The Well Guided Bullet

Part II

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Introduction to *Part II*

In *Part I* of this article, we outlined the problems encountered in attempting to build and operate our long-range rifles using short-range bench rest design concepts. Here in *Part II* we propose the design changes necessary to help us safely overcome those problems.

The Long Range Accuracy System

The objects of this design exercise are (1) to insure that the Very Low Drag (VLD) bullet will be *forced* always to enter the rifling straight-on and (2) to accomplish this with the least possible bullet deformation. If we properly incorporate this design into our long-range target rifles, we should be able to launch high-BC, long-range, VLD match bullets as consistently as we can now fire our short-range, light-for-caliber, bench rest bullets. Alternatively, some of these bullet alignment problems could be alleviated by selecting new designs for our long-range, high-BC, match bullets, other than the excellent VLD designs currently available. Two candidate new bullet designs that show promise are (1) CNC-turned, monolithic, low-drag bullets featuring narrow driving bands and a "bore-riding nose," and (2) the Flat-Based VLD bullets (having *no* boat-tails) described by Robert L. McCoy in the October 1995 issue of ***Precision Shooting Magazine***.

As shown in Figure 2, we are employing in this design both (1) a "*fitted neck*" and (2) a "*fitted ball seat*" so that there will be the *least possible clearance* around each end of the bullet body when it is held in the firing position. Together, these two features guarantee the best possible guidance of the back end of the bullet as it takes the rifling. At the same time, the bullet ogive is cradled in (3) a *tangent contact* leade-angle cone of the polished ends of the rifling lands. This leade angle causes the back of the lands to fit the bullet nose as well as the bolsters of a sailboat trailer fit the boat hull it carries. The tangent contact of the ogive of the VLD bullet with the ends of the rifling lands also provides the farthest forward bullet nose alignment that is possible with conventional bullets. In this way, we are utilizing the longest possible lever arm to align any given bullet mechanically in its custom-designed barrel throat. Thus, the bullet is as

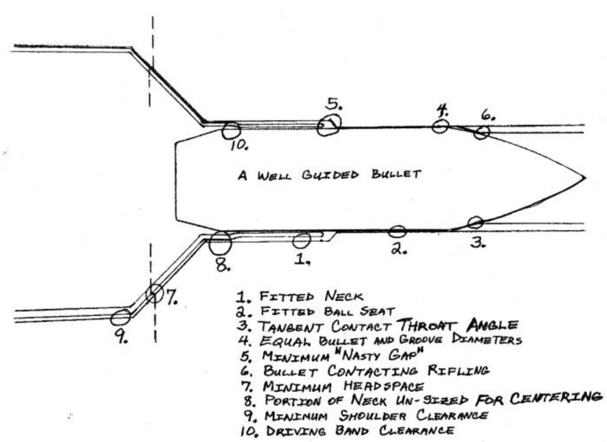

Figure 2. Features of the Long Range Accuracy System

perfectly centered as it can be at each point of contact and will be well guided as it moves into the rifled portion of the barrel.

Requiring that the bullet diameter, the ball seat diameter, and the barrel's groove diameter (4) *all match each other* as closely as possible not only mechanically forces the bullet body to remain well centered on the barrel bore axis, but also minimizes the amount of bullet body *deformation* by "slugging-up" and "swaging-down" during firing. Perhaps the *most important effect* of closely matching these three sizes is to insure that the ball-seat-cutting portion of the chamber finishing reamer will *barely remove the rifling lands*. Since our soft-lead-core match bullets will always "slug-up" to fill any reasonable ball seat during firing, we must guarantee that the selected ball seat diameter does not exceed the barrel's groove diameter—lest the steeper throat angle just recommended (above) cause greater "bullet start forces" and consequently higher chamber pressures. That is, swaging the entire bullet body down to groove diameter *and then* engraving the rifling should require about twice the amount of "starting force" required merely to engrave the lands of the rifling when each is measured using the same throat angle.

Minimizing the (5) *nasty gap* at the end of the case neck *(not to exceed 0.010 inch nor to fall below 0.005-inch)* reduces bullet deformation by swaging upon the **45-degree** shoulder at the end of the chamber neck cut. Soon after barrel break-in, this **45-degree** shoulder becomes worn into an ugly, blackened, "rolled-over" shape. In addition to the wear of slightly swaging-down the diameter of each bullet's jacketed body, this shoulder is burned and blasted by taking the full brunt of the stream of hot, corrosive powder gasses and abrasive, burning particles exiting the case neck.

Also, requiring that the bullet ogive of each loaded round (6) *contact the rifling*, at least lightly, optimizes static bullet alignment and, it is fervently hoped, improves the efficiency and the repeatability of the powder combustion process. We expect the secant-ogive VLD bullet to start engraving the rifling when the chamber pressure reaches about **10,000 psi**, as it would have done in a **1.5-degree** throat with an oversized ball seat diameter. These six design elements are at the heart of the proposed new "Long-Range Accuracy (LRA) system" of bullet guidance into the barrel.

Readying a New Barrel for the Bullet

If you are planning to install a new barrel blank in your long-range target rifle using the LRA system, the first thing you should do is to select a long-range match bullet and a barrel blank that *agree in diameter* with each other. For example, if we want to fire a JLK 140gr VLD bullet at 0.2631 inch body diameter, we might select an 8 inch twist button-rifled barrel blank with a "tight" groove diameter of 0.2630 inch. Or, if we want to fire a 0.2644 inch diameter Berger 140gr VLD, we might be happier selecting a barrel having the nominal 0.2640 inch (or a few tenths larger) groove diameter. Reversing these pairings would only yield two unhappy combinations. We want a snug fit of the bullet into a ball seat diameter *that barely removes the rifling* from that portion of the installed barrel. This ball seat to barrel groove diameter fit will *eliminate* the tapered, leade-angle, solid steel ring that is usually cut into the front portion of the ball seat (and its attendant bullet swaging effects). [I would order at least 1000 of the selected long-range bullets, because that bullet will work better than any other in your new barrel.]

Now that you have selected your bullet and barrel, you should select your brass cartridge cases. [I would order about 100 or 200 of them.] Prep a few pieces of brass and seat five of your bullets all to the exact position in the resized case neck where you want to load them. [I like about half of the boat-tail of a VLD bullet hanging out of the neck below the junction with the case shoulder.] Measure the case neck diameters of your five dummy rounds in several places, and decide on a chamber neck diameter that will allow minimizing clearance around the back end of the bullet body as it is being released by the case neck in firing. Select a chamber neck diameter that will allow a "fine tuning" adjustment of neck clearance by slightly varying the neck wall thickness in neck turning. [I use a chamber neck inside diameter about 0.5 to 1.0 thousandth of an inch larger in diameter than my loaded-round outside neck diameter.] Also, while your chamber neck length *must* be at least 5 thousandths of an inch longer than your "trim-to" neck length, as witness your prepped cases, you want to keep this gap to no more than 10 thousandths of an inch.

> *CAUTION: these two clearances just mentioned are well under the normal "safety minimums" in handloading. Measure or gauge the neck diameter of each round before firing it. Measure or gauge the over-all-length (OAL) of each case after re-sizing. Pay attention or you* ***will*** *blow up your rifle. This is only for the careful operator who is pushing the edges of the envelope for long-range accuracy. Who else would be dedicated enough to build an expensive target rifle that could only fire one kind of bullet?*

Box up three of your new dummy rounds, a few of your prepped cases, and a few of your selected bullets, and send them off to your preferred chamber reamer grinder with a brief note explaining what you want.

Tell your reamer maker that your installed chamber headspace will be between zero (the preferred end of the range) and plus 0.001 inch with respect to the headspace minimum (his GO gauge). I mention chamber headspace here because all axial dimensions in front of the reference datum line through the shoulder area of the chamber (and of the loaded round), are measured from this datum line and are, in turn, related to the bolt face and case head locations via the rifle's particular headspace distance. Also, find out your selected barrel's bore and groove diameters and pass along these dimensions as well. Measure and record the body diameters of a good number of your selected bullets. If your bullets have some taper to the body, jig them so that you mic each at a point that would be just outside the case neck. Select a ball seat diameter about 0.1 or 0.2 thousandths larger than your *most frequently occurring bullet size*, and include this information in your note.

Finally, ask your reamer maker to use his optical comparator to measure your dummy rounds and recommend a *freebore distance* and *leade angle* to provide tangent contact of your bullet ogives with the backs of your rifling lands at the *bore diameter* of your barrel. This leade angle will provide flat, metal-to-metal, tangent contact at the forward-most point that is possible on the VLD bullet's ogive for optimum bullet guidance during firing. [I use a 4.0 degree throat angle for Berger 140gr VLD's]. The rifling is able to contact the ogive of our secant ogive 6.5mm VLD bullet fully 0.080 inch farther forward than would have been the case with a 1.5 degree throat. This change in throat angle *significantly enhances* bullet guidance. The correct freebore distance produces your desired bullet seating depth in the case neck when the ogive of the seated bullet in the chambered round is just touching the backs of the rifling lands. [I prefer a slight, but definite, “feel” of bullet contact on bolt closure.] In the proposed new LRA system, there is no longer any particular value in *jamming* the bullet hard into the lands, but we do *require contact* between the bullet ogive and the lands.

Expect to pay a “custom reamer” price premium for this level of service. Of course, the bore diameter of the barrel also indicates the live pilot diameter that should be requested with the new finish reamer. [I recommend that, at this time, you also order a GO headspace gauge, a reamer drawing, and a custom-made leade-polishing hob ground from tool steel to match your new throat design.] When the parts and tools are in hand, chamber the barrel to minimum headspace as verified with the GO gauge made by the maker of your new chamber finishing reamer. Polishing the leade with your new polishing hob using tiny amounts of 1200 grit abrasive is a nice touch. This should minimize barrel “break in” problems. This throat polishing could be repeated every 200 rounds, or so, to prevent possible increases in chamber pressure due to roughness in the throat and to maintain top accuracy throughout the life of the barrel. [A bore scope is invaluable for this work.]

Modifying a Previously Chambered Barrel

A previously chambered target rifle barrel can be re-chambered and re-throated to a better leade angle, but the barrel will probably need to be set back one or two threads to achieve the desired bullet seating depth. Be wary of partially implementing this LRA system, lest your results prove disappointing. If you have a “fat bullet ball seat” already installed in a tight barrel, or a really sloppy chamber neck in diameter or in length, you may need to set the barrel back a quarter inch or more and re-chamber it. An otherwise correct chamber finishing reamer could be returned to the maker for modification as described above. Alternatively, you could just have the integral throater ground off (removed) and purchase a separate throating reamer made to produce your desired ball seat diameter and leade angle cuts. Remember to match your bullet selection (and thus, your throater specifications) to your barrel groove diameter.

Measuring Bore and Groove Diameters of Your Barrel

What *are* your barrel’s bore and groove diameters, anyway? You can tell with most barrels by oiling the clean bore and dropping an oiled, soft lead cast bullet of the correct (or slightly smaller) caliber straight into the chamber with the barrel pointed downward. Push the bullet just ahead of any roughness in the throat with a blunt-ended cleaning rod, and, while backing it with the first rod, lightly tap the front of the bullet a few times with a second rod. This will readily “slug-up” your test bullet. Remove the second cleaning rod and pay careful attention as you push the slug through the bore to the muzzle. You can tell a lot about your barrel by slugging it this way. If the slug feels loose at any point ahead of the throat, repeat the slugging, starting at different places and going either direction. If you should locate a loose spot in the middle of your barrel or a reverse-tapered bore, you should select a different barrel blank. By the way, you can use one bullet repeatedly by re-slugging it. Catch the bullet you wish to measure as it exits the barrel (Don’t drop It.) and carefully wipe the oil from it. You can readily mic the outside (groove diameter), but you can only measure the bore diameter with narrow mic jaws, and then only if there is an even number of lands. You are out of luck with an odd number of lands unless you can locate someone with the special equipment to measure them. [In my shop, we can tell bore diameters pretty well by gauging the barrel ends with the interchangeable live pilot bushings available in caliber sets graduated by 0.0001 or 0.0002 inches. An indicator rod makes a convenient handle for this gauging operation.]

Keeping It Straight

An extensive list of "talking points" is presented below as suggested topics to keep in mind in reloading the most accurate ammunition for your target rifle:

- Measuring and Gauging Tools:
    - Digital micrometer (1.0 inch capacity by 0.00005 inch resolution).
    - Digital calipers (6 inch capacity by 0.0005 inch).
    - Specially modified case neck micrometer (reading to 0.0001 inch).
    - Cartridge headspace measuring add-on kit for caliper.
    - Headspace GO gauge used to zero calipers for headspace.
    - Bullet seating-depth measuring add-on kit for caliper.
    - A "dummy round" made as a seating-depth gauge. [Store in die box.]
- Case Preparation:
    - Use a lubricated "snug-fitting" carbide mandrel in the neck turning tool.
    - The carbide mandrel should also have end-cutting teeth to remove cleanly any "dreaded doughnut" ring which might appear after fire-forming.
    - 100 Percent "clean-up" neck turning is required.
    - Turn all the way "into the shoulder" with **45-degree** beveled cutter.
    - Make a few light polishing turns with **0000** steel wool after turning.
    - Fine tune loaded-round neck diameter by adjusting neck wall thickness.
    - Primer pocket uniforming is required.
    - Flash hole uniforming and beveling is optional with the best brass.
    - Square case mouths at maximum possible over-all length (OAL). [One of the major design flaws in the 6.5/284 Norma case is its too short neck, which shortens barrel throat life un-necessarily.]
    - Chamfer case mouth lightly outside.
    - Ream a **4 degree** (per side) leade inside case mouth up to **0.025 inch** in width.
- Reloading Equipment:

    - Redding Competition Full-Length Type-S (bushing) die set.
    - Titanium nitride bushings of neck size *minus* **.002** and **.003 inch.**
    - Leave bottom portion of neck (about **0.080 inch**) un-sized to clear the bullet driving band (if present) and for positive centering of the neck in the chamber.
    - Use FL bushing die like a "shoulder bump die." [We are after "minimum brass movement" in successive firing and resizing cycles.]
    - Set shoulder back **0.5 to 1.0 thousandth** (*maximum*) each time the case is reloaded after fire-forming:
        - Consider altering a **+.002** Redding Competition Shellholder, as necessary, to achieve precisely the required minimum shoulder set-back by solidly abutting the FL die at the top of the ram stroke of your press.
        - Use reamer maker's GO headspace gauge to zero your headspace measuring equipment accurately.
    - Keep cases dedicated to this rifle chamber only.
    - Redding competition bullet seater with floating chamber or Wilson chamber-type bullet seater and light duty arbor press for best alignment and concentricity of seated bullet.
- De-capping and re-priming:
    - Use separate pliers-type de-capper (a hand tool) to keep highly abrasive primer residue out of your FL sizing die.
    - Clean out and re-deepen fired primer pocket with carbide uniformer.
    - Clean primer dust from cases and from hands.
    - Use BR-style hand primer seater.
    - Seat edges of primer cup just to bottom of pocket every time.
    - Add a small, consistent primer pellet compression to each seated primer by use of your "calibrated thumb."
- Powder charging:
    - Automatic-weighing powder dispensers work well where AC power is available.
    - Plus or minus **0.1 grain** repeatability required.
    - ***Swirl*** powder into cases with a powder funnel.
- Bullet seating:
    - Concentricity of loaded round is critical.

  - Cold-welding problem of bullets in case necks [Re-seat to final depth just before firing].
  - Contact with lands is required.
  - Use "dummy round" to set seating depth desired.
  - Notice the feel of the bullet "popping into place" as the pressure ring (if so equipped) clears the neck-sized portion.
  - If a bullet seating operation produces *any* perceptibly different feel, ***do not*** fire that round in competition.
- Do not *heat*, *vibrate*, or *invert* the loaded rounds before firing.
- Short-range testing and chronographing of long-range loads:
  - Accuracy at short range (100 or 200 yards) is necessary, but not sufficient, to guarantee long-range accuracy.
  - Smallest possible (single digit) *extreme spread* in muzzle velocities (not just in *standard deviation*) is needed for long-range match ammunition.

Summary

I believe that *in-bore bullet yaw* is the most important remaining accuracy problem with our long-range target rifles. I propose a new approach to chambering Long-Range Accuracy (LRA) target rifles, which is an extension of the tried-and-true Short-Range Benchrest (SRBR) system, with features added to better guide VLD match bullets into the rifling. This LRA approach requires measuring barrels and bullets, matching them in diameters, and having a new finish chambering reamer made to incorporate a proper throat for the selected match bullet. I offer arguments to support the use of "tangent contact" leade angles and very snug, "fitted" chamber necks and ball seats. I present mathematics in the following Appendix to allow the reader to calculate these leade angles for any of his long-range match bullets.

Mathematical Appendix: A New Slant on Throat Angles

In this section, we examine the variations that we may encounter in long-range bullet ogive shapes and in bullet dimensions, and the corresponding variations in throating reamer leade angles that we should use. I present mathematics to assist you, the reader, in calculating either tangent or secant ogive shape parameters from your bullet's measurements and in calculating optimum leade angles from your barrel and bullet measurements. "Optimum throating angle" means specifying the throating reamer angle so that it cuts the ends of the rifling lands to provide *tangent contact* with your selected bullet's ogive at your selected barrel's bore diameter. No math more complicated than trigonometry is required.

I expect that the question of throating angles has been previously investigated, but not in the past several years, or at least not specifically for small bore, secant ogive, VLD bullets. According to Robert L. McCoy, the secant ogive, as used on our VLD bullets, possesses almost the lowest-drag nose shape ever investigated for small caliber, supersonic projectiles. The secant ogive is used on all of our long-range “VLD bullets.”

The ogive, or nose part, of a Spitzer bullet can be envisioned as being made up of two pieces glued together and then stuck on the front of the (rather short) cylindrical bullet body. Figure A1 illustrates the pertinent part of a secant ogive bullet in side profile. The

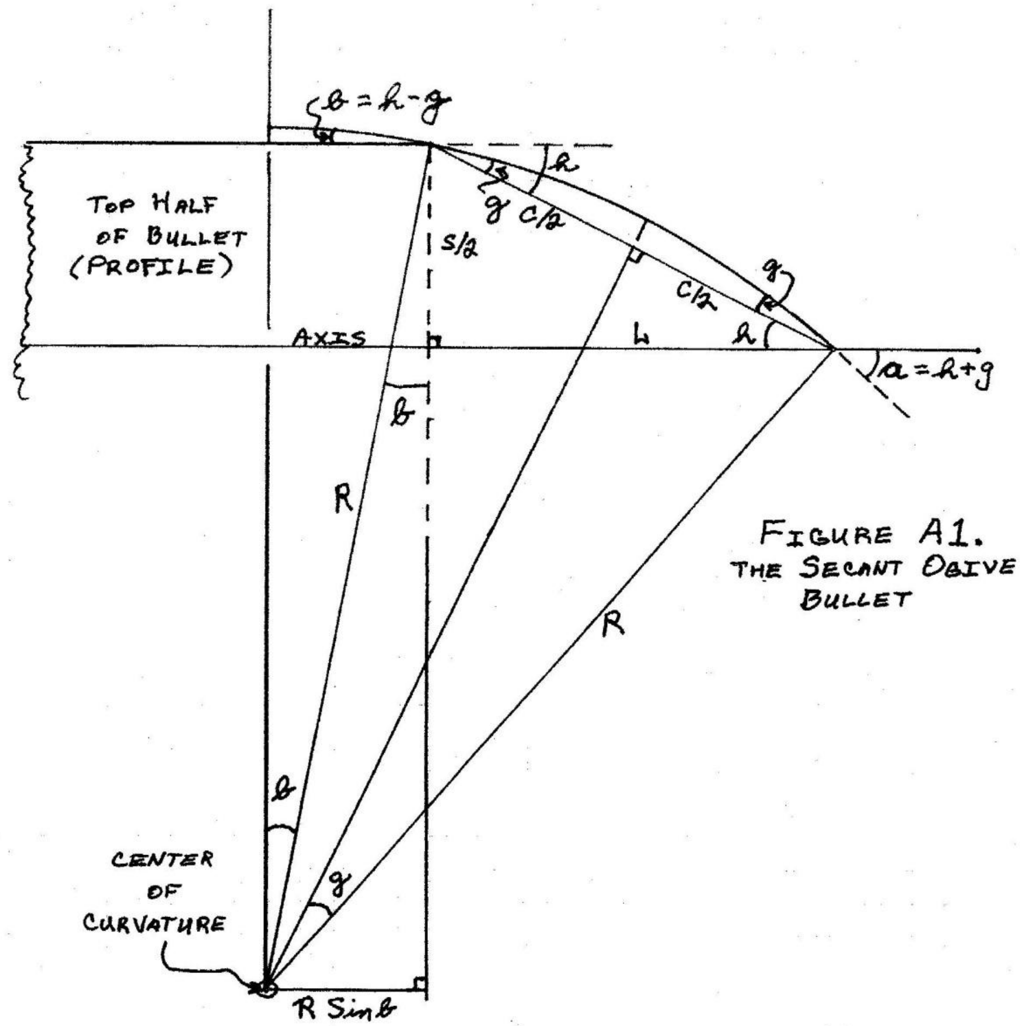

FIGURE A1.
THE SECANT OGIVE
BULLET

first piece of the secant ogive is a long right-circular cone with a base diameter of one caliber **s** and with a height equal to the full, non-truncated, nose length **L**. The half cone angle **h** of this “interior cone” is given by

$$h = \mathrm{ArcTan}(s/2L)$$

The second piece of the secant ogive nose is a “solid of revolution,” defined by a circular arc of large radius **R**, stretching along the outside of the cone from base to tip. The ogive radius **R** is usually expressed in “dimensionless units” as some number **r** of calibers **s**, as in an “**18s** ogive,” for example. Thus, the ogive radius **R** (in distance units) is given by

$$R = r*s$$

The side-view profile of the interior cone discussed above is an isosceles triangle, and each of the two equal sides is a “chord line” cutting off a small arc of one of the large radius circles defining the ogive. The chord length **C** can be calculated from the complete (non-truncated) nose length **L** and from the half cone angle **h** as

C = L*Secant(h) = L/Cos(h)

The center of curvature of this ogive-defining arc lies along the perpendicular bisector of this chord line at a large radius. The small central angle **g** subtended by one half the chord length (**C/2**) from a radial distance **R** from the arc is computed from

g = ArcSin(C/2R)

From geometry, this small central angle **g** is the same size as the angles at each end of the segment area cut off by this chord. The nose half-angle **a** at the bullet tip is just

a = h + g

If we coin the term *“break angle”* to mean the quite visible (non-zero) angular change in the surface of a secant ogive bullet at the ogive-to-body join line, we can calculate the size of this break angle (**b**) quite simply from

b = h – g

Any throat angle smaller than this critical break angle **b** can only result in the full-diameter shoulder of the secant ogive bullet seating against the ball seat cut into the back of the rifled barrel, as diagrammed in Figure A2 (which is the same as Figure1, above).

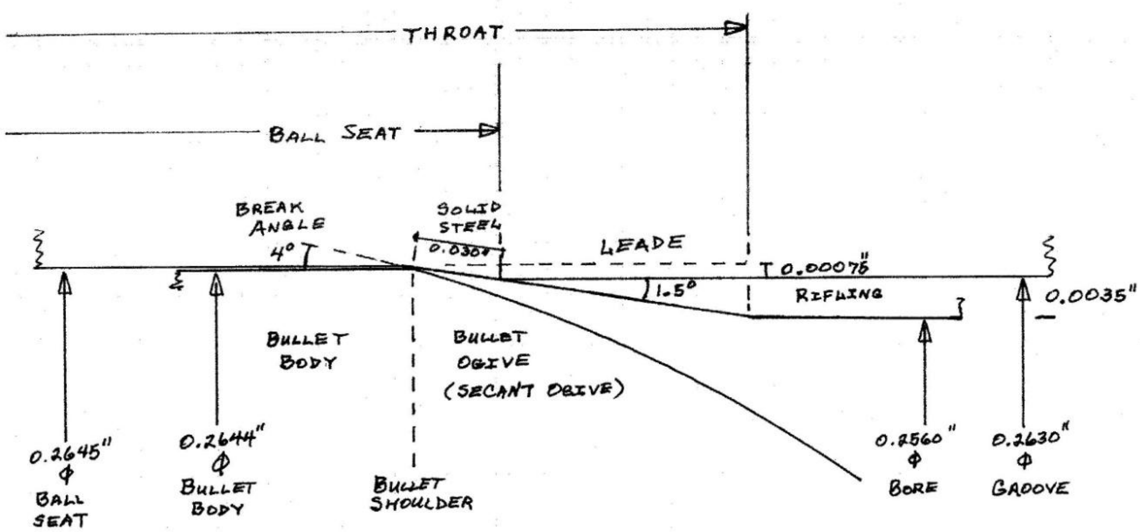

Figure A2. VLD Bullet in a 1.5-Degree Throat.

The inward distance **d** to the contact point of the bore diameter end of the throat on the ogive of the bullet is one half of the difference between the bullet body and barrel bore diameters, or

d = (Bullet Body Diameter – Barrel Bore Diameter)/2

Finally, the reason for wading through all this mathematics is so that we can calculate a new kind of leade angle for use with these modern bullet designs in our long-range target rifles. The traditional **1.5 degree** leade angle no longer works well with our new high Ballistic Coefficient (BC) match bullets. We need a throat angle that will provide tangent, or flat, metal-to-metal contact between the backs of the rifling lands and the bullet ogive. Furthermore, we need this contact point to be *as far forward as possible* on the ogive for optimum bullet guidance. This point in the barrel throat will be at, or near, the top edges of the rifling lands (and is at the barrel bore diameter). Figures A3 and A4 show a comparison of the geometries of secant and tangent ogive bullets as to how they interface the leade into the rifling.

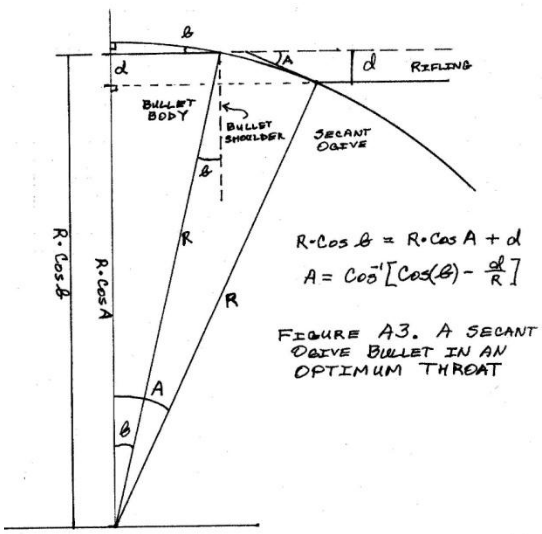

FIGURE A3. A SECANT OGIVE BULLET IN AN OPTIMUM THROAT

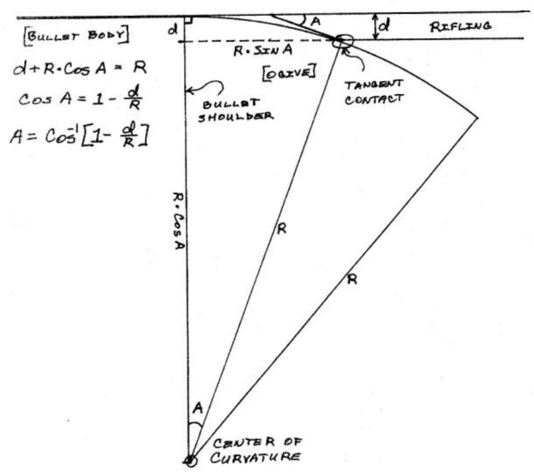

FIGURE A4. A TANGENT OGIVE BULLET IN AN OPTIMUM THROAT

The throat angle **A** to provide optimum contact for use with a secant ogive bullet is found from

A = ArcCos[Cos(b) – d/R]

And this contact point occurs at an axial distance **X** ahead of the shoulder of the secant ogive bullet, where

X = R*[Sin(A) – Sin(b)]

Note that if, for example, we were gradually to shorten the radius of curvature of the ogive **R** so that the segment angle **g** approaches the same size as the half cone angle **h**, the break angle **b** goes to **zero**, the nose half-angle **a** becomes just twice **h**, and the "secant ogive" reduces exactly to the *special case* called the "tangent ogive." The 6.5mm ***Sierra*** 142gr ***MatchKing*** (SMK) bullet is an excellent example of a long-range match bullet which uses a very long tangent ogive nose. Table A1 compares this 142gr SMK bullet with 140gr VLD bullets from two custom bullet makers. The last two table entries compare tangent contact leade angles for two different contact depths **d**, which bound the range of values that may be encountered in 6.5mm target rifles.

For those who do not wish to fit their throat angle to the ogive of a specific long-range bullet (or who do not wish to pursue the math), we conclude this section by recommending that a **4 degree** leade angle will be the optimal single choice for an unspecified long-range 6.5mm match bullet. This is probably a useful single change in throating for an existing barrel, but will not bring out the full accuracy potential as would implementing the complete long-range accuracy system. Use of a slightly too-steep leade angle is preferable to use of a too-shallow throat angle, but the correct "tangent contact" angle is ideal.

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**