

## Development of Copper ULD Rifle Bullets

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After two years of development and testing, our new copper ULD rifle bullets are working reasonably well, but some unexpected new problems have also come to light.

### Progress:

1. The dual-diameter design of these copper bullets makes them self-aligning in the throat of the rifle barrel before they are engraved by the rifling. They suffer no *in-bore yawing* as routinely occurs when firing conventional bullets from standard chambers. These bullets do not need tight-necked chambers or neck-turned brass in order to be fired in perfect alignment coaxial with the rifle bore, nor do they need (nor allow) jam seating against the origin of the rifling for front-end alignment. A 5-percent drag reduction and BC improvement is a side benefit of selecting this dual-diameter bullet design. Our dual-diameter 338-caliber copper ULD bullet flies as if it were a conventional 0.330-inch diameter bullet.
2. Simply by lathe-turning these monolithic bullets from cold-rolled copper rod stock, the recurring problem of *bullet static imbalance* which is universal with jacketed, lead-cored bullets has been eliminated. Center-of-Gravity (CG) offset from the bullet's axis of external form should be immeasurably small for each one of these copper bullets. Accuracy destroying trajectory deflections due to *lateral throw-off* do not occur in firing these copper bullets.
3. The design goal of producing *Ultra-Low-Drag* (ULD) rifle bullets has certainly been achieved. The average ratio of Coefficients of Drag (CD's) measured for our Mark II copper 338-caliber bullets compared to those the G7 Reference Projectile is **0.72** averaged over all supersonic Mach speeds up to Mach 3.5; that is, the aerodynamic form-drag is 28-percent less than that of the "Very Low Drag" VLD-shaped G7 Reference Projectile. This average ratio of aerodynamic drag functions is termed the G7 Form Factor (**i7**), and lower is better. The G7 Form Factor for most conventional long-range rifle bullets is in the range of 0.90 to 1.10, with VLD bullets ranging from 0.90 to

0.95. This Form Factor (**i7**) is used in calculating the Ballistic Coefficient (**BC**) of the bullet relative to the well determined drag function of the G7 Reference Projectile. A bullet's BC(G7) value is formulated as its Ballistic Sectional Density (bullet weight in pounds divided by the square of its caliber in inches) divided by this **i7** value. The Mark II bullet design uses a truncated secant-ogive head-shape having an RT/R ratio of 0.500 and length of 3.2-calibers. The new Mark III design will use a similarly truncated LD-Haack nose shape of 3.5-calibers in length and is expected to produce a G7 Form Factor of about **0.69**. Measured supersonic air-drag is largely determined by the fineness ratio (nose length divided by caliber) of these low-drag nose shapes.

4. We have shown that, as a necessary precondition for achieving their designed minimum aerodynamic drag in use, these new copper bullets must be fired with an initial gyroscopic stability **Sg** of at least **2.5**. These longer copper ULD bullets can then achieve "hyper-stable" (minimum coning angle) flight after just the first 10 to 20 yards of early, highest-drag flight through the ambient atmosphere (after having penetrated the muzzle-blast shockwave 2 or 3 yards from the muzzle). At this high initial gyroscopic stability **Sg**, the bullet's ballistic travel distance while damping out its initial excessive yaw-drag is determined by its muzzle speed and the period (time duration) of its first gyroscopic coning cycle. Because these new copper bullets are so much longer, they must be fired from rifle barrels made with a much faster *rifling twist-rate* than could be used with conventional jacketed, lead-cored rifle bullets to achieve their needed initial **Sg** values. Lengthening the bullet's nose to improve its fineness ratio for significant drag reduction also just slightly decreases that bullet's Coefficient of Yaw-Drag (**CDa**); so that the rapid damping of any initial coning angle-of-attack remains critical for achieving minimum-drag flight to long ranges. A twist-rate of 20 calibers per turn (6.6 inches per turn in 338-caliber) will produce an initial gyroscopic stability **Sg** of about 3.0 for these new copper bullets.
5. During development testing of our Mark II copper ULD bullet, we became aware that they were not *obturing the bore* of our test barrels anywhere nearly as well as do conventional jacketed, soft lead-cored match bullets. We recovered many copper ULD 338-

caliber bullets test-fired into a swimming pool and analyzed their barrel markings and soot deposition patterns. Solid test bullets made of half-hard copper with rear driving bands of 0.3382-inch OD were not expanding enough dynamically to seal the hot powder gasses at peak base pressure, when fired at 60,000 psi peak chamber pressures in a Krieger cut-rifled test barrel having 0.3380-inch groove ID. Careful mechanical analysis showed the bore of this stress-free test barrel was expanding internally by **1.65 thousandths of an inch** at peak base pressure, which is the root cause of the gas sealing problem. The 246-grain Mark IIc 338-caliber bullets were then designed with **0.125-inch** drilled bases to port this base pressure internally for adequate gas sealing. David Tubb fired a 5-shot test group using these Mark IIc copper bullets over his 1,000-yard instrumented range and measured a **4 fps** extreme spread of the muzzle speeds—indicating very good gas sealing in his pre-stressed, button-rifled Schneider test barrel, which we estimate was only expanding internally by **1.1 thousandths** at similar peak base pressures. Gary Schneider's P5 rifling pattern is one which is specifically designed to provide good sealing of the propellant gasses by the rifling-engraved bullet. We enlarged the base-drill diameter to **0.152-inch** for the Mark III bullet design largely to assure adequate gas sealing when they are fired from any type of 338-caliber rifle barrel or rifling pattern having a standard 0.3380-inch groove ID.

### Problems Remaining:

In test-firing the Mark IIc version of these copper ULD bullets in 338-caliber, two separate accuracy-related issues have emerged:

1. David measured very low average air-drag values, but the measurements for each individual bullet over 1000 yards varied unacceptably from one shot to the next. While the 5-shot group spanned only 8 inches on the distant target, the measured times-of-flight to the target varied significantly even though the extreme spread in launch speed was only 4 fps. This variance in flight times is likely attributable (mostly) to variation in aerodynamic skin-friction drag caused by lengthwise variations in the tripping point of the boundary layer flow-field from its initial lower-drag laminar flow into its final higher-drag turbulent flow. The design intent for these Mark II ULD

bullets was for the 4.5-degree surface break-angle, where the base of the secant ogive joins the cylindrical shank of the bullet, reliably to trip the boundary layer flow at that point for all shots. Had the length of the secant-ogive nose been shorter (as with conventional VLD bullets), this break angle would have been larger, and the boundary layer tripping at that point might have been more consistent. The newly redesigned Mark III ULD bullet uses an LD-Haack nose shape which is essentially tangent to the shank at this join, and completely eliminates that surface break angle which is only sometimes tripping the boundary layer flow-field. This inevitable tripping of the boundary layer flow-field should instead occur much farther aft at the 7.5-degree surface break angle at the start of the full-diameter rear driving band for Mark III 338-caliber ULD bullets. A firing test of these redesigned bullets will indicate how well this approach works.

2. Another, more serious accuracy problem appears to be due to a significant randomly oriented trajectory deflection caused by an aerodynamic jump occurring during the first half coning cycle (10 yards, or so) of ballistic flight, starting when the bullet exits the muzzle-blast shockwave. This problem has so far prevented firing 5-shot groups reliably smaller than **0.75 MOA** with these 338-caliber copper ULD bullets fired in my wind-free indoor 105-yard test range from a 7-inch twist Schneider test barrel. This same test rifle with a 10-inch twist Krieger barrel has reliably fired conventional 300-grain jacketed match bullets (Sierra MatchKings) into **0.35 MOA** groups in this indoor range.
  - a. Apparently, these bullets are being more disturbed in yaw and/or yaw-rate than would heavier conventional bullets while each is transiting the muzzle-blast zone, so that they are flying with significant yaw attitude at the beginning of ballistic flight. My take is that conventional bullets simply produce smaller angular trajectory deflections due to this same type of aerodynamic jump after entering the atmosphere with similarly caused, but smaller sized, yaw disturbances. As a first-order approximation, we might assume that the size of these yaw disturbances is *inversely proportional* to bullet weight. Using the 300-grain conventional bullet as a reference, the expected size

of the initial yaw in firing a 246-grain copper bullet would then be increased by a factor of  $300/246 = 1.22$ .

- b. In lengthening the secant ogives of these ULD bullets for significant drag reduction, we also necessarily decreased slightly their Coefficients of Lift (**CL**) and, thence, their resulting cross-track aerodynamic lift forces which ultimately drive them away from their intended trajectories. [Bob McCoy's Interim Lift estimation program INTLIFT estimates **CL** directly from nose length alone for each Mach-speed above Mach 2.0.] Comparing the estimated **CL** of **3.0445** for a jacketed match bullet having a typical 2.25-caliber nose length with a **CL** of **2.7267** for the 3.2-caliber nose of our Mark II ULD bullet, INTLIFT estimates **CL** at only **89.6-percent** as much for the longer-nosed copper bullet at launch speeds of Mach 2.8. The presumed **22-percent** larger initial yaw disturbance, together with this 11-percent smaller **CL**, would result in a net **9.2-percent** greater cross-track aerodynamic lift impulse force **F<sub>L</sub>** with the new copper bullet:  $(300/246)*0.896 = 1.092$ .
- c. Another significant aeroballistic difference between shorter conventional bullets and these necessarily longer copper ULD bullets is in their mass distribution **ly/lx** ratios. These ratios of second moments of inertia for the bullet's crossed principal axes run from about 8:1 to 10:1 for conventional jacketed match bullets, but is about 17:1 for our longer monolithic copper bullets. Tri-Cyclic Theory shows *directly proportional* increases in the periods (i.e., longer time durations) of these slower-rate gyroscopic motions of the spin-axes of these longer, higher inertial ratio, monolithic copper ULD bullets for any given bullet spin-rate. While we do spin these copper bullets up to twice as fast as conventional rifle bullets, the typical doubling of the **ly/lx** ratio actually results in them coning at much slower rates as determined by the increased gyroscopic stability (**Sg**) of these copper bullets. The time duration of the cross-track impulse force is *inversely proportional* to the bullet's coning rate. The impulse duration for a ULD bullet coning at 34.4 hertz, relative to that of a conventional bullet coning at 60 hertz, would increase by a factor  $60/34.4 = 1.746$ . Thus, the cross-track

impulse (force multiplied by duration) which is laterally displacing the copper bullet would be larger by a factor of  **$1.092 \times 1.746 = 1.907$** . Subsequent analysis shows that the initial coning rate of a rifle bullet is very nearly *directly proportional* to the rifling twist-rate  **$n$**  (in calibers per turn), all else being equal. So, we can decrease the duration of the cross-track impulse by speeding up the initial coning rate of the bullet, which in turn is done by selecting a slower rifling twist-rate having more calibers per turn (larger  **$n$**  value).

- d. The typically 22-percent lighter-weight copper bullet is also typically launched at 12-percent faster muzzle speed  **$V_0$** . Thus the initial *linear momentum* (mass times velocity) of the lighter-weight, but faster, copper bullet is only  **$(246/300) \times 1.12 = 0.9184$** , or **92-percent** of that of the heavier conventional bullet.
- e. The tangent of the very small accuracy-robbing trajectory deflection angle is given by the ratio of its cross-track momentum to its initial linear (forward) momentum. But, from physics, the cross-track momentum (or actually its change from zero initially) is equal to the cross-track impulse. In terms relative to the conventional bullet reference, the trajectory deflection angle for the copper bullet would then be  **$1.907/0.9184 = 2.076$**  times larger. [In this analysis, the majority of this accuracy loss is attributable to the slower coning rate of the longer copper bullet, which is in turn due to firing them with higher initial gyroscopic stability  **$S_g \approx 2.5$  to  $3.0$** .] Group size (measured as its extreme spread) on a target at any range would increase by this same ratio of **2.076**. Thus, our **0.35 MOA** indoor 105-yard group size with conventional 300-grain match bullets would correspond to an indoor group size of  **$2.076 \times 0.35 = 0.727$  MOA** with our 246-grain copper ULD bullets, which is about what we are seeing in our indoor test range, and David Tubb's **0.8 MOA** group at 1000 yards is very impressive outdoor long-range shooting indeed.
- f. The larger base-drill diameter of **0.152-inch** selected for the Mark III 338-caliber bullet not only provides improved its gas sealing, but also marginally improves (reduces) that bullet's  **$I_y/I_x$**  inertial ratio from 17.28 to 16.76 which speeds up its

coning rate by **3.1 percent**. The base-drilling penalty in bullet-weight using this larger drill size increases from 10 grains to 15 grains, leaving the final Mark III 338-caliber bullet weight at **265 grains**. Repeating this comparative accuracy estimate for our new Mark III 338-caliber bullet indicates we should expect **0.600 MOA** 5-shot groups with that new prototype bullet fired from a barrel with a 6.6-inch twist (or **20 calibers per turn**). Perhaps a slightly slower recommended rifling twist-rate of about **24 calibers per turn** (or about 8-inches per turn for 338-caliber) would prove a better compromise in trading some marginal increase in air-drag for better real-world accuracy (**0.500 MOA**) with these new copper Mark III ULD bullets. David's P5 Schneider barrel is rifled at 7.5-inches per turn, which is **22.7 calibers per turn**.

### Summary

We have learned how to make statically and dynamically balanced monolithic copper rifle bullets which fly at supersonic airspeeds with ultra-low aerodynamic drag (ULD), which can be launched without having suffered from in-bore yaw, and which can demonstrate very low dispersion in muzzle speeds due to proper gas sealing within the barrel. We are still working on improving the shot-to-shot consistency of that portion of the air-drag which is attributable to skin friction.

We can improve the target accuracy of these copper bullets at all ranges by using rifle barrels made with rifling patterns which promote improved gas sealing and by selecting a rifling twist-rate of approximately **24 calibers per turn**, instead of the previously recommended **20 calibers per turn**.

We still need to minimize the yaw disturbance of these bullets in transiting the muzzle-blast zone which causes inaccuracy due to aerodynamic jump deflections of their subsequent trajectories. One method which might be worth exploring would be to eliminate most of the muzzle blast by porting the top and sides of rifle barrel itself well behind the muzzle. While some of the gas pressure is being bled off, the bullets are still being guided in the bore until muzzle exit. However, this approach would have the significant disadvantages of slightly reducing muzzle velocities and of making muzzle-attached brakes and suppressors completely ineffective.

