Rifling Twist-Rate Effect on Chamber Pressure

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Introduction

Interior ballistics calculations usually assume a rifle bullet will be fired through a barrel rifled at a standard twist-rate of about 40 calibers per turn, as with a 30-caliber barrel having a 12-inch twist for example. For some new applications we need to use barrels rifled at much faster twist-rates of about 20 calibers per turn where the spin-up inertia of the accelerating bullet might significantly augment the linear inertial resistance provided by the mass of the projectile. Riflemen know that inertial resistance is increased when selecting faster twist-rate barrels, but we have had no way to quantify the effects of that increase. We shall formulate this increased inertial resistance in terms of an increase in effective bullet mass so that we can then use conventional interior ballistics programs like QuickLOAD© to calculate realistic chamber pressure curves with these fast-twist barrels. We are not concerned here with possible mechanical issues affecting bullet integrity when weaker types of bullets are fired through fast-twist rifling.

Analysis

We will ignore bullet-to-bore friction in this formulation because it is difficult to quantify and because, whatever its effects, this friction is not primarily affected by our choice of rifling twist-rate in that barrel. We shall start our analysis just after the bullet has been engraved by the rifling lands in the throat of the barrel because very little rotation of the bullet is occurring during that brief high-stress mechanical process. Peak rotational acceleration of the bullet occurs along with peak linear acceleration at the time of peak base-pressure when the bullet has moved just a few inches into the bore.

The instantaneous force **F(t)** driving the rifling engraved bullet down the barrel is given by the product of the instantaneous base-pressure **P(t)** behind the bullet and the cross-sectional area **S** of the bore:

$$\mathbf{F(t) = P(t)*S}$$

Most of this driving force **F(t)** is matched by the inertial force **F_L(t)** resisting the linear acceleration of the bullet down the bore. Neglecting friction, this linear inertial force **F_L** is given by the product of the bullet's mass **m** and its linear acceleration **a** according to Newton's Second Law of Motion:

$$F_L = m*a = m*d^2x/dt^2$$

where $m = (\text{Bullet Weight})/g$

and $g = 32.174 \text{ feet/second}^2$.

The position of the bullet along the axis of the bore is our **x-axis** here.

Neglecting friction, the remainder of the driving force **F – F_L** is matched by an instantaneous axial force **F_A** spinning-up the bullet due to the rifling twist. This axial force **F_A** is attributable to the second moment of angular inertia **I_x** of the bullet's mass distribution about this same **x-axis** and the second time derivative **$d^2\Theta/dt^2$** of the bullet's angular orientation **Θ**.

If the caliber of the bore is **d**, we can define the twist-rate of the rifling as **n*d** where **n** is the number of ***calibers per turn*** of that rifling. Each full turn of the rifling pattern represents **2*π** radians of angular motion in **Θ**. The engraved bullet remains mechanically locked into the rifling as it moves, so that:

$$\Theta(t) = [2*\pi/(n*d)]*x(t)$$

Since the twist-rate **n** and caliber **d** are taken as constants here,

$$d^2\Theta/dt^2 = (2\pi/nd)*d^2x/dt^2$$

The second moment of inertia **I_x** of the mass distribution of the bullet about its **x-axis** can be expressed as:

$$I_x = m*k^2$$

where **m = Mass of the bullet**

and **k = Radius of Gyration** of its mass distribution.

The inertial resistance to spinning-up the bullet is a torque **T** such that, from the rotational form of Newton's Second Law of Motion:

$$T = I_x*d^2\Theta/dt^2$$

or $$T = [m*k^2]*[(2\pi/nd)*d^2x/dt^2].$$

Now we need to relate this rotational resistance torque **T** about the **x-axis** of the bore to an equivalent linear resistance force F_A acting along that axis, neglecting friction but taking into account the twist-rate of the rifling. Fortunately, we recognize this as being mechanically equivalent to the relationship between the tightening torque **T** of a threaded fastener and its resultant axial clamping force F_A in the absence of friction. From mechanics, this relationship is:

$$F_A = (2\pi/nd)*T$$

where our twist-rate **n*d** takes the place of the ***thread pitch*** of the fastener.

Substituting our expression for **T** above and rearranging, we have:

$$F_A = (2\pi/n)^2 *(k/d)^2 * m*d^2x/dt^2$$

Summing the two reaction forces, we now have the formulation:

$$F = F_L + F_A$$

or

$$F = [1 +(2\pi/n)^2 *(k/d)^2] * m*d^2x/dt^2$$

From the mass properties calculated for monolithic copper Ultra-Low-Drag bullets of my own design, we can estimate the likely ratio of **k/d** to be approximately **0.36** for any similar ULD or VLD rifle bullet.

Results

Let us examine the second term above in the square brackets, the fractional equivalent mass increase of the bullet when taking spin-up inertia into account. For a traditional rifling twist-rate of **40 calibers per turn**, we calculate:

$$(2\pi/40)^2 *(0.36)^2 = 0.00320 \text{ or } 0.32 \text{ percent}$$

Since about this amount of standard spin-up inertia is already included in applicable interior ballistics programs such as QuickLOAD©, we should modify our formulation to compensate for that fact:

$$F = [0.99680 +(2\pi/n)^2 *(k/d)^2] * m*d^2x/dt^2$$

Now, when we need to calculate the equivalent bullet mass (or weight) to enter into QuickLOAD for calculating the pressure effects with a fast twist barrel with **n = 20 calibers per turn**, for example, we simply multiply the bullet mass (or weight) by:

$$\mathbf{0.99680 + (2\pi/20)^2 * (0.36)^2 = 1.00959}$$

Thus, for example, one could simply enter into QuickLOAD an effective bullet weight of **302.9 grains** when firing a **300 grain** bullet from a very fast-twist **20 calibers per turn** rifle barrel. All QuickLOAD calculated outputs would then be corrected for the use of this very fast-twist barrel.