

## Rifling Twist Rate Concerns

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We have been exploiting Coning Theory in the development of our new turned copper Ultra-Low-Drag rifle bullet designs. We ran into an accuracy problem in our test-firing which we did not properly anticipate. Having addressed and ameliorated each of the persistent accuracy issues experienced with conventional and monolithic rifle bullets; in-bore yawing of the engraved bullet, lateral throw-off caused by static imbalance of jacketed bullets, gas leakage past monolithic bullets causing varying velocity losses, and a few others, we expected to see improved target accuracy in our latest test results. However, that has not yet happened.

David Tubb measured almost **30-percent reduced aerodynamic drag** over 1,000 yards compared to the G7 reference projectile shape, well below the drag predictions of Bob McCoy's McDRAG estimations (outside his 5-percent estimation limits). We correctly attributed much of this air-drag reduction to reduced yaw-drag in those tests. David used a Schneider 338-caliber barrel with a 7.5-inch twist (**n = 22.7 calibers per turn**) which produced an initial gyroscopic stability (**Sg**) of **2.75** with our earlier copper ULD bullets. We correctly intuited that by using a rifling twist-rate of **n = 20 calibers per turn**, any monolithic bullet of up to 6 calibers in length could fly with its lowest possible total air drag.

### The Yaw-Drag Problem

After additional analysis based on Coning Theory, we can now explain exactly why yaw-drag is minimized by selecting smaller **n**-values for the firing barrel's rifling twist-rate:

- (1) The bullet's aeroballistic yaw attitude "aerodynamic angle-of-attack" **a** is identically that bullet's coning angle **a**.
- (2) For **dynamically stable** rifle bullets, this yaw angle **a** is exponentially damped in ballistic flight with damping factor **lambda**, here given in **inverse seconds of ballistic flight time t**, so that

$$a(t) = a_0 * \exp[-\lambda * t]$$

- (3) This slow-mode damping factor **lambda** has now been formulated in Coning Theory (details available), and it has been found to be **inversely proportional to the square of n**, the rifling twist-rate in calibers per turn.
- (4) For fast-twist barrels, the total extra velocity loss due to yaw-drag (**delta-V**) during a long flight occurs early in that flight while the bullet's initial yaw angle **a<sub>0</sub>** is damping into insignificance and while its dynamic pressure **q** is at its greatest level. The

size of **delta-V** can be found by integrating the loss in kinetic energy due to yaw-drag of that bullet over just its first few coning cycles using *initial values*:

$$(m/2) * (\text{delta-V})^2 = q * S * V_0 * a_0^2 * CD_a / (2 * \text{lambda})$$

(5) So, the total **velocity retardation delta-V** due to yaw-drag over the long flight is **directly proportional both to the rifling twist-rate  $n$**  in calibers per turn **and to the initial magnitude  $a_0$**  of the yaw attitude angle. Dropping back from  **$n = 20$**  to  **$n = 24$**  would increase the yaw-drag component of total aerodynamic drag attributable to any initial yaw  **$a_0$**  by **20-percent**.

The large variation in times-of-flight measured over 1,000 yards with David's Oehler System 88 instrumentation is thus attributable to random amounts of initial yaw  **$a_0$**  varying by about 2.5 to 5 degrees within each 5-shot group. Note that the **shortest** measured time-of-flight over 1,000 yards indicates the individual shot which suffered the **least** yaw disturbance while transiting the muzzle-blast zone before commencing ballistic flight, so its (highest) calculated **BC** value is most representative of that bullet design's nose-forward air-drag  **$CD_0$** .

### The Accuracy Problem

This initial yaw disturbance hypothesis is strongly reinforced by the disappointing accuracy results with these copper ULD bullets test-fired both by David and in our wind-free indoor test range. We each are seeing about **0.8 MOA** 5-shot groups with these fast-twist rifle barrels when everything else is done correctly.

The same analysis based on Coning Theory which allowed earlier formulation of the angular trajectory deflection termed "aerodynamic jump" due to a horizontal crosswind at the firing point holds for a bullet entering a wind-free atmosphere with a non-zero initial aeroballistic yaw attitude. [In fact, this is exactly how Bob McCoy handled the simulation of crosswinds in his own 6-degree-of-freedom simulator.] The resulting angular deflection drives the bullet away from its intended trajectory in a radial direction 90-degrees advanced in the sense of the rifling twist from the roll orientation of the initial yaw angle itself. As an angular deflection given in milliradians or minutes of angle (MOA), the miss distance produced on the target is strictly proportional to firing distance. A randomly oriented initial yaw disturbance which is also random in magnitude will simply increase extreme spread shot-group sizes as measured on the target.

This aerodynamic jump is caused by an aerodynamic lift-force moving the CG of the rifle bullet away from its intended trajectory during the first half of its first coning cycle in ballistic flight. This transient lift-force is integrated over the time of the first half-period of the bullet's coning motion to produce a cross-track **impulse** which shifts the direction of that bullet's linear momentum vector. This lift-force directionally cancels during all subsequent coning motion.

The size of this aerodynamic lift-force is **directly proportional** to the size of the initial yaw angle  $\alpha_0$  causing it. The amount of time over which this cross-track impulse accumulates is **inversely proportional** to the initial **coning rate**  $f_2$ . The initial coning rate  $f_2$  is determined from the Tri-Cyclic Theory as

$$f_2 = (I_x/I_y) * [V_0 / (n * d)] / (R + 1)$$

where  $I_x, I_y$  = Second moments of inertia of the bullet's mass distribution about crossed principal axes

$d$  = Caliber of the bullet in feet

$R = f_1/f_2$  = Gyroscopic stability ratio.

The gyroscopic stability ratio  $R$  conveys **1:1** the same information as the classic gyroscopic stability  $S_g$ , but in a more directly usable form:

$$S_g = (R + 1)^2 / (4 * R)$$

Both  $S_g$  and  $R$  vary **inversely with the square** of the rifle barrel's twist-rate  $n$  in calibers per turn (details available).

Examining the above expression, it becomes apparent that the initial coning rate  $f_2$  varies **directly with the rifling twist-rate**  $n$ , which causes both the cross-track impulse integration time and indeed the resulting size of that impulse to vary **inversely** with the value of  $n$ .

So, in a practical sense, we could simply say that, all else being equal, "Accuracy is **proportional** to the twist-rate  $n$  of the rifle barrel." Competitors in rifle accuracy sports have long sought to use the slowest possible twist-rates (largest number  $n$  of calibers per turn) in their match rifle barrels. Now we see another rationale supporting that wisdom.

For **best accuracy** in the presence of some initial yaw disturbance, we want the slowest possible rifling twist-rate, but for **lowest air-drag** with the same yaw disturbance we want the much faster **20 calibers per turn** twist-rate. We cannot have it both ways.

In extreme long-range (ELR) riflery, we need the lowest possible air-drag even at some expense in gilt-edge accuracy, so those ELR riflemen might stick with my recommended **20 calibers per turn** twist-rates. On the other hand, 100-yard benchrest competitors might stick with their **60, or more, calibers per turn** 6 mm PPC barrels. I now recommend **24 calibers per turn** for general use of monolithic rifle bullets.

### Takeaways

The problems caused by **yaw destabilization** of fired rifle bullets occurring while transiting the muzzle-blast zone are much more serious than had been expected. By reducing the initial coning rate from a typical **65 hertz** for jacketed match bullets to the

range of **25 to 45 hertz** for our copper ULD bullets fired from fast-twist barrels, we have inadvertently amplified this problem both in its variable air-drag and accuracy destroying effects. We are currently convex-radiusing the boat-tail bases of our copper ULD bullets at **0.74-calibers**, which does help in controlling their yaw destabilization in the muzzle-blast. We might also try slightly beveling the rear corners of those boat-tails, as well.

More research is needed into rifle building techniques which facilitate launching monolithic bullets with little or no initial ballistic yaw. Barrel porting and the use of integral suppressors come to mind, as does trying other non-tubular styles of muzzle brakes. Perhaps artillery designers already have a handle on this yaw destabilization problem.