Ballistics Model for an Autoloading Device

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Purpose of Experiment

The purpose of the experiment was to develop a math model for predicting the pressure inside the gas tube of an autoloading device. Understanding the exact amount of pressure needed to recoil the device without causing damage is essential, and could save engineers precious time and resources.

With too much pressure, the impact between the recoil piston and the firing hammer would be too great and would fatigue and damage both parts. With too little pressure, the hammer would not fully reload, and the device would malfunction.

With an equation known to relate the two pressures, the limiting factor of the pressure inside the gas tube would be the diameter of the gas port. This is because of a phenomenon called choked flow. As seen in figure 1, choked flow occurs when a fluid is pressurized to the point where it's mass flow through a port can no longer increase.

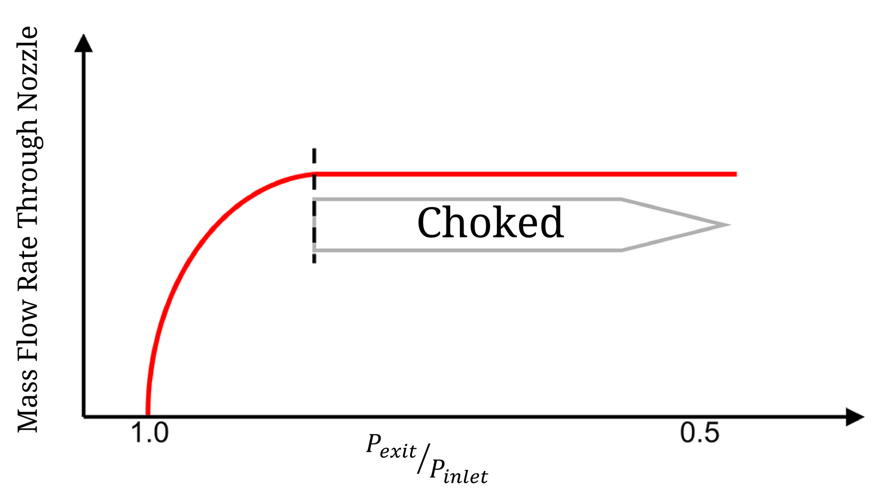

Figure 1: Visual Representation of Choked Flow

Background

Initially when a rifle is fired, the pressure inside the barrel can reach 16,000 psi. This is an outstanding pressure that still puzzles experts today.

The image below, Figure 2, is of an AR-15 in action. When the rifle is fired, the gases created from the powder burning are recycled through a gas port and through a gas tube where they push a small piston that resets the firing process.

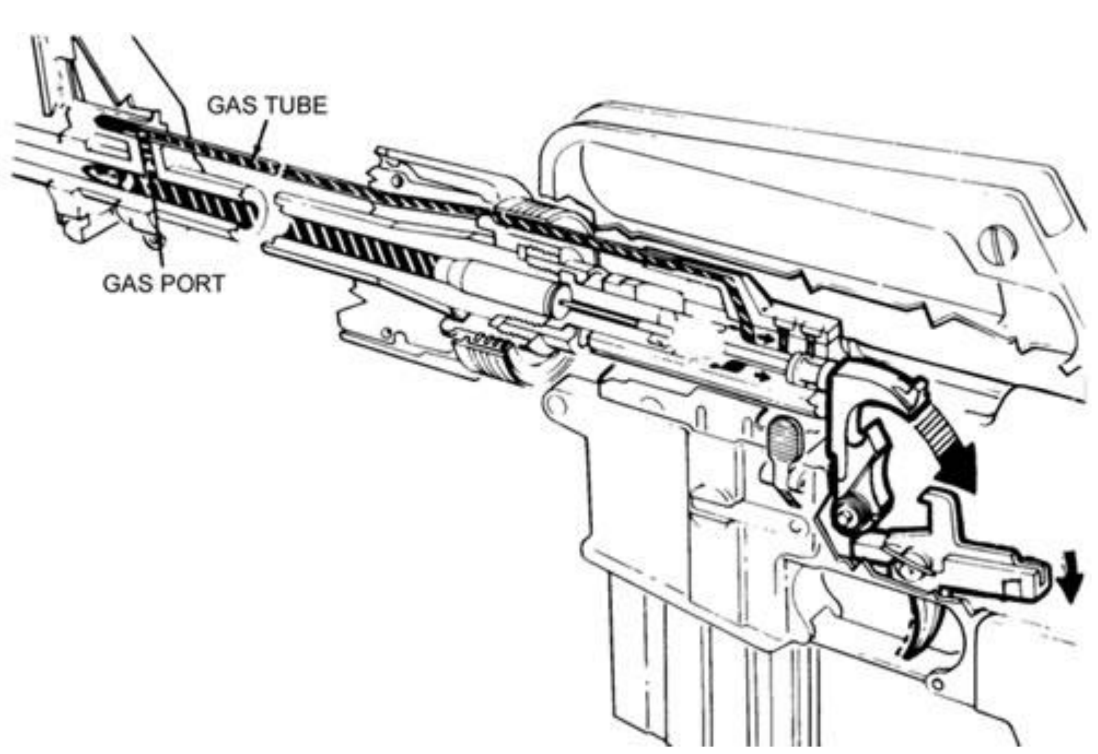

Figure 2: AR15 Firing Schematic

Forming an Equation

Before deciding on equations assumptions were made:

1. Barrel gas obeys Nobel-Abel gas law.
2. Ratio of specific heats of barrel gases is constant. (Calorically perfect)
3. Temperature of the barrel gases is constant.
4. Gas in the gas tube behaves as an ideal gas.
5. The gas flow through the gas tube is an isentropic process.
6. The flow of the gas is 1-D and compressible (no viscosity).

Next, relevant equations were selected:

Temperature of Gas:	$T = T_0 * \left(\frac{P_0}{P}\right)^{(1-k/_k)}$	(Eqn. 1)
Subsonic Velocity:	$v = \sqrt{2 * c_p * (T_0 - T)}$	(Eqn. 2)
Subsonic Mass Flow:	$\dot{m} = \rho_0 * v * A$	(Eqn. 3)
Choked Mass Flow:	$\dot{m} = \rho_0 * c * A$	(Eqn. 4)
Speed of Sound:	$c_0 = \frac{\sqrt{k * R * T_0}}{1 - b * \rho_0}$	(Eqn. 5)
Ideal Gas Density:	$\rho = \frac{P}{R * T}$	(Eqn. 6)
Nobel-Abel Eqn. of State:	$\rho_0 = \frac{P_0}{R * T_0 + P_0 * b}$	(Eqn. 7)
Gas Tube Pressure:	$P = P_0 \left[1 + \frac{(K-1)Ma^2}{2(1 - b * \rho^*)^2}\right]^{-k/_{k-1}}$	(Eqn. 8)

Defining the Variables

To make an analysis of this work simpler for the view, the variables used in the equations are defined as the following:

$P_0(t)$: *Absolute barrel pressure.*
$\rho_0(t)$: *Barrel gas density.*
T_0: *Absolute gas temperature in barrel (constant).*
k_0: *Specific heat ratio of gas in barrel(constant).*
b_0: *Volume of gas in barrel.*
R: *Gas constant for combustion gas.*
A: *Area of gas port.*
$\dot{m}(t)$: *Mass flow rate though gas port.*
$V(t)$: *Subsonic velocity through gas port.*
c_0: *Speed of sound for combustion gas in barrel & gas port.*
$\rho(t)$: *Gas denisty in gas tube.*
$T(t)$: *Absolute has temperature in gas tube.*
$P(t)$: *Absolute gas pressure in gas tube.*
W: *Volume of side chamber.*
t_i: *Time after i^{th} time step $(1 \le i \le 100)$.*

Gathering the Data

Data collected for this experiment was taken from taken from a test firing of a semi-automatic rifle. Professor Brian Vuksanovich attached a pressure sensor to the barrel of the rifle, fired it, and took 10,000 iterations of data over the 3 millisecond window of firing. For a better idea of how the sensor work, figure 3 shows a section view of a sample apparatus

It can be seen how dangerous it would to be place the sensor in front of the bullet - The bullet could deform the sensor or vice versa.

Next, it was time to plot the data. The computer software Matlab was used to solve equations 1-8 and plot. Solving equations 1-7 first, then plotting equation 8 on a graph versus time a result was found.

Figure 3: Barrel Pressure Sensor

Results & Conclusion

Both the barrel pressure and the gas tube pressure were plotted against each other as seen in Figure 4. It can be noted that the barrel pressure is much higher than the gas tube pressure, but the gas tube pressure follows a similar contour.

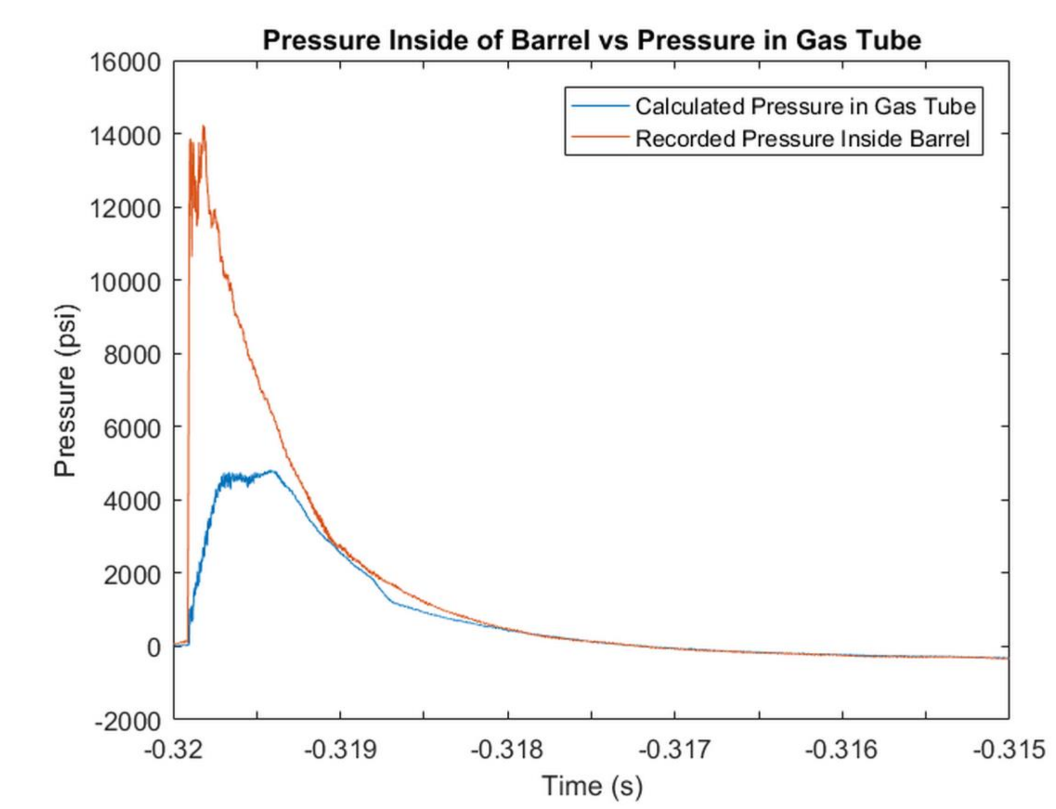

Figure 4: Plotted Results

Concluding, the results were satisfactory. The gas tube pressure follows the contour that was expected and the values fall within an acceptable range. Future tests could increase accuracy by using less restrictive assumptions but the difference in results would be miniscule. Now that these equations are verified, they may be used to calculate the critical diameter of the gas port, or the critical stiffness of the spring used on the recoiling piston.