The Well Guided Bullet

Part I

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Introduction

I think we should re-examine what happens to our carefully crafted match bullets as we fire them through equally well crafted target rifle barrels. Over the years, gunsmiths and benchrest shooters have developed a system that works quite well to guide our bullets straight into the rifling of the barrel. The 6PPC Sporter Class benchrest competition rifle firing custom made tangent ogive bullets is the specific example that I have in mind. [I was trained always to speak in generalities, but to think in specific at the same time.] I call this time-tested and reliable accuracy formula the "short-range bench rest system." However, when using the more sharply-pointed, longer-nosed, shorter-bodied, boat-tailed, bullet designs that we have come to prefer for minimizing aerodynamic bullet drag when firing shots across longer ranges, we set ourselves up to fail Bullet Guidance 101 in the School of Interior Ballistics—that is, we may be disappointed if we expect to build our 1000 yard bench rest (BR) guns relying solely upon the bullet guidance concepts that work so well in this short-range bench rest (SRBR) system. Poor initial bullet guidance, if it is occurring, could explain the poor accuracy we sometimes experience with very-low-drag (VLD) long-range bullets. In the SRBR system, we often rely on a 1.5-degree leade angle to hold our short-range bullets in place during firing, but our long range VLD bullets do not seem to work the same way.

I will begin this article by propounding the idea that in-bore bullet yaw is a frequent cause of inaccuracy in our current target rifles, present a theory of bullet behavior in the barrel, continue by discussing how this problem is handled in the SRBR system, and conclude (in *Part II*) by recommending a long-range accuracy (LRA) system for small-bore (6.5mm) target rifles. A mathematical appendix presents an examination of the shape of the ogive, or nose part, of our long-range match bullets so that the reader may calculate (for the bullets he uses) the optimum leade angle to provide the best possible guidance of his bullets. Table A1 presents the results of these calculations for three popular 6.5mm, 140gr-class, long-range match bullets.

BEWARE: In the past, many of the terms I must use in this article have been used more or less inconsistently. And my usage of some terms may be equally novel. To minimize confusion, I will note what I mean by certain terms. For example, the nominal *bore diameter* of a 6.5-millimeter match barrel is the minor inside diameter (0.2560-inch), and it is the diameter of a circle that would just touch the tops of the rifling lands. The major inside diameter (nominally 0.2640-inch for a typical match-type 6.5mm barrel) is termed the *groove diameter* (and is nominally 0.008-inch larger than bore diameter in this caliber). [Here, I address only conventionally rifled match barrels with normal, relatively narrow, rifling lands.] The term *bullet body* will be used to indicate the full diameter portion of the bullet—between the rear of the *ogive*, or pointed nose of the bullet, and the front of the *boat-tail*, or tapered base of the bullet. I use the term *barrel throat* to refer to the entire reamer-cut portion that is at the rear of the installed barrel, but ahead of the chamber neck cut. As I use these terms, the *throat* consists of two separately specified and important parts: the *ball seat* and the *leade*. The ball seat cut has parallel (or only slightly tapered) sides and is just large enough to accept the front portion of the bullet body so that the base of the bullet can be seated out enough to clear the powder chamber of the cartridge.

Table A1. Ogive Comparisons for Three 6.5mm Long-Range Bullets

Parameter	**Sierra MK**	**Berger VLD**	**JLK VLD**	**Units**
Ogive Radius (**R**)	**2.756**	**4.752**	**4.752**	Inches
Complete Ogive Length (**L**)	**0.843**	**0.902**	**0.836**	Inches
Bullet Ogive Base Diameter	**0.2640**	**0.2640**	**0.2631**	inches
Bullet Mid-Body Diameter	**0.2640**	**0.2644**	**0.2636**	Inches
Bullet Rear Body Diameter	**0.2642**	**0.2646**	**0.2639**	Inches
Interior Cone Half Angle (**h**)	**8.9**	**8.3**	**9.0**	Degrees
Segment End Angles (**g**)	**8.9**	**5.5**	**5.1**	Degrees
Ogive Tip Half Angle (**a**)	**17.8**	**13.8**	**14.1**	Degrees
Shoulder-to-Contact Distance	**0.148**	**0.303**	**0.381**	Inches
Meplat Diameter	**0.052**	**0.052**	**0.046**	Inches
Truncation Length	**0.086**	**0.178**	**0.146**	Inches
Critical Break Angle (**b**)	**0.0**	**2.8**	**3.9**	Degrees
Contact Angle (**A**, for d = 0.0033 inches)	**2.8**	**3.5**	**4.4**	Degrees
Contact Angle (**A**, for d = 0.0045 inches)	**3.3**	**3.8**	**4.6**	Degrees

The length of the ball seat reamer cut, up to where the leade begins, I call the *freebore* distance. [Note: This freebore in no way refers to the former practice of allowing the bullet a free run for a half inch (or more) before crashing into the rifling, in an effort to allow more powder to be burned before reaching pressure limits.] The leade is the conical (tapered) reamer-cut part of the throat beginning immediately in front of the ball seat and running from the larger ball seat diameter down to the smaller barrel bore diameter. The shallow angle that is cut across the backs of the rifling lands is called the *leade angle*, (but I sometimes call it the *throat angle*, just to keep things interesting). This angle is always given as a "one-sided" cone angle (or "half-cone angle") as opposed to the full cone apex angle (which would be twice as large and which machinists often term the "included angle"). [By the way, the practice of specifying leade angles as "so many degrees, so many minutes, and 36 seconds," as has been enshrined in certain SAAMI specs, is absurd mumbo jumbo. We will skip the engineering humor and give these angles in degrees and tenths of degrees, which is sufficient to the task.]

The Problem of In-Bore Yaw

My primary thesis is that our largest unsolved accuracy problem with small-bore, long-range target rifles firing VLD bullets is *in-bore yaw* due to inadequate bullet guidance in the barrel throat. Furthermore, this in-bore bullet yaw can only happen in our match quality barrels by *asymmetrically distorting* the relatively short bullet body as it takes the rifling in the firing process. We do not normally have the chance to recover and to examine our fired match bullets, so we do not see the direct evidence of in-bore yawing. Bullet yaw in flight can be detected via simultaneous two-axis spark photography or by examining the shapes of the perforations through multiple, uniformly spaced, paper targets all penetrated by the same fired test round. The deleterious effects of allowing in-bore bullet yaw are presented in this section.

If the long-range, target-style, Spitzer bullet enters the rifling at a slight yaw angle, it will *maintain* that yaw throughout its traverse of the rifle barrel. The center of gravity (CG) of the distorted Spitzer bullet will necessarily be offset from the axis of the bore by a small distance. Upon exit from the muzzle, a yawed bullet will deviate from its intended path even at short ranges because of a small cross-track velocity "jump" produced as it begins to rotate about its CG. The path of the bullet from the muzzle is deflected away from the intended path at some radial orientation depending on the roll-orientation of that particular bullet as it is exiting the muzzle. This in-bore yaw also causes the bullet to begin a "coning" motion as soon as it encounters the atmosphere. Unless and until this erratically flying bullet settles down (damps out) and "goes to sleep," it also flies as if it possessed a slightly lower Ballistic Coefficient (BC) and is slightly more sensitive to crosswinds. Poor guidance of the Spitzer bullet as it is taking the rifling will *always* result in this "in-bore yaw" condition.

Because of the volume difference between the VLD bullet's long nose and its short boat-tail, any in-bore yaw of the bullet body will offset its center of mass from the axis of the bore through which it is traveling. I expect that the one place in the bullet that does not shift laterally with in-bore bullet yaw will be the center-of-form of the original, undistorted, bullet body. The center-of-mass of a long-range bullet is usually located on the principal axis near the front end of the bullet body. On exit from the muzzle, the yawed bullet begins to rotate about its center of mass and will deflect by a significant amount and in a cross-track direction from the intended trajectory. This deflection of the path of the bullet is caused by a small tangential-direction velocity kick resulting from this sudden change in axis of rotation. The magnitude of this deflection is proportional to the product of the size of the off-axis center-of-gravity displacement and the spin rate of the bullet. [This is just one of several reasons to select the slowest bullet-stabilizing barrel twist rate.]

As the rear part of the bullet's bearing surface is about to clear the restraining barrel at the crown of its muzzle, "centrifugal force" acting at the bullet's center-of-gravity "slings" the nose of the bullet out to a larger yaw angle just as aerodynamic flight is beginning. This yawing, spin-stabilized bullet will travel along a slightly helical path around the deflected trajectory in aerodynamic flight, especially for the first 50 to 100 yards in front of the muzzle. According to Robert L. McCoy's useful and accessible book, "Modern Exterior Ballistics," (1999, Schiffer Publishing Ltd., Atglen PA, 610-593-1777) the initial yaw angle in aerodynamic flight for our long-range match bullets is about ***twenty times*** the size of the in-bore yaw angle (from Kent's equation). But air drag and bullet spin damp down this initial yaw angle fairly quickly in flight. In the meantime, the yawed bullet has been *coning* and *oscillating* (both clockwise as seen from behind when using a right-hand twist barrel) somewhat like a spinning toy top that is about ready to fall over. Depending upon the *gyroscopic stability* of the spinning bullet, the "slow mode" coning rate will initially be a little over **60 hertz** (cycles per second), and the "fast mode" oscillation rate will be about **five to seven times faster**. I should point out that since both the (1) offset center-of-mass effect and (2) the initial aerodynamic yaw effect are caused by the *same* in-bore yaw problem, these two effects are perfectly correlated and are difficult to separate. However, a poorly balanced bullet or a nick in the barrel crown can, and does, cause either effect separately and independently. I should also point out that, even in precision target shooting, we only see the *variation* of these effects from shot to shot—and not the *systematic* bullet path deviation of all of our bullets. We target shooters tend not to know or to care how our bullets got there, as long as our bullets all impact at the desired spot.

On the other hand, when everything comes together perfectly, some short-range bench rest competitors term the barrel a "hummer barrel" because it is capable of launching a series of bullets, each with *essentially zero initial yaw angle* so that each flies with minimum air drag throughout its brief flight, and, consequently, with *minimum wind sensitivity,* especially during the critical first yards of flight. This could be called "shooting through conditions" because wind sensitivity is directly proportional to the bullet's air drag at any point in its flight. One of the reasons we have learned to pay more attention to the wind just in front of our shooting bench is that our non-hummer-launched bullets are busy doing a high-drag fandango through that local airspace before they "straighten up and fly right." Of course, any wind effects occurring in early flight will deviate the bullet path over the longest time-of-flight and will, therefore, cause the largest bullet displacements on the target. The "everything" that has to be right to produce a "hummer barrel" includes the barrel blank, the bullet, the chamber and throating reamer, the gunsmithing and, of course, the operator. But starting the bullet straight into the rifling with near zero in-bore yaw is apparently the *most difficult* area in which to achieve this perfection.

Having finally disposed of the question of the "hummer barrel," we now bravely take on a claimed advantage of impact-plating our match bullets with molybdenum disulfide (moly). In-bore yaw is reduced with moly-plated bullets because (1) they "self-align" better in the leade while taking the rifling (due to the lubricating effect of the moly?), and (2) they are, after all, slightly larger in diameter (by about 0.2 thousandths of an inch) so there is less slop in any given case neck and ball seat. Walt Berger first reported several years ago discovering the improved alignment of moly-plated bullets during his rifling engraving studies. Less in-bore yaw means less initial aerodynamic yaw, lower initial (and average) aerodynamic drag, and a *higher computed Ballistic Coefficient* (BC), as claimed by certain bullet coating aficionados. If it occurs, any measurable improvement in the BC of a moly-plated bullet would be attributable to *how the spin-stabilized bullet behaves in flight*, ***not*** to any presumed effects of how the bullet was engraved by the rifling (bearing surface roughness or bullet rifling "fins"). [Now, if someone can just figure out how to impact-plate our hollow-pointed match bullets without deforming the bullet's ogive and without getting an unbalanced load of swarf into the hollow nose cavity….]

Even if launched perfectly with no initial yaw, our long-range match bullets will develop a small in-flight yaw attitude if the time-of-flight is long enough. In addition to causing some extra aerodynamic drag force, the gyroscopic motions of a spin-stabilized, yawing bullet generate a rotating *aerodynamic lift* force vector which causes the CG of the ***coning*** bullet to fly in a slightly helical path through the air, rotating about the nominal trajectory. While the bullet's nose follows the nominal trajectory pretty well, its afterbody swings around the mean trajectory in a clockwise motion as seen from behind. With typical cone angles of 2 to 5 degrees, the radius of the circular orbit of the CG about the mean trajectory will normally be *less than one caliber*. In the field of flight dynamics, an object never experiences an aerodynamic *lift force* without also experiencing an associated aerodynamic *drag force*.

What Probably Happens to the Bullet in the Barrel

[The uncertainty indicated in the title of this section is because I am presenting here my "working hypotheses" of bullet behavior in the barrel. These theories seem to agree with my observations and with much of what I have read on the subject, but I cannot prove that they are correct or complete.]

As the primer ignites and the powder starts to burn, the pressure on the base of the bullet spikes to a few thousand pounds per square inch (psi), then falls back and then starts rising rapidly again toward a peak of 60,000 psi, or so. Each of the two times when the chamber pressure reaches about 1,000 psi, the thinned (turned) case necks of our benchrest cartridge *releases* the bullet (assuming a typical bullet pull of 40-50 pounds). If the ogive of the bullet has not been wedged solidly into the leade upon loading, the released bullet will be free to rattle around and will be driven into the rifling with its tip slightly off axis. Using flat-base bullets with a "pressure ring" at the base or using a closely "fitted-neck" on the cartridge case, can help alleviate this loose-bullet yaw problem. But use of a boat-tailed, or beveled-base, short-range BR bullet design would only exacerbate this mis-alignment problem unless the bullet is held tightly in the leade after being released by the case neck. In any case, if the lightly-gripped BR bullet's ogive was *not* in contact with the leade as loaded, it *will make contact and then stop* after the primer ignites but before the powder combustion gets well underway, provided the primer energy is large enough with respect to the effective case volume. I do not know how you might feel about it, but I do not want my bullets starting and stopping only to start moving again, for real, a short time later. This haphazard version of "jam seating" is likely what occurs in "bullet jumping."

The next thing that happens to our carefully made match bullet is even more traumatic—at least for the bullet. It gets smacked in the behind by a force of 2000 to 3000 pounds as the chamber pressure rises very rapidly. [Static force equals static pressure multiplied by the cross-sectional area of the bullet.] A 6.5mm bullet seated up against the rifling lands cannot start engraving the rifling until the chamber pressure exceeds about 10,000 psi. [This is calculated from static bullet engraving force measurements.] Then within the next 200 microseconds, the chamber pressure peaks at maybe 60,000 psi. At some point during this sharp pressure rise, the base of the bullet starts moving forward while the tip of the bullet remains stationary. [Think of acceleration rates of over 100,000 times the acceleration of gravity (**g**) in back, versus "inertia" and "engraving force" resistance in the front part of the bullet.]

Under this much pressure, the soft, low-alloy, lead core of the match bullet behaves as an incompressible liquid, and the body of the bullet expands to fill completely the inside of the ball seat and the inside of the case neck (held inward by the chamber neck walls) ahead of the forward-moving bullet base. In football, this type of activity would be flagged for "backfield in motion" before the snap. The rapidly shortening bullet also expands, at least partially, into the nasty gap between the end of the case neck and the start of the ball seat. This whole process is called "slugging-up" and is remarkably easy to accomplish with our thin-jacketed, soft lead core match bullets. Lead is called a "dead metal" because it does not seem to exhibit any "shape memory" when it has been deformed, unlike our brass cartridge cases and the gilding metal jackets of our match bullets. Once the lead-alloy bullet core has been deformed, it tends to stay that way, simply waiting to be deformed again.

As the bullet body enters the rifling, the bullet gets "swaged-down" to the groove diameter of the particular match barrel. The 45-degree shoulder at the front of the chamber neck cut and the leade-angle conical taper cut into the front of the ball seat and onto the rear of the rifling lands are the steel surfaces performing this bullet swaging. If the barrel groove diameter is smaller than the original bullet diameter (as is often the case), the recently-shortened bullet body is now squeezed out to greater-than-original length. The large hollow cavity in the ogive of the bullet helps to prevent "nose slump," and, perhaps surprisingly, the boat-tail (if present) survives this trauma relatively unscathed. I like to think of the conversion of *chamber pressure* (equal in all directions) into bullet-deforming *force* (a directional vector quantity) as occurring across (and normal to) the plane of a swaging aperture. The boat-tail of the bullet is still in the pressure chamber (interior to the swaging aperture) and is principally subjected to *pressure* which can only produce normal-acting forces and does not distort the shape of the boat-tail (because the jacketed lead-core bullet is virtually incompressible). The after parts of the bullet are *dragged* into the swaging aperture by virtue of their attachment to the bullet's foreparts that have already been swaged. The engraving of a few narrow, rather shallow rifling lands into the periphery of the bullet body is actually a relatively minor event compared to the other bullet trauma involved in starting it down the barrel.

An important thing to point out about these slugging-up and swaging-down processes is that they both work just as well on a yawed bullet as they do on a perfectly aligned bullet. You probably hoped the bullet would try to align itself upon entering into the tapered barrel throat or into the rifling—no such luck, at least not with most of our modern, boat-tailed, Spitzer-type bullets. Real self-alignment of the bullet in the barrel throat just about disappeared from the internal ballistics scene with the demise of the very long, heavy-for-caliber, round-nosed full-patch bullets that were in common use from the dawn of the smokeless powder era until about a century ago. Two modern developments which *do* promote bullet self-alignment are (1) the advent of longer-bodied, secant ogive bullets such as the Hornady 140gr A-MAX bullet, and (2) the use of lubricating bullet coatings such as moly plating. Unfortunately, unless we actively design to prevent it doing so (as in the SRBR system, for example), the modern Spitzer bullet will *always* engrave itself more or less crookedly.

How the Short Range BR System Works at Long Range

In the SRBR system, we prevent this in-bore yaw problem by presenting the bullet to the bore accurately on-axis and by then forcing the bullet into the shallow 1.5-degree throat as we load the round into the rifle. This standard 1.5-degree leade angle works quite well in this SRBR system because of the type of .224 caliber or 6mm match bullets that we use at short range. These are all ***tangent ogive*** bullets with ogive radii of usually seven to nine calibers. These bullets all have matching 1.5-degree angled, ring-shaped contact surfaces on their tangent ogives at around 0.001 to 0.0015-inch smaller than bullet diameter. Optimally, the bullet is held straight in the case neck and "wedged" into the origin of the rifling using "***jam seating***" with the maximum force (varying from about 10 to 50 pounds) which case neck tension allows. It is no coincidence that this 1.5-degree leade angle matches very closely the 1.507-degree half-cone angle used on the "self holding" shanks of the #5 Morse-taper lathe centers and drill chuck holders in my shop. Full cone-angles of from about 2.4 to 3.6 degrees seem to possess a maximum of this remarkable self-holding capability, consistent with not damaging the tool holder during removal. If we were to try even shallower leade angles (for example 0.5 or 0.75 degrees) as many have done, we would find bullet-to-leade contact to feel quite "vague" and "grabby," but these very shallow-angled throats would be somewhat less effective in guiding the bullet straight into the rifling. On the other hand, depending on the internal barrel dimensions and on the nose radius of our tangent ogive bullets, we should find that a leade angle of around 3 to 4 degrees provides even better bullet guidance (compared to using the standard 1.5-degree leade) while retaining good "bullet wedging" capability and with even better "feel" for bullet-to-rifling contact. [See the mathematical appendix at the end of this article to calculate your optimum "tangent contact" leade angle.]

Apart from producing the annoying side effect of pulling the bullet and spilling gunpowder into the action each time at the range when you must remove an un-fired round from the chamber, this wedging of the bullet into the leade is the *most reliable way* to keep the bullet aligned with the axis of the bore throughout the firing process in the SRBR system. This jam seating approach works, but perhaps somewhat less well, if we use it with the much longer and heavier 6.5mm long-range match bullets often used at 600 to 1000 yards—as long as they are *tangent ogive* bullets. [The 6.5mm Sierra 142gr MatchKing is the specific example of this type match bullet that I have in mind, as it appears to have a tangent ogive.]

Why the SRBR System Does Not Work at Long-Range

Now consider a 1000 yard BR rifle chambered in 6.5/284 Norma featuring the following combination of bullet, barrel and chamber design parameters:

- A loose "factory" 0.301-inch chamber neck diameter,
- Using a standard 1.5-degree throat angle,
- With an oversize (0.2645-inch) ball seat diameter that will accommodate the largest diameter 6.5mm match bullet,
- Shooting "skinny" (0.2631-inch) 140gr secant ogive VLD bullets
- Through a tighter-than-nominal 0.2630-inch (groove diameter) match barrel.

The SRBR system *breaks down in three important ways* if we try to apply it directly to this "worst-case" example of long-range rifle design:

(1) The 1.40-inch long VLD bullet has only a 0.50-inch bearing surface length, but its ogive length is 0.70 inch. This short-waisted VLD bullet shape means that the *sum* of whatever ***diameter clearances*** exist at the front and at the rear of the undeformed bullet body after it is released by the case neck will show up, multiplied by a *factor of approximately 1.5*, as the off-axis bullet tip displacement of the in-bore yawed bullet. Use of the "skinnier" (smaller body-diameter) VLD bullet than the neck diameter and ball seat will accommodate, causes worst-case misalignment if the bullet cannot be held into alignment by some other way (maybe a sabot?). In this example, the front body diameter clearance is 1.5 thousandths of an inch, but the rear body clearance is 9.1 thousandths. The offset of the bullet tip from the bore axis is 0.016-inch (or a 1.2-degree in-bore yaw angle), which results in an initial maximum aerodynamic yaw angle of about 24 degrees. This amount of in-bore bullet-tip offset is at least *ten times* the maximum acceptable amount. Note that the fit of the bullet ogive in the leade will not constrain the bullet from assuming an in-bore yaw attitude of 1.2 degrees. [See below.]

(2) The ***secant-ogive*** nose of the VLD bullet cannot contact a 1.5-degree leade at any point ahead of the bullet shoulder because of a 3.9-degree *break angle*, or discontinuity, in the bullet surface angle at that shoulder. There is simply *no portion* of the bullet ogive available for "self holding" in a 3.0-degree "included angle" throat. In other words, the shallowest cone-angle that could be tangent to any part of this bullet ogive is the 7.8-degree cone that could be tangent to the ogive at its base (big end). Any other cones, tangent farther forward on the ogive, would necessarily have even larger apex angles. The cone-angle for flat contact with the ogive at the nominal bore diameter of 0.2560-inch is 9.0 degrees. In machinery design, this would be bordering on what is called a "self releasing" cone-angle. But the real problem is the *mismatch* between the barrel throat angle (1.5 degrees) and the cone angle (4.5 degrees) that would produce tangent contact with the bullet ogive. This mismatch of 3 degrees on each side means that the leade will constrain the bullet axis only to remain ***within 3 degrees*** (maximum in-bore yaw angle) of the bore axis. Also, because the inside of a 3-degree cone

cannot get much grip on the outside of a 9-degree cone, the secant ogive VLD bullets *cannot* stick in a 1.5-degree throat as can tangent ogive bullets. This 3.9-degree break angle and 4.5-degree bore contact angle are for a 0.2631-inch diameter JLK 140gr VLD bullet. [See Table A1 of the Mathematical Appendix.] Having this small, non-zero, break angle at the bullet shoulder is the very feature that distinguishes a *secant ogive* bullet and is the feature that provides the bullet much of its VLD characteristic.

(3) The bullet is initially guided *only* by the leade-angle taper which was cut into the front end of the ball seat (and not by any part of the rifling lands) even if the bullet has been "jam-seated" into the leade with all the force that case neck tension can supply. The ability to seat out a "fat" (0.2644-inch diameter) bullet requires a ball seat diameter of 0.2645-inch for clearance. This ball seat is 1.5 thousandths larger than the groove diameter (0.2630-inch) of the selected "worst-case tight" match-grade 6.5mm barrel blank. The front 0.030-inch of the ball seat is a 1.5-degree taper cut into *solid stainless steel*. Figure 1 illustrates this situation in a schematic diagram showing the relationships between the secant ogive bullet, the reamed 1.5-degree barrel throat, and the inside diameters of the barrel. It is this solid steel taper in the front of an oversized ball seat that has caused poor results (high chamber pressures) whenever steeper throat angles have been tried in the past.

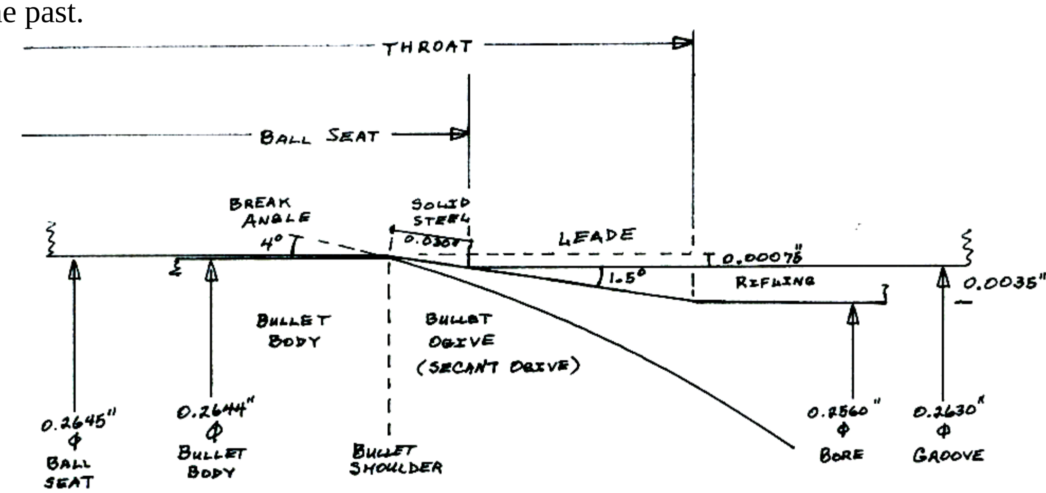

FIGURE 1. A SECANT OGIVE BULLET IN A 1.5° THROAT

The sharp-radius, 4-degree shoulder of our secant ogive bullet cannot be "engraved" by this tapered, solid steel leade even with jam seating. Bullet-swaging forces of at least 1000 pounds (corresponding to 20,000-psi chamber pressure) will be required to move this bullet forward into this tight barrel. You might hope that use of the "skinny" 0.2631-inch bullet would eliminate this swaging-down problem. I think not. Instead, I reckon that this skinny bullet will just shorten all the more while it slugs-up to fill that oversize 0.2645-inch ball seat, the 0.273-inch inside diameter of the expanded-until-constrained case neck, and partially to fill the 0.020-inch axial length of 0.301-inch diameter "nasty gap" in front of the brass case neck. After this bullet has slugged-up, we will have about the same situation as with the fat bullet. The annular ring of jacket material on the jam-seated bullet's ogive that matches the barrel's bore diameter still lacks (before swaging) about 0.060-inch of contacting the back of the rifling lands all the way up to their top edges (i.e.; at bore diameter). Thus, the "swaging-down" of the "slugged-up" VLD bullet establishes the permanent bullet orientation in the bore ***before*** the engraving of the rifling even starts. The process of engraving the bullet with the rifling cannot straighten out a bullet that has just been swaged into a yawed in-bore form. [I once recovered buckets full of old, fired, military boat-tailed bullets, many of which showed rifling marks indicating that they had been badly yawed in the barrel. These particular bullets looked really strange, with half the rifling engraved on one side of the bullet's ogive and the other half down on its boat-tail on the opposite side. These were the very tough, 30-caliber M1, 172gr FMJ bullets that had been fired into the soft, freshly-installed dirt backstop of a WWII rifle training range.]

End of *Part I*

In *Part II* of this article, we will propose a new design approach to be incorporated into our long-range rifle building techniques so that we can launch high-BC, long-range match bullets as well as we currently fire short-range bench rest bullets. The mathematical appendix is also given after *Part II*.