supplied by other manufacturers may not be the average, but ones tested at short range at one or more velocities

BC Myths and Facts

1. BC's are calculated all the same way.

No they aren't. They are calculated with different measuring equipment, some using ICAO standard atmospheres and other using Army Std Metro Atmospheres. Some are measured close to the chronographs and others are measured at some distance away. Some lower velocity BC's are measured with down-loaded cartridges at close range.

2. G_1 BC's change with velocity(3).

Yes they do. As described earlier as velocity changes, so does the drag and therefore the FF. Change the FF and the G_1 BC changes.

3. G_7 BC's don't change with velocity(3).

Yes they do. Only an exact G_7 projectile will not, as the G_7 BC of a G_7 projectile is only capering it against itself. Other projectiles that are close to the G_7 profile will have a different form factor from the G_7 value of 1.0. As these other projectiles' form factors ($\boldsymbol{i}_7$) change with velocity, so do the BC's., just to a lesser degree than G_1's.

4. All Form Factors are the same.

No they are not. The FF to calculate a G_1 BC must be a G_1 Form Factor represented as $\boldsymbol{i}_1$.
A G_7 BC needs a G_7 Form factor represented as $\boldsymbol{i}_7$. The FF numerical value of a G_1 projectile equals 1.0. The FF numerical value of a G_7 projectile equals 1.0. The G_7 FF of a 30 cal 210gn Berger VLD may be 0.983, showing it is a little more efficient than the G_7 standard projectile. The G_7 BC of this would then be;

$$\frac{0.316\ (SD)}{0.983\ (\boldsymbol{i}7)} = 0.321$$

5. BC's are not important.

Yes they are. Without this knowledge we cannot estimate the loss of velocity down range. Knowing the muzzle velocity is great but knowing the terminal velocity just before the projectile strikes the target in a hunting situation is very helpful. This can educate us as to what projectiles will perform on the game we choose to take.

6. Sectional Density information is helpful(5).

Yes it is. Especially when hunting dangerous game. When taking dangerous game, the projectiles should have a sectional density of over 0.300. This gives the professional hunting guide (PH) vital information on the penetration capabilities of the projectile.

Summary

Modelling drag on free flight spin stabilised projectiles has been going on for a long time now. Born out of necessity as a result of War, these calculations as previously stated are very complicated and therefore very misunderstood by the sport shooter and hunter.
Some of us only require small amounts of this information and other, a fair bit more. There is a lot of information available today which can be highly attributed to the speed at which information travels. With the massive steps forward in technology in the last 20 years, information such as this is now required by some sport shooters, particularly those in the long range shooting community.

Three simple areas should be remembered;

1. The higher the BC, the better it slices through the air.
2. The higher the Drag Coefficient (C_D), the worse it slices through the air.
3. The higher the Sectional Density, the deeper the penetration.

The term Ballistic Coefficient is a very loose one in itself and someone should say is…what type of Ballistic Coefficient? This term, when understood a little better can help you the shooter make better informed decisions when choosing projectiles in the future.

Glen Roberts
Chief Instructor
Precision Shooting Australia
www.precisionshooting.com.au

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