EFFECT OF A LUMPED MASS ON A RIFLE BARREL

A Harmonic Analysis utilizing Solidworks Simulation

Orientation: The objective of this study was to gain some insight on the harmonic behavior of a rifle barrel submitted under impulse loading, and how a lumped mass at the end will affect this behavior.

The analysis was done with Solidworks Simulation using the harmonic response module. This being a powerful tool and very user friendly. It was used to calculate the displacement of the muzzle once a high-pressure impulse load was initiated in the chamber at the breach end of the barrel.

The Analysis

First things first, why exactly are we doing this?

We must first understand what a firearm is.

What is a firearm?

- Internal Combustion Engine.
- Designed to perform work in the form of Kinetic Energy.
- In contrast to Armor systems, it is designed to perform a high amount of work over a small interval of time.
- Usually used to incur impact damage on mechanical and electrical objects (anti-material).
- Or remote wounding in the form of hydrostatic shock and mass hemorrhaging in living organisms (anti-personnel).

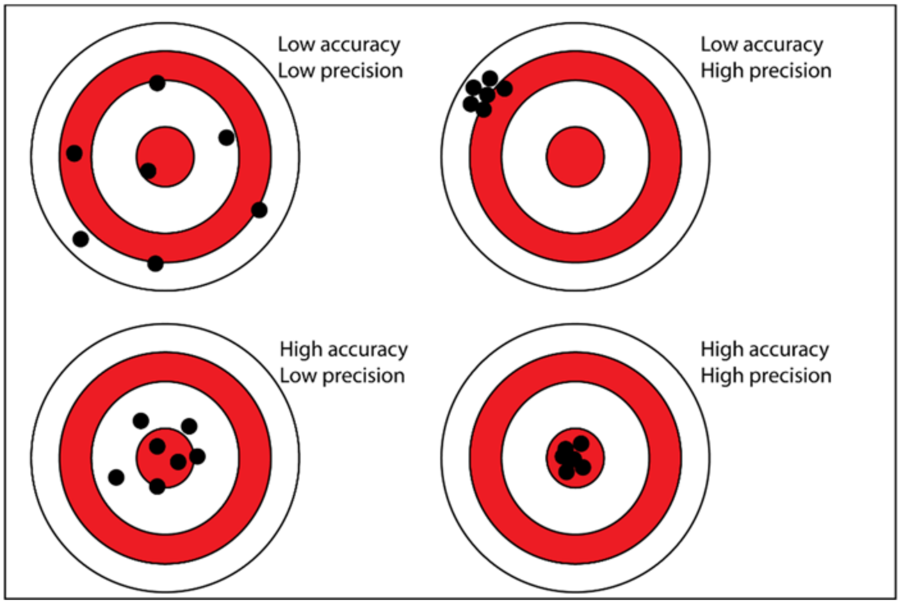
The Problem.

There are two types of error in any given system. Systematic error, which is the error occurring from controllable parameters, and random error, which occurs from the chaotic behavior in all systems.

In terms of Firearms

<u>Accuracy</u> – Generally controlled by the user

<u>Precision</u> – Generally controlled by the machine



We are trying to minimize the systematic error caused by the device. Weapon precision is a function of many variables. Among these are stock material, stock bedding material, load configuration (head space, powder burn rate, powder charge weight, bullet mass, bullet seating depth, etc.). Barrel configuration is what we are looking at here, holding all other variables constant. These include variables of length, stiffness, thickness, etc.)

<u>Barrel Harmonics</u>

Barrel Harmonics are a phenomenon where which the barrel vibrates under impulse loading of the ignited powder charge. It is also known as "barrel whip" on the range. The idea is not to eliminate it but to make it consistent with repeatable results. Modern precision rifles have barrels that are mounted in a cantilever fashion wherein the barrel never touches the for-end of the stock. When the barrel is fastened to the stock then you get an inconsistent harmonic response, the cantilever configuration allows the barrel to vibrate at its natural frequency with little variance.

Modern competitors utilize a Tuner to find the sweet spot for each load configuration. It nothing more than a lumped mass mounted at the end of the barrel.

Figure 1 Photo of an actual competition barrel tuner.

<u>The Model</u>

The model shall consist of a standard 26" bull barrel, chambered in 7.62 x 51 mm NATO with the rifling omitted. Barrel material shall be AISI Type 316L Stainless Steel (E = 29,000 psi). Four configurations were created including one "naked" model with no tuner attached, and two others with a 5 oz., 10 oz., and 15 oz. tuner respectively.

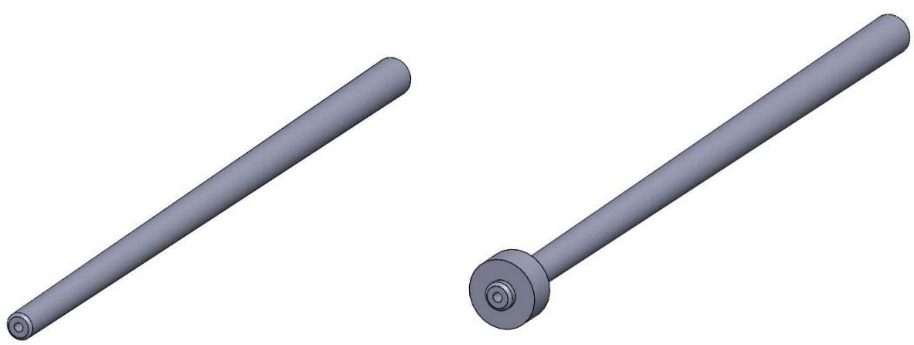


Figure 2 Barrel models in Solidworks

<u>Parameters and Boundary Conditions</u>

The Chamber was modeled after actual dimensions of the cartridge itself.

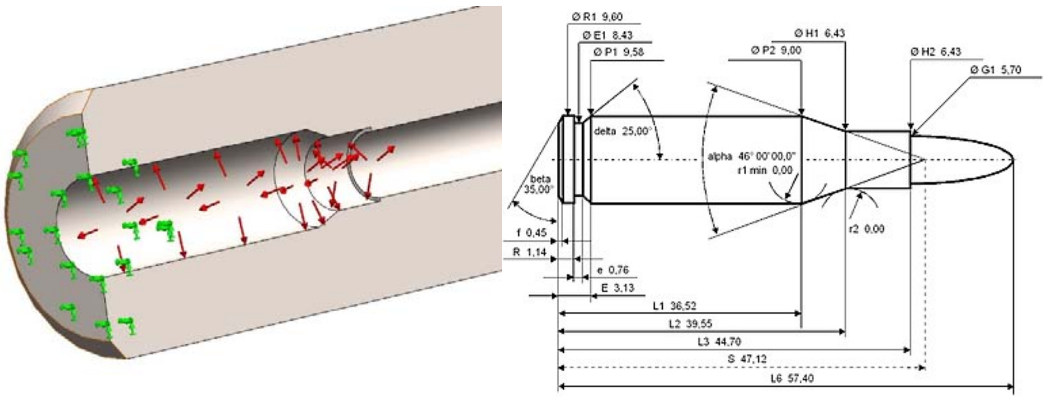


Figure 3 Green arrows indicate fixed geometry and red arrows indicate vector field for applied pressure curve. To the right is the nominal dimensions of the 7.62 x 51 mm NATO round.

The breach end was fixed to simulate the cantilever mounting.

<u>Pressure Curve</u>

Nominal Chamber pressure taken from ballistic data (NATO EPVAT) is 60,191 psi. This was implemented into the simulation with a pressure curve shown below.

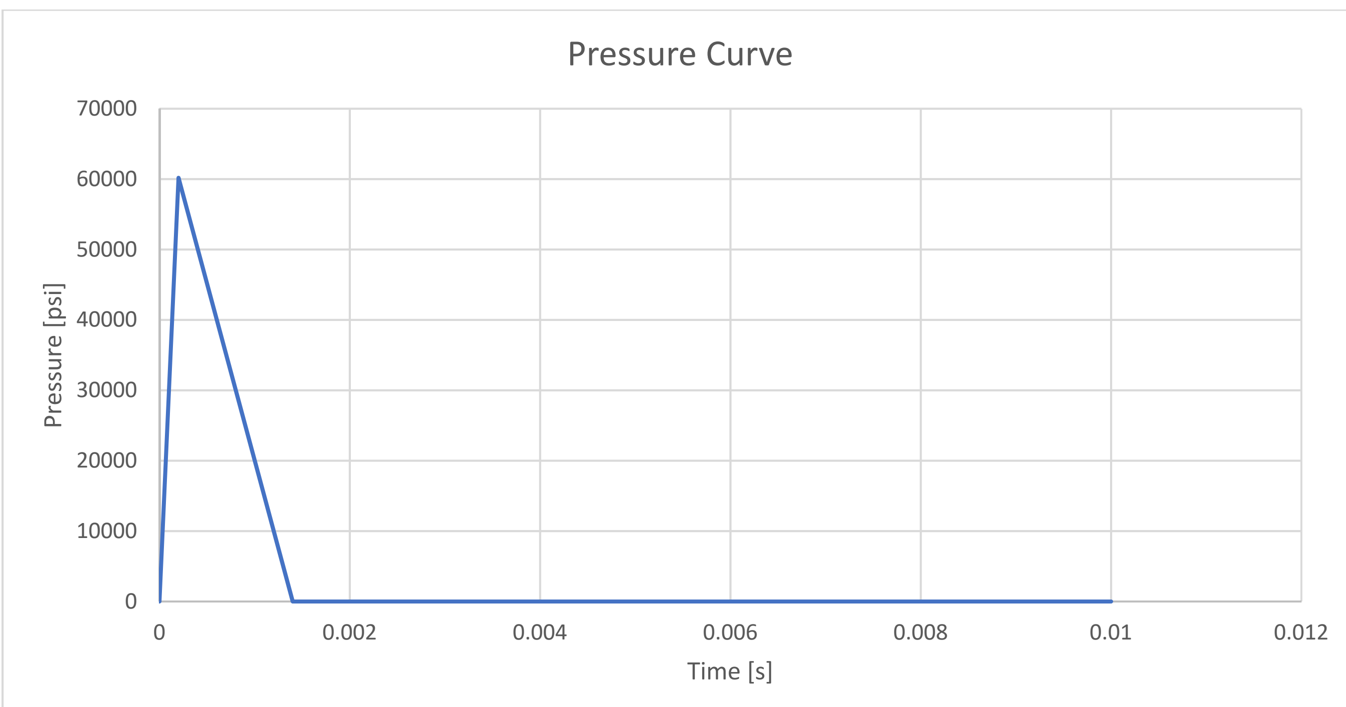


Figure 4 Pressure curve applied to vector field.

With maximum pressure occurring at 0.2 ms and linearly receding back to 0 at 1.4 ms. These values were obtained from other similar studies.

Modal Parameters

Modal damping was set to 2% (a good general rule of thumb), and the upper bound frequency to be studied was set to 1600 Hz (from a modal analysis it was seen that no natural frequency of interest occurred over this limit).

Mesh

The mesh was standard with no mesh controls applied. This is because the geometry is simple in nature and not overly complex. One improvement however, would be the implantation of a hexahedral curvature-based mesh. However, unfortunately Solidworks Simulation does not allow the elements to be configured in a hexahedral fashion. The standard tetrahedral was used.

Sensors

A displacement sensor was placed at the top apex of the muzzle diameter in order to plot the response of most interest to this study which is the deflection of the muzzle with time.

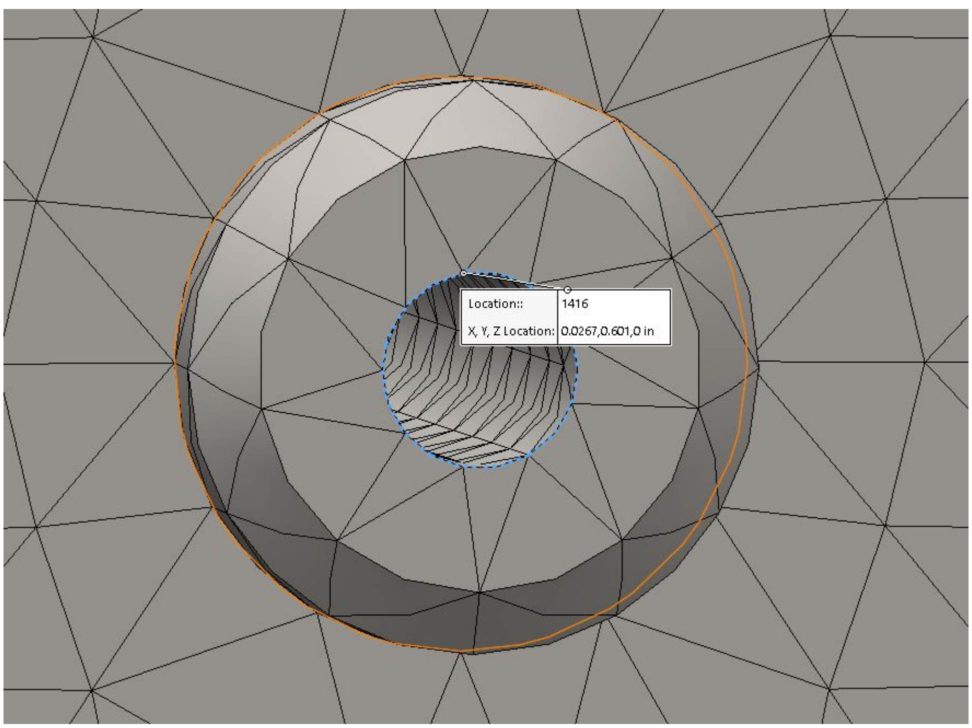


Figure 5 Location of displacement sensor at the end of the barrel.

The last parameter that was needed was the time to bullet exit. This is a very important piece of information, because we need to know exactly where the muzzle is pointing relative to the point of aim at exactly the time the bullet is leaving the barrel. I admit this eluded me for a time as I could not seem to figure out how to find this information. Initially I set up a dynamics problem, but I was unsure of how to find the function of pressure without experimental data.

It finally occurred to me that you could extract this from another piece of given ballistic data: muzzle energy. The energy of the projectile at time of muzzle exit must include the time it took to traverse the barrel itself.

where,

$$E_{muzzle} = \frac{L_{barrel} \cdot m_{bullet} \cdot v_{muzzle}}{t_{exit}}$$

and,

$$t_{exit} = \frac{L_{barrel} \cdot m_{bullet} \cdot v_{muzzle}}{E_{muzzle}}$$

Thus

$$t_{exit} = 1.5\ ms$$

Results

The motion results were constrained in the y direction. The fact that the weapon's center of mass lies below the bore axis, this means that the response in the y direction is of the most importance.

The displacement response plot is as follows

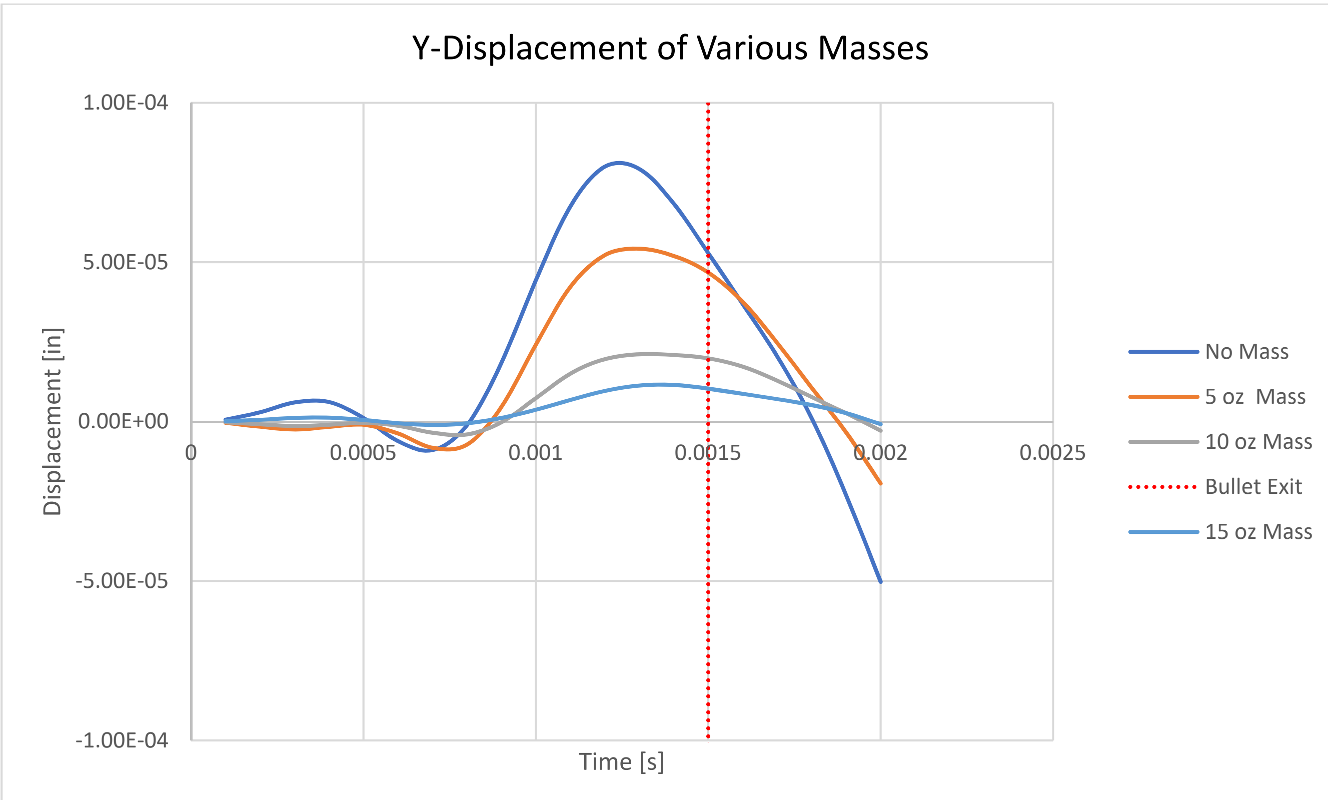


Figure 6 Displacement plot for varying lumped masses.

As we can see here, the tuner does indeed align the muzzle at time of bullet exit better and better within each iteration. At first, I thought this a complete success, however after more research it become known that the big peak or "Apex" is very significant, and even more importantly the location of the time of exit in relation to it.

If time of bullet exit occurs on the right side of the apex that means that the projectile is exiting on the down swing side of the oscillation, conversely if it is exiting on the left side of the apex then it is on the up-swing side of the oscillation. Every lot of ammunition has a nominal value and then a systematic mean about that nominal value. In layman's terms, no matter how well you load every round there will always be slower and faster rounds in relation to the reported muzzle velocity.

Because of this,

- Smaller Groups Left of the Peak – UPWARD SLOPE:
  Higher velocity shots exit early while pointing lower at the target but drop less in reaching the target.
  Lower velocity shots exit later while pointing higher at the target but drop more in reaching the target.
  Counteracting combination. Good.

- Larger Groups Right of the Peak – DOWNWARD SLOPE:
  Higher velocity shots exit early while pointing higher at the target and drop less in reaching the target.
  Lower velocity shots exit later while pointing lower at the target and drop more in reaching the target.
  Bad additive combination. Bad. Also called "Negative Compensation".

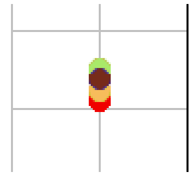


Figure 7 Left side of apex exhibits smaller grouping.

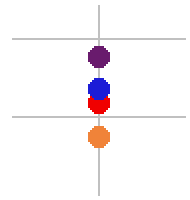


Figure 8 Negative compensation exhibits larger grouping

Additionally, a plot was generated of y position at bullet exit versus the increasing masses to see if there was a predictable relationship of some sort

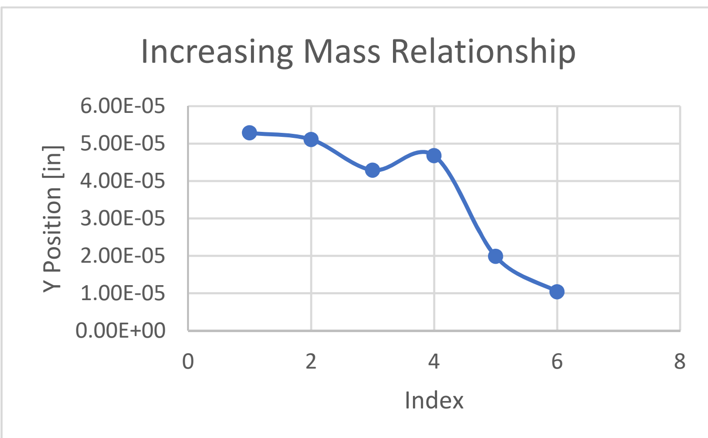


Figure 9 Plot of muzzle position vs. Increasing masses.

As we can see the curve does slightly resemble a linear relationship. If this is the case than it can be noted that the muzzle displacement will decrease proportionally with increasing mass. Which could better serve us to predict the behavior of the system. The data set for this example, however, is much too small and more data points are needed to verify this.

Conclusion

In conclusion, we learned from this study that an increase in mass will indeed better align the muzzle to the target, however it is important to note that because the bullet exited on the right side of the apex, that this round is not optimized for this weapon system. One could surmise that if we alter certain variables, say, cartridge configuration, then we could bring bullet exit to the left side of the apex and all would be good. This can adversely alter other parameters such as muzzle velocity, energy, etc. It is also worth noting that because this is a standard round adopted by the NATO alliance it would be much easier to alter the weapon system than the round itself, since millions of these rounds are already in circulation.

Other Considerations

A few things that were not simulated that would be good things to start with if this analysis is to continue are altering barrel length or load configuration and/or placing the tuner at different locations down the length of the barrel.