Twist Rates and Projectile Stability for Distance Shooting

Many firearm enthusiasts who are in the running for purchasing new rifle are attracted to certain things the rifle has to offer. The look, the feel, balance, barrel length and weight to name just a few. These are all important factors that must be considered as one has to be happy when handing over hard earned cash.

One thing that is often missed is the rate of twist the rifling grooves are cut or forged into the barrel. Paying no attention to this can leave the shooter a little upset when wanting to reload heavier projectiles for example, and finding out later through trial and error that these heavier projectiles do not stabilise and will not group on a target.

Rifle Grooves and Lands

Most of us will know that the rifling grooves and lands inside the barrel impart a certain rate of spin onto the modern elongated projectiles we use today. This force (*centrifugal force*[1]) imposed is a must if we want the nose of the projectile to stay pointing forward during flight. How much force must be imposed or what rate of spin is required, well that is a question that only physics and experience in this field can answer.

Projectile or Bullet Stability

Before we go any further, a few things need to be explained. Firstly, "*Stability(1) is the ability of a projectile keep it's nose in the same direction of flight, and return to that same direction is it is disturbed*". Most of us are very familiar with objects that maintain this orientation, such as darts, arrows and rockets. These objects are stabilised buy the use of fins, which is called fin stabilisation. The centre of gravity on an arrow would be somewhere near the middle of the arrow. Air striking the fins at the rear of the arrow causes an air pressure force in this area. This force will keep the arrow pointing forward in flight. The centre of this area that this

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[1] Centrifugal Force - represents the effects of inertia that arise in connection with rotation and which are experienced as an outward force away from the center of rotation.

force is acting on is called the *"Centre of Pressure(2)"*. The arrow having the centre of pressure located behind the centre of gravity is known to have *"Static Stability"*.

A projectile such as a rifle bullet does not have fins to stabilise it in flight so other means are used for stability. Elongated projectiles with pointed tips have the centre of gravity back from the centre and the centre of pressure is located forward of this. Supersonic shock waves and/or wind resistance acting on the tip of the projectile cause it to have a pressure force acting on the frontal area. This causes the projectile to be *"Statically Unstable"*. These projectiles to put it simply, want to fly backwards.

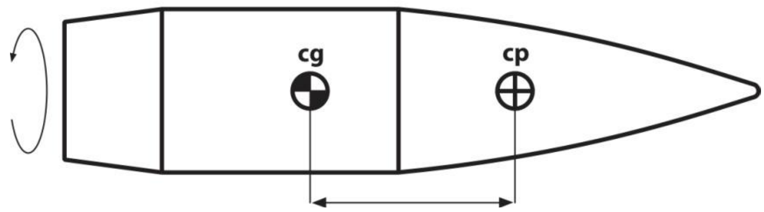

Figure 1. The Centre of Pressure (C_p) is in front of the Centre of Gravity (C_g). The distance between is called the Static Margin.

Secondly, to cater for this, these projectiles, in the absence of fins, need to be spun around their longitudinal axis in order to create *"Gyroscopic Stability"*. Gyroscopic Stability(3) causes a rigidity along it's axis that resists the forces acting on the centre of pressure, making it want to turn around in flight and fly backwards or at very least wobble somewhat. A spinning top uses gyroscopic stability to stay upright or vertical over it's spinning axis.

A certain amount of this force is required to be applied to all non spherical projectiles to maintain stability. The twist rate of the rifling grooves will determine, along with launch velocity, the amount of spin placed on a projectile. A rifle barrel with one complete revolution in 8 inches of forward travel, (1/8" Twist) is considered to be quite a fast twist. Rifling grooves with one complete revolution in 16 inches of forward travel, (1/16" twist) is considered to be a slow rate of twist. Why the difference?

Basically, projectiles that are quite short for their width i.e. (55gn .224 cal), require a slower twist in order to have enough gyroscopic stability. Due to their short length, the force levering effect(4) on the front of the projectile is less than if it were a longer one such as an 80gn .224 cal projectile. Longer projectiles of the same width (*calibre*) have greater levering effect acting on the nose. Put it this way, it is easier to lever a rock from the ground using a 6 foot crow bar than when using a 2 foot one on the same rock. Less force is required to dig up the rock with a longer bar. The longer the "Static Margin" on a projectile, the longer and more powerful the lever is.

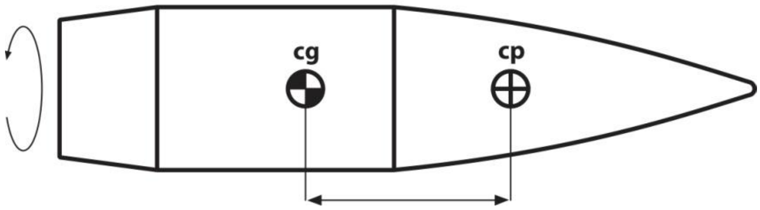

Figure 2.

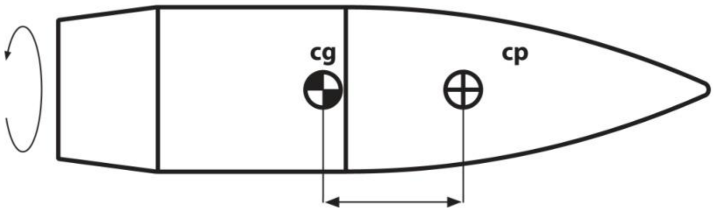

Figure 3.

The Projectile in Fig 3 is shorter for the same calibre and therefore has a smaller "Static Margin". This projectile would require a slower barrel twist rate than that illustrated in Fig 2. Therefore when wanting to use longer projectiles of the same calibre in the same cartridge, a faster twist rate may be needed to achieve enough force to overcome the same pressure forces using a longer lever.

Most "off the shelf" rifles available only come with one barrel twist rate, however more manufacturers are starting to provide rifles with two twist rates. Firearms manufacturers will twist their barrels with certain twist rates for certain cartridges. They will do this on the educated assumption that most shooters will be using a particular range of projectiles for what the cartridge was intended for. An example of this would be the .223 Rem cartridge. The majority of shooters will use this cartridge for light thin skinned game for which a 55gn flat based hunting projectile is ample. A 1/12" twist is more than adequate. To increase sales, the firearms manufacturers will make all of these rifles in a 1/12" twist.

What about using an 80gn very low drag (VLD) projectile in this same cartridge? With a 1/12" twist barrel you will now run into problems. The problem that arises is, "I wanted to shoot rabbits and foxes with this rifle and now I also want to use this rifle in a 600m shoot at the rifle club". You will have been told that you will need higher ballistic coefficient (BC) longer bullets to go the distance but now you require a 1/7" twist to do so.

Rule of thumb: Select your rifle on its twist rate before anything else for the heaviest projectile you think you are going to use in it.

Gyroscopic Stability Factor

OK back to gyroscopic stability. For a projectile to be considered gyroscopically stable it must have a Gyroscopic Stability Factor(3) (GS factor) of 1.0. Any less than this, 0.95, 0.80 etc it will <u>not</u> be gyroscopically stable. Between 1.0 and 1.5, the projectile is considered to have marginal stability. Over 1.5 and you are good to go. The rate of the loss of spin is far less than the rate of forward velocity loss over distance. In other words, the rate of spin per velocity actually increases over distance. Any projectile in supersonic flight when launched with the GS factor of 1.5 and over, the chances are, that you will achieve stability all the way to the target so long as the projectile hits that target with a terminal velocity of over 1350fps (at sea level air pressure).

If this projectile enters a zone where the remaining velocity is under 1350 fps, then it may not have enough " *Dynamic Stability*" to overcome other forces acting on it, and it may tumble and keyhole into the target if it hits it at all.. Dynamic Stability(1) is another ballgame all together and this will be discussed in a later article.

If you want to use a 210gn Berger Hunting VLD in your 300WSM or 300 WinMag cartridge, what rifle twist are you going to need in your rifle to ensure gyroscopic stability at average environmental conditions? Well, using the Millers Stability formula[2] can assist you. All you need to know are the following seven points.

1. Projectile velocity
2. Projectile Length
3. Calibre
4. Weight
5. Barometric or Station Pressure
6. Temperature
7. GS Factor of 1.5

Enter these parameters into the Millers Stability formula and then you will be given the minimum required twist rate for gyroscopic stabilisation. These factors previous mentioned of course, when varied, can have an effect on the GS of the projectile. Drive a projectile faster and the GS increases. Shoot it at a higher altitude and it also increases. Basically, the minimum required twist rate to achieve a GS factor of 1.5 for the Berger 210gn VLD is rate of 1/11"s.

Twist Rate Selection

The best way to go is to have a twist rate in your barrel fast enough to handle the heaviest bullet you want to or may want to in the future. However you must be aware that when using projectiles that are shorter and therefore lighter in fast twisted barrels, issues may arise that aren't as dramatic as key holing, but are issues nonetheless.

It is often said and written, that over spun projectiles may not group as well at shorter distances to due inconsistencies in the projectile's construction that are exacerbated when spun too quickly causing dispersion(5). Short range (100 – 300yd) benchrest shooters quite often twist their barrels to achieve a GS factor of around 1.3 so as to achieve this *"Ragged Edge of Stabilisation"*. I have found this to be rifle/projectile specific and not a general rule at all. The best groups I shot from a Savage 1/9" twist rifle chambered in .223 Rem were 55gn Nosler Ballistic Tip's loaded in Federal Premium factory ammunition. The twist rate

[2] A formula for estimating the twist rate of projectiles in sporting arms first published by Don Miller in the United States Precision Shooting Magazine, June 2005.

apparently most suited for these projectiles is 1/12". Obviously there are many more factors that come into play than just twist rate and projectile weight. Factors like, in-bore cant, projectile base shape and tolerance, throat length, chamber dimensions, crimping, powder compatibility, barrel length, rifle power to weight ratio and the list goes on.

With projectiles fired from small arms weapons and in this case, rifle projectiles, all trajectories resulting whether fired at high angles or not, are called "Flat Fire Trajectories". Projectiles like mortar rounds are "High Angle Trajectories". In most cases the "angle of departure" in relation to the "line of sight" is no more than 5 or 6 degrees. Throughout the entire flight of a projectile fired at a long range target it will <u>never</u> have a zero degree pitch or more commonly known a "Zero Yaw". A projectile having zero yaw is said to be "Point on Flight". However, theoretical zero yaw projectile flight characteristics are required in exterior ballistics calculations when it comes to quantifying things such as changing drag coefficients.

Figure 4 illustrates what the theoretical projectiles zero yaw position would look like.

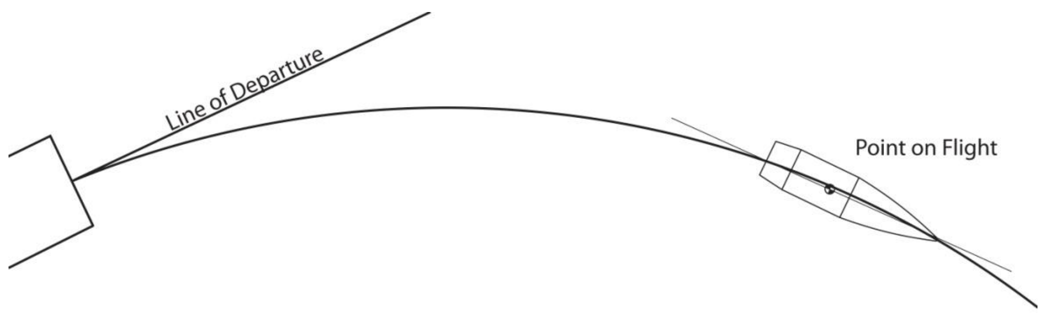

Figure 4. A projectile experiencing "Point on Flight". This has no aerodynamic lift from having "Zero Yaw".

In reality, and looking sideways at the projectile's position, the nose of the projectile is slightly up. Figure 5 illustrates an exaggerated position of the nose so that you can get some idea. In reality this angle is much smaller. This position is also a "Net or Mean" position. Other motions such as spin and gyroscopic precession have been removed for simplicity.

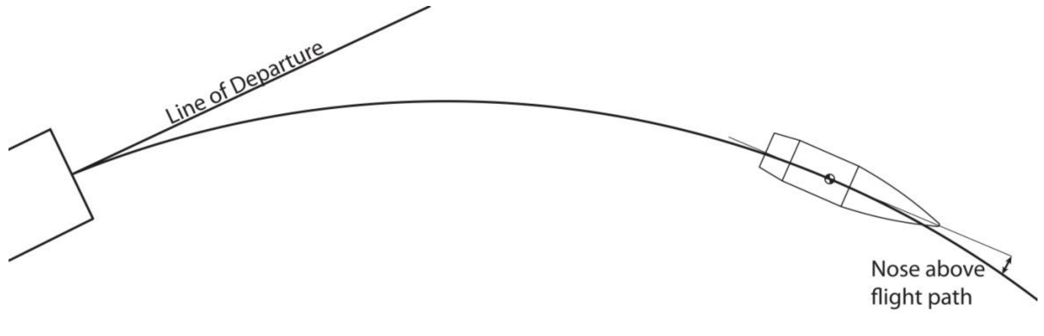

Figure 5. This projectile is experiencing aerodynamic lift from a small Yaw angle called the "Angle of Attack". This angle has been increased to allow it to be graphically observed.

The rate of barrel twist of the rifle/projectile does <u>not</u> change the "Mean" position or "Angle of Attack". New studies by Bryan Litz from Applied Ballistics LLC in 2013 (6) have confirmed that precession angles (Bullet wobbling about its axis) do change with changing twist rates. This change in wobbling or "Epicyclical Motion" does in fact change the efficiency of the projectile in flight and therefore changes in Ballistic Coefficient (BC) have been documented from accurate bullet drop recordings utilising exactly the same projectiles, velocities and rifling grooves etc. leaving only changes in twist rates.

A 175gn .30cal projectile fired through a rifle twist of 1/12" a velocity of 2600ft/s may have an overall average G_1BC of 0.505 over 900m. The average angle of Yaw created from its "Slow Arm" Precession Cycle's or Precession may be 4 degrees. Fire this same projectile at the same velocity through a barrel with a 1/8" twist and the projectile fly's with a smaller average angled Yaw of say approx 1 – 2 degrees, therefore exhibiting an average G_1BC of 0.510 over 900m. The yaw angle that projectiles settle on during flight is called the "Limit Cycle Yaw". Figure 6. illustrates the Limit Cycle Yaw from a 1/8" twist barrel. (7)

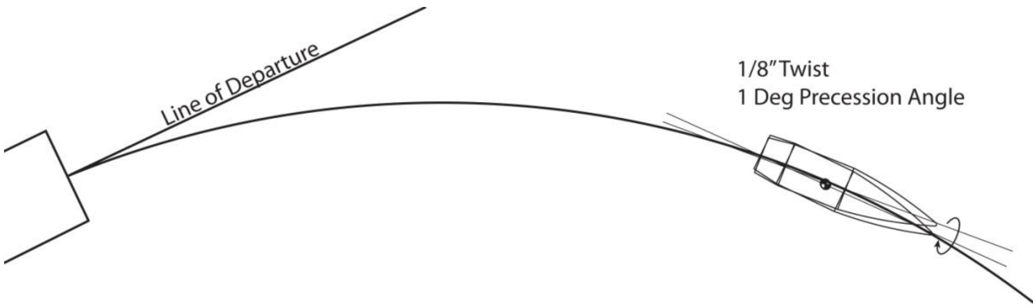

Figure 6. This projectile is wobbling about its centre of gravity with an angle of approx 1 degree resulting from Yaw created from a barrel with a 1/8" twist. The projectile is a Sierra 175gn Matchking. The average G_1BC of 0.515 may be experienced.

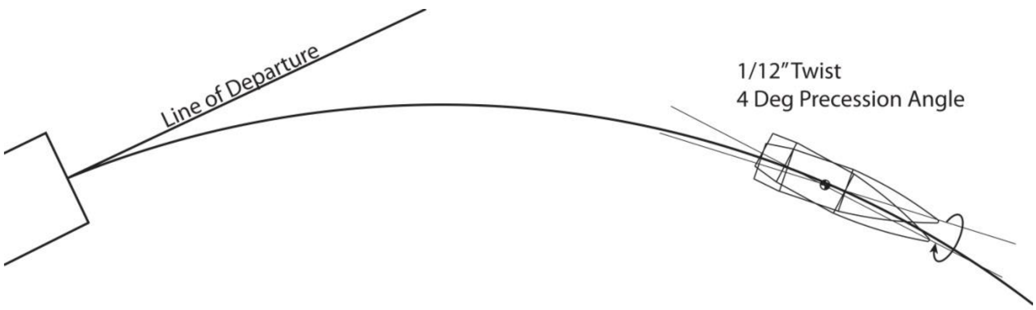

Figure 7. This projectile is wobbling about its centre of gravity with an angle of approx 4 degrees resulting from Yaw created from a barrel with a 1/12" twist. The projectile is a Sierra 175gn Matchking. The amount of drag is marginally increased throughout its flight. The average G_1BC of 0.496 may be experienced.

Conclusion

For long range shooting, select the correct twist rate to achieve that GS factor of at least 1.5 with the heaviest projectile you are going to use and don't expect accuracy miracles with lighter ones. Keep the lighter faster ones to shorter distances of say 300m or so. When shooting at longer ranges for the cartridge you are using i.e. 700 - 800 yards with .308 Win, and trajectories are being calibrated utilising various forms of ballistic software, be aware that the efficiencies (BC) of the same projectile can change with changing twist rates.

In reality, unless you have two exact rifles with only differing twist rates, then a change in twist rate from one rifle to another chambered in the same cartridge may not be the sole reason for an observed change in BC. Changes in velocity, bore size, throat size and condition, barrel/receiver concentricity, chamber dimensions and crown condition to name a few, are all other factors present with rifles of differing manufacturer chambered in the same cartridge. Any one, a combination, or all of these factors can lead to small changes in projectile efficiency through the air while in supersonic flight.

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

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