Modern Advancements in Long Range Shooting

Volume I

By Bryan Litz
With contributions from Nick Vitalbo

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Volume 1

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Introduction

Modern Advancements in Long Range Shooting is an ongoing series which deals with the progression of equipment and scientific knowledge used for long range shooting. In particular, new equipment and ideas are tested to determine if and how they can help shooters be more effective at long range shooting. In an industry which is full of advertising and myths, the scientific approach taken by Applied Ballistics is refreshing. Rather than rely on popular opinion or marketing hype, we approach the matter with careful experimentation which is then described in a way that's easy to understand and apply.

Each Volume in the *Modern Advancements* series is comprised of several parts which explore various topics. There is a pattern to how the subjects are addressed. First we'll discuss why the topic is interesting, meaning why it's important to long range shooting. Then we'll consider the common beliefs/opinions, and how that relates to the scientific theory. Finally, we conduct an experiment to determine the truth of the matter, and analyze the results. When necessary, statistical methods are used to help interpret the meaning and certainty of the test results. In every case, an explanation is given as to why the subject is significant and how it represents a *Modern Advancement in Long Range Shooting.*

Part 1 of this Volume is comprised of 4 chapters which explore various aspects of twist rate, stability and bullet flight. Twist rate effects tend to be subtle and difficult to see. Testing different twist rates means two different barrels, which usually means two different guns. This makes it hard to isolate twist rate effects from other variables of the rifles. For the twist rate testing, multiple barrels from the same manufacturer were used which were identical in every way except for the riflings. The barrels were interchanged on a common rifle platform in order to isolate twist rate as much as possible. The effects of twist rate on: muzzle velocity, Ballistic Coefficient (BC), and precision were tested, as well as the effects of rifling profile on spin rate decay over long range. Some very interesting relationships were found between stability and drag which are documented in Chapters 2 and 3.

The interest in studying twist rate effects arose from sniper instructor Todd Hodnett. Todd has been observing and talking about the effects of *faster than conventional* twist rates for years. Part 1 of this book explores the effects which Todd first observed shooting .308 Winchester's out to a mile.

Part 2 goes into modern rifle and bullet design. Here we take a look at how designs are evolving to enable long range shooters to achieve higher performance and hit targets at longer ranges. There are so many new things coming out in the industry which claim to offer an advantage, but much of it is smoke and mirrors. The material in Chapter 2 presents some of the fundamental advancements that some rifle, optic, and bullet manufacturers are providing.

Part 3 covers the advancements being made in predictive modeling (like ballistics programs). In past decades, limitations in the precision of long range shooting equipment prevented shooters from hitting small targets at long range. In other words, groups were larger and the accuracy of ballistics programs was not the weak link in the kill chain. However, modern rifles and ammunition have become so capable and precise that ballistics programs now need to provide more accurate fire solutions to longer ranges. Furthermore, shooters need to have the knowledge to use these tools to their full capability in order to get the most out of their equipment. The relatively new practice of Weapon Employment Zone (WEZ) analysis is used to determine hit percentage of long range shots in different conditions.

Finally, Part 4 presents some of the tools used to measure the variables which are important to long range shooters. Muzzle Velocity (MV) is a very important thing to measure, and the tool for measuring it is a chronograph. Despite the importance of accurate MV measurements, there's been little scientific review of the commercially available chronographs. Chapter 15 presents a review of many different chronographs, focusing on their accuracy and precision capabilities.

Except for the chronograph chapter, all of the content in Part 4 was provided by Nick Vitalbo. Nick is an expert in electronics, in particular, laser technology. Nick presents some interesting and useful material on the importance of laser rangefinders and how they work. Nick also describes how laser technology is being adapted to devices which are capable of measuring the wind along a shooters line of sight.

***Modern Advancements in Long Range Shooting* aims to end the misinformation which is so prevalent in long range shooting. By applying the scientific method and taking a *Myth Buster* approach, the state of the art is advanced both in terms of the available tools, and the knowledge to best apply them.**

Chapter 1: Twist Rate and Muzzle Velocity

It's a commonly held belief by many shooters that faster twist barrels produce lower muzzle velocity than slower twist barrels, *all else being equal*. This question was briefly addressed in *Applied Ballistics for Long Range Shooting* **[REF 1]** but only from a theoretical standpoint. Is it true? Is there something about faster twist barrels that suppresses muzzle velocity? In this chapter, we'll first review the theory of this issue, and then explore the issue experimentally to see for sure.

Theoretical Approach

The physical reasoning behind this issue is that the steeper rifling pitch resists the bullets forward motion more than a shallower rifling pitch. In other words; faster twist rate robs from the bullets forward velocity by forcing greater rotational velocity. When you're talking about *robing forward* acceleration with *added rotational* acceleration, you're talking about an energy balance.

Kinetic Energy (KE) is a common measure used to describe a bullets terminal performance potential. Basically, KE is a measure of how hard a bullet hits based on its mass and velocity. Kinetic energy is measured in foot-pounds (ft-lb). Although it's not explicitly stated, the discussion of KE as it relates to rifles is usually referring to the bullets forward, or linear KE.

In addition to linear kinetic energy, a spinning bullet also has *rotational kinetic energy* which is proportional to its axial inertia and spin rate. As it turns out, a .30 caliber 175 grain bullet fired at 2660 fps has about 2747 ft-lb of linear kinetic energy. When fired from a 1:12" twist barrel, that same bullet has 7.4 ft-lb of rotational kinetic energy.

The basic idea of an energy balance analysis is that you assume the system has a constant amount of energy available. In this case, the energy is produced by a fixed powder charge. The energy is split between pushing the bullet forward and forcing it to spin. The more energy it takes to spin the bullet, the less energy is available to accelerate it forward. Solving the energy balance basically consists of balancing the equations for linear and rotational kinetic energy. The following steps will explain how this is done in principle.

The effect of twist rate on muzzle velocity can be calculated as follows:

1. First determine the total energy possessed by the bullet when fired from a given twist rate. For the 175 grain bullet fired at 2660 fps from a 1:12" twist barrel, the total energy possessed by the bullet is:

   Linear kinetic energy of 2747 ft-lb plus
   Rotational kinetic energy of 7 ft-lb
   Total kinetic energy = 2754 ft-lb

   This *total kinetic energy* of 2754 ft-lb is a fixed amount of energy that's provided by the powder charge. Regardless of how the energy is distributed between forward motion and spin, 2754 ft-lb is all there is.
2. Next, determine the rotational kinetic energy for the same bullet fired from a faster twist. For a 1:8" twist barrel, the 175 grain bullet will have 17 ft-lb of rotational kinetic energy[1].
3. Next, subtract this energy from the total available in the system: 2754 ft-lb – 17 ft-lb = 2737 ft-lb.
4. Finally, determine what forward velocity corresponds with the remaining 2737 ft-lb of linear kinetic energy: 2655 fps.

So according to the theoretical analysis, going from a 1:12" twist to a 1:8" twist should reduce the average muzzle velocity by 5 fps in the case of a 175 grain bullet in the 2660 fps range. That breaks down to 1.25 fps per inch of twist rate.

To put this result into perspective, typical random variations in muzzle velocity for good long range ammo is around 30-40 fps, not to mention shifts in average muzzle velocity due to temperature effects which can easily exceed 10 fps.

To summarize the theoretical conclusion:

Barrel twist does have an effect on muzzle velocity. However the effect is so small that it's of no practical concern.

Although this theoretical result is compelling, there are many examples of shooters who believe they've witnessed faster twist

[1] In the same way that linear kinetic energy is proportional to velocity squared ($KE = \frac{1}{2} mv^2$) rotational kinetic energy is proportional to spin rate squared ($KE_R = \frac{1}{2} I_x\Omega^2$).

rates depressing muzzle velocity. Because of this, we'll now shift gears from theoretical calculation to live fire experimentation.

Experimental Approach

The key to this (and many other) experimental analysis is related to a phrase used in the first paragraph of this chapter: *all else being equal*. In Latin, this phrase translates to Ceteris Paribus, and is a common caveat used in scientific analysis. *The trouble with many observations in the shooting world is that conclusions are drawn based on observations in which all else is not equal, weather the shooter knows it or not*.

For example, imagine you had a .308 with a 1:12" twist barrel that produced a certain velocity with a given handload, then fired that handload from a different .308 with a different twist rate and observed a difference in velocity. Could you say the difference in MV was attributable to the different twist rate? There may be too many other variables involved to know for sure. For example, if the barrels are not the same length, the comparison obviously wouldn't be valid. If the chambers are different in the rifles, that could cause a difference in MV as well. If you tested the muzzle velocities with different chronographs which weren't both accurate, it could give you the impression there was a difference in velocity when actually there's not. In fact there's a long list of things that might affect muzzle velocity and have nothing to do with twist rate. These effects may have given rise to the perception that a correlation exists, when in fact, there is none.

Figure 1.1 Savage rifle with 6 barrels

In order to conduct a meaningful experiment in which variables are controlled as much as possible, the following procedure was used.

The testing was conducted all on the same day within the span of a couple hours to minimize effects of temperature.

The ammo used in the testing was hand loaded with weighed powder charges all of the same lot number. The bullets and primers used were also from the same lot number.

Two similar but different bullets were loaded for this test:

1. .30 caliber 175 grain Sierra MatchKing and
2. .30 caliber 175 grain Berger Tactical OTM.

Both bullets were seated to the same SAAMI COAL of 2.800” (very similar to the military’s M118LR ammunition).

Six barrels of equal length (24”) and contour (1.125” straight) were obtained from Bartlein Barrels. All the barrels were made at the same time, chambered with the same .308 Winchester SAAMI spec reamer and set up for the Savage precision target action. After break-in and fouling, 10 shots were fired from each barrel and the velocity of each shot was recorded. The barrels were rotated on and off the same platform (stock, action, and scope) see Figure 1.1. Three of the barrels were made with standard 5R riflings in 1:8”, 1:10”, and 1:12” twists. Three additional barrels were also fired to determine if details of rifling configuration (other than twist) would have an effect on muzzle velocity.

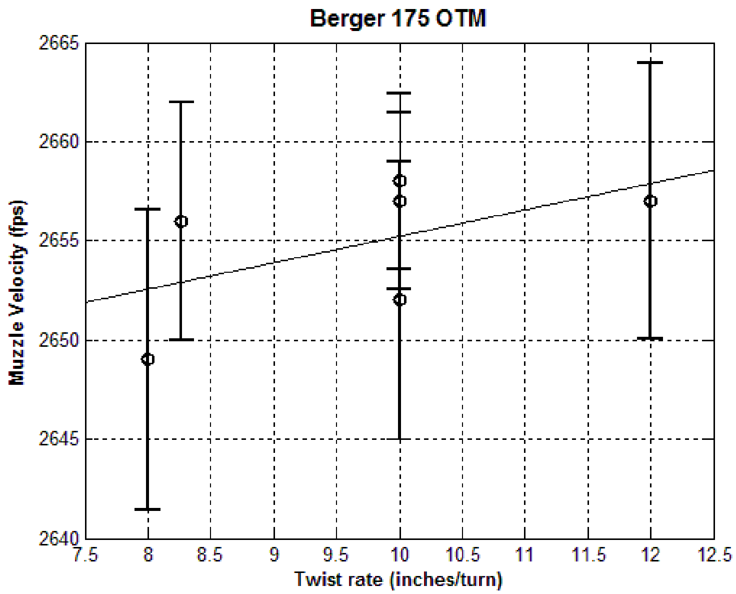
One of the barrels tested was a 1:10”-8” gain twist. There is an argument to be made for gain twist rifling having an effect on muzzle velocity due to the energy expended in shearing the surface of the bullet as the twist rate gradually changes. The other two barrels were constant 1:10” twist standard 5-groove riflings; one in right hand twist and the other in left hand twist. The comparison between standard rifling and 5R rifling will be interesting to see if rifling profile effects muzzle velocity. However there’s really no reason why the left twist barrel should be different, it was just included because it was available.

Experimental Results

The average muzzle velocity and standard deviation (SD) for the 10 shots from each barrel are shown in Figures 1.2 and 1.3. Also shown in the figures are plots showing how the velocity trends with twist rate.

In this analysis where we’re attempting to measure a very weak relationship, it’s important to consider the measurement uncertainty. The error bars shown on each data point represent the 95% confidence intervals for the sample mean of velocity. In other words, based on the Standard Deviation of the sample, the error bars show where another 10 shot average would be likely to fall, with 95% confidence[2].

The significance of this statement and the placement of the error bars suggest that the experimental results *do not statistically prove* that there is *necessarily* a correlation between twist rate and muzzle velocity. In other words, the effect is *in the noise*, as our theoretical analysis suggested.



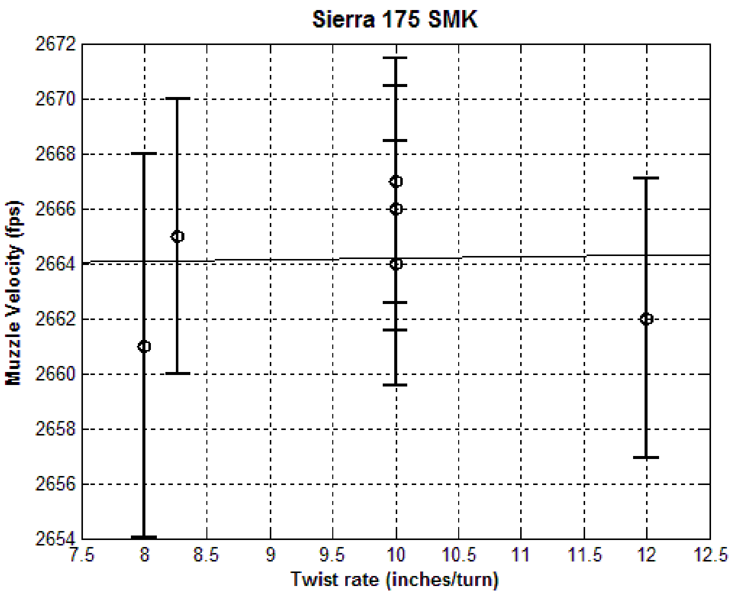
Barrel Twist / riflings	Average MV	SD of MV sample
1:8” / 5R	2649 fps	12 fps
1:10”- 8.3” gain twist	2656 fps	10 fps
1:10” / 5R	2658 fps	7 fps
1:10” / 5 Groove	2657 fps	7 fps
1:10” / 5 Groove LH	2652 fps	11 fps
1:12” / 5R	2657 fps	11 fps

Figure 1.2. Data showing weak relationship between twist rate and MV for various twist rates and rifling profiles. From fast-to-slow, the three 1:10” twist barrels are: 5R, 5-Groove, 5-Groove Left Twist.

However, statistics can do more for us here. The sloped line going thru the data points is the best fitting linear relationship to the

[2] This is a different confidence interval than where a single shot would be expected. See Appendix A for a supporting discussion of standard deviation vs. standard error and other statistics based on the Central Limit Therom.

data. The two relevant attributes of this line are its slope and its correlation coefficient. In layman terms, the slope of the line represents how much the velocity changes in relation to barrel twist. The correlation coefficient says how real the relationship is.



Barrel Twist / riflings	Average MV	SD of MV sample
1:8" / 5R	2661 fps	11 fps
1:10"- 8.3" gain twist	2665 fps	8 fps
1:10" / 5R	2664 fps	7 fps
1:10" / 5 Groove	2666 fps	7 fps
1:10" / 5 Groove LH	2667 fps	7 fps
1:12" / 5R	2662 fps	8 fps

Figure 1.3. Data showing weak relationship between twist rate and MV for various twist rates and rifling profiles. From fast-to-slow, the three 1:10" twist barrels are: 5-Groove Left Twist, 5-Groove, and 5R.

The data for the Berger 175 OTM suggests a relationship of 1.33 fps per inch of twist. This relationship has a correlation coefficient of 0.55.

The data for the Sierra 175 SMK suggests a relationship of 0.05 fps per inch of twist. This relationship has a correlation coefficient of 0.03. Note the data point for the 1:12" twist barrel in the Sierra bullet data appears to be the outlier which disrupts the trend.

Considering the stronger correlation coefficient for the Berger data, we should have more confidence in the relationship of 1.33 fps per inch of twist than the 0.05 fps per inch of twist suggested by the Sierra data which correlated more weakly.

Remember that our theoretical analysis suggested a relationship of 1.25 fps per inch of twist, which compares reasonably well to the experimental result of 1.33 fps per inch. We'll come back to the theoretical vs. experimental result in a moment, but first let's discuss a few more interesting results of the testing.

You'll notice that the Sierra ammunition produced 9 fps higher velocity on average compared to the Berger loaded ammunition (2664 fps vs. 2655 fps). What could be the cause of that? One possibility is a difference in surface finish. Another possibly is that the Berger bullet is slightly longer than the Sierra, thereby taking up more room in the case when loaded to the same 2.800" COAL.

Another noteworthy result is the effect of the various rifling profiles in the 1:10" twist barrels. Given the overlapping error bars, the data suggests that rifling profile has no significant effect on muzzle velocity. Because the velocity was so similar for all three 1:10" twist barrels of various profiles, it's not surprising that the fastest barrel for the Sierra bullet was not the fastest barrel for the Berger bullet. In fact, the fastest and slowest barrels were reversed for the two bullet brands, while the middle (standard 5-Groove) was the same. In other words, since rifling profile has no real effect, there's no reason to believe the order would be the same for both bullet types. There was only a 3-6 fps difference for all 3 profiles.

Overall the experiment was a success. Results were produced that are repeatable, and have defined uncertainty bounds. Furthermore, the experimental results agree well with the theoretical calculation. The testing was done in a way to minimize or eliminate effects which are not related to twist rate (such as chamber, barrel length, bore finish, rifle weight, etc.) When theory is supported with real world experimentation, broader application of the theory is justified.

Expanding the Scope

The previous two sections presented a theoretical calculation and experimental results for the relationship between barrel twist rate and muzzle velocity which agreed fairly well. However, both these studies were limited to 175 grain .30 caliber bullets fired around 2660 fps. Within this realm, we concluded and demonstrated that a correlation does exist, but it's not worth considering.

What about bullets of other weight, caliber, and velocities? Just because there's not a large effect for 175 grain .308 bullets, we shouldn't assume that there's no effect for any bullets!

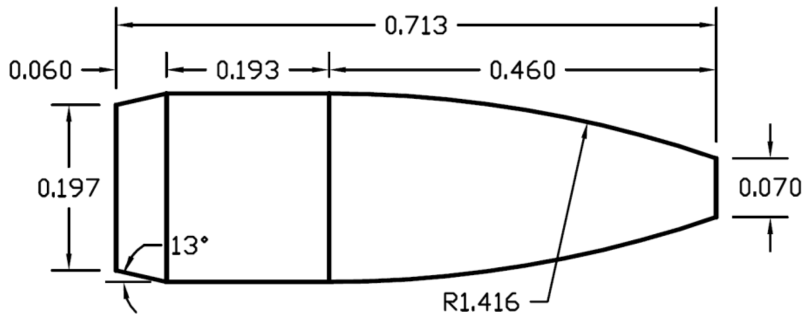
Generalization of results is a common scientific folly of the shooting sports and we're not going to make that mistake here.

However we're also not going to actually live fire similar tests with 6 barrels of every caliber either. Instead, *we'll use the theoretical method which was validated for .30 caliber, and scale it to other applications.*

Returning to the theoretical calculation at the beginning of this chapter, we'll examine calculations for a range of; bullet caliber/weight, muzzle velocity and barrel twist rate.

In our first example, we'll consider a 52 grain varmint bullet fired at 3600 fps from a 1:14" vs. 1:12" twist barrel. This is a typical varmint hunting application based on the common .22-250 or .220 Swift cartridges.

52 grain Varmint Bullet



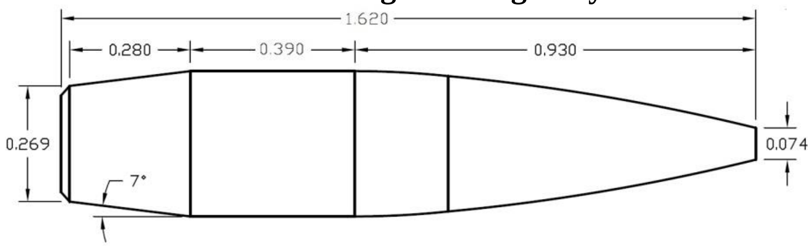
			Kinetic Energy (ft-lb)		
Twist	**Fps**	**RPM**	**Rotational**	**Linear**	**Total**
1:14"	3600	185,143	17.5	1494.9	1512.4
1:12"	3592.5	215,550	23.7	1488.7	1512.4

Figure 1.4. A 52 grain Flatbase Varmint bullet loses about 3.75 fps per inch of twist.

As you can see, the 1:12" twist produces 7.5 fps less velocity than the 1:14" twist, which is a difference of 3.75 fps per inch of twist. Due to the differences between this varmint bullet and the .308 bullet (smaller caliber, lighter weight, traveling at higher speed, with slower twist) produces a different relationship between twist rate and muzzle velocity. Going from a 1:14" to a 1:10" twist is a 4" difference, and would reduce muzzle velocity by about 15 fps. Although the actual fps/inch of velocity loss is different for this varmint bullet than for the .308 caliber example, 3.75 fps is still rather insignificant for a bullet traveling at 3600 fps.

Let's look at another example. Moving up in scale, you can see in Figure 1.5 that the .338 caliber 250 grain Berger Hybrid bullet slows from 2800 fps to 2795.5 fps when twist is increased from 1:12" to 1:10" fps. That's about 2 fps per inch. Again this is an insignificant difference from any way you look at it. To summarize the calculations, we've seen everything from 1.25 fps per inch for the .30 caliber example to 3.75 fps per inch for the Varmint round.

.338 caliber 250 grain Berger Hybrid



Twist	Fps	RPM	Kinetic Energy (ft-lb) Rotational	Linear	Total
1:12"	2800	168,000	29.3	4347.8	4377.1
1:10"	2795.9	201,303	42.1	4335.0	4377.1

Figure 1.5. This .338 caliber 250 grain bullet loses about 2 fps per inch of twist.

I've repeatedly made the statement that the effect of twist rate on muzzle velocity is *insignificant*, but what does that really mean? With no further description, insignificant is a subjective term. How do we know that, for example, the 15 fps lost in going from 1:14" to 1:10" twist is truly insignificant for a Varmint hunter? More velocity is better, but at some point the difference isn't big enough to worry about.

In this case, one way to consider the significance of a number like 15 fps is to think of it in terms of the normal fluctuation in shot-to-shot muzzle velocity. Good hand loads will have standard deviations (SD's) of 10 fps or less, meaning that 95% of shots will be within +/- 20 fps from the average. This window of uncertainty encompasses the difference in velocity between the 1:14" and the 1:10" twist. From this point of view, it seems reasonable that we can call the difference in velocity *insignificant.*

Another way to look at the 15 fps difference in muzzle velocity is in terms of hit percentage on a certain target. Assuming correct fire solutions in both cases, how much would your hit percentage increase based on the difference in ballistic performance resulting from that 15 fps in a varmint hunting scenario?

A Weapon Employment Zone (WEZ) analysis can shed some light on this for us. Using the Applied Ballistics Analytics software package, we're able to calculate the hit percentage for this particular bullet on a given target, range and environment. To model this varmint hunting scenario, we'll use a 5" circle at 400 yards. We'll assume a +/- 2mph uncertainty in wind, and a +/- 10 yard uncertainty in range. Rifle and shooter will be modeled as capable of ½ MOA groups, and ammo as having 10 fps Standard Deviation.

Figure 1.6 shows the results of the WEZ analysis. At 3600 fps, the ballistic performance produces a 94.0% hit percentage on the 5" circle at 400 yards. At 3585 fps, the hit percentage is reduced by 0.1% to 93.9%.

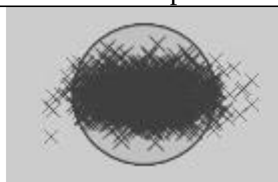
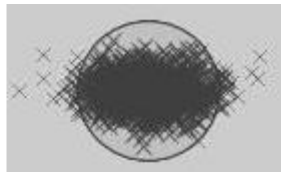
Twist	1:14"	1:10"
Muzzle Velocity	3600 fps	3585 fps
Hit Percentage on a 5-inch circle		
	94.0%	93.9%

Figure 1.6. This table shows how much is hit percentage is affected by going from a 1:14" twist to a 1:10" twist.

Based on this analysis, it's safe to say that *the difference between the 1:14" and the 1:10" twist barrel is* *<u>insignificant</u>* *because the difference in hit percentage is* *<u>negligible</u>*.

Final Conclusion

The conclusions reached in this chapter are supported by a combination of experimental and theoretical results.

The effect of barrel twist rate on muzzle velocity is minimal across the spectrum of small arms. Any performance metrics related to muzzle velocity are not significantly affected by barrel twist rate effects.

Even in the worst case scenario (varmint round) where the velocity is affected almost 4 fps per inch of twist, that's 4 fps out of 3600 fps; a very minor affect. It's been shown thru WEZ analysis that the hit percentage on a 5" circle at 400 yards is only affected by 0.1%.

In the real world of lot variation, muzzle velocity uncertainty, temperature effects, etc. there is simply no practical reason to worry about muzzle velocity reduction due to twist rate.

This general conclusion has eluded common knowledge for years due to the *less than scientific* observations and anecdotal evidence on which such opinions were based and strongly held.

Now that the matter has been put under the microscope and scientifically examined, we can consider the potential advantages of faster twist rates without the irrational fear of depressing muzzle velocities.