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Investigation of kinetic energy of .308 projectiles of different masses

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ABSTRACT

Projectile kinetic energy is a useful metric in ballistics that allows for the understanding of the magnitude of chemical potential energy that is transferred to projectiles in firearms. The purpose of this report is to investigate the effect that .308 projectile mass has on the kinetic energy of projectiles at muzzle exit of a .308 target rifle. Velocity was measured with the use of a radar chronograph, which was used to calculate the kinetic energy of the projectiles at that point in time. It was found that although velocity decreased as mass increased, kinetic energy increased as mass increased. The kinetic energy increased from approximately 3275J at 155 grains to 3962J at 220 grains. This was explained by the greater opportunity for work to be done on projectiles of greater mass due to slower volume expansion behind the projectile. This acts as a demonstration of Newton's Second Law and variables that influence projectile behaviour in ballistics such as pressure evolution over time.

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YASJ Editors' Note: This study presents a clear investigation of how projectile mass relates to muzzle velocity and kinetic energy under controlled loading conditions. The use of chronograph measurements and statistical analysis gives the work a strong experimental structure. Readers should note that the findings are specific to one rifle and loading configuration, and that the 220-grain group contains four valid measurements rather than five. The proposed explanation involving pressure evolution within the barrel is plausible, but was inferred rather than measured directly.

LITERATURE REVIEW

The behaviour of projectiles when fired by a firearm is dictated by internal ballistic processes, in which chemical energy from propellent (smokeless powder) is converted into kinetic energy of the projectile. Understanding the factors that affect the muzzle velocity and energy is central to applications in ballistics. These processes occur within the barrel and involve the generation of dramatically expanding gases due to propellent combustion which results in the acceleration of the projectile. The evolution of pressure within the barrel is highly dynamic, increasing dramatically initially after ignition then decreasing as the volume behind the projectile expands, as explained by Ongaro et al. (2024).

Muzzle velocity, defined as the velocity of a projectile the instant it exits the barrel of a firearm, is a crucial parameter in determining projectile behaviour such as range, trajectory and impact characteristics. It is governed by a range of variables such as projectile, propellent and barrel characteristics. As such, it is a significant measurable indicator on the efficiency of the energy transfer occurring within the firearm, as noted by Rogers et al. (2024).

A particularly significant parameter affecting muzzle velocity is projectile mass. As described by Newton's Second Law, $F = ma$, an increase in mass results in a decrease in acceleration for a given force, and as such the resulting velocity of such a mass will be decreased. However, the motion of the projectile also affects the pressure

evolution within the barrel. A decrease in acceleration slows the extent to which the volume behind the projectile expands, allowing higher pressures to be sustained over a greater length of the barrel. The kinetic energy of a projectile is given by $KE = \frac{1}{2}mv^2$, displaying how kinetic energy depends linearly on mass but quadratically on velocity. This indicates competing behaviour, as velocity tends to decrease with increasing mass due to lower acceleration, lowering kinetic energy, but increasing mass increases kinetic energy through the mass component, thus the result will represent some balance of these effects, accounting for the work done on the projectile while inside the barrel. The work-energy theorem states that $W = \int F\,dx$, indicating that a higher pressure sustained over a longer length of the barrel can result in an increase in the kinetic energy at muzzle exit. This is noted in detail in Ongaro et al. (2024).

The use of a radar chronograph in experimental ballistics studies is a highly accurate and well supported as seen in Silva-Rivera et al. (2021). It functions by measuring the time taken for a projectile to pass between two sensors on the device, thus making them a reliable and efficient tool for the measurement of muzzle velocity.

Experimental studies have demonstrated a strong correlation between theoretical physical models and experimental measurements, supporting the validity of studies on highly impactful parameters such as kinetic energy of projectiles, as noted by Kagankiewicz and Magier (2024). Importantly, many studies are investigating the impact of firearm, projectile and propellant characteristics, especially in the realm of optimising energy transfer and the prediction of projectile trajectories, as seen in Xiao and Zhang (2026), reinforcing the relevance of research into energy transfer in firearms.

While many studies investigate the effects of propellant charge or barrel characteristics, few have specifically isolated the effect of projectile mass on the muzzle velocity of firearms and thus the transfer of kinetic energy to the projectile. Thus, this study seeks to investigate the relationship between projectile mass and the net transfer of kinetic energy, providing insight into factors such as pressure evolution, acceleration, mass, muzzle velocity and kinetic energy.

SCIENTIFIC RESEARCH QUESTION

Does the mass of a .308 calibre projectile affect its kinetic energy at muzzle exit of a .308 calibre Custom Barnard P Action rifle with a 30 inch Krieger barrel?

SCIENTIFIC HYPOTHESIS

The .308 projectiles of greater mass will have greater kinetic energy at muzzle exit of a .308 calibre Custom Barnard P Action rifle with a 30 inch Krieger barrel.

METHODOLOGY

25 total .308 cartridges were loaded with 40 grains of ADI AR2208 smokeless rifle powder (gunpowder) and 220 grain Berger Target, 200 grain Berger Hybrid, 185 grain Berger Juggernaut Target, 168 grain Berger Hybrid Target HPBT and 155 grain Sierra Match King HPBT projectiles (all of which were match-grade hollow point boat tail design (HPBT) for greatest consistency in internal ballistic performance), 5 cartridges for each projectile mass to reduce the effect of variance within each group (see Supplementary Methods S1). The actual mass of the projectiles was verified using an Ohaus Precision Standard electronic balance. At St Marys Indoor Shooting Centre, a .308 Custom Barnard P Action rifle with a 30 inch Krieger Barrel was set up on a shooting table using an adjustable rest to maintain stability and a consistent firing position. A Garmin Xero C1 Pro chronograph was positioned behind the end of the barrel, which records instantaneous velocity at the moment the projectile exits the muzzle using radar. In a seated shooting position, the shooter fired a 220 grain projectile cartridge and the chronograph velocity reading was recorded in feet per second while connected to an iPhone 8 Plus via Bluetooth on ShotView™ mobile application, which was used exclusively to record the velocities from the chronograph, which are inputted automatically from the chronograph to the app after each measurement. This was repeated for the remaining 4 220 grain projectile cartridges, waiting 1:30 minutes between each shot to reduce variance due to barrel temperature. This process was repeated for the 200, 185, 168 and 155 grain projectiles. The experiment was conducted under a documented risk assessment and in accordance with the applicable shooting-range procedures. The velocity of each projectile was documented in Microsoft Ex-

cel and utilised to calculate the kinetic energy of each projectile mass at muzzle exit using relevant equations.

RESULTS

The muzzle velocity of projectiles was measured with a degree of uncertainty ±0.05ft/s and were transferred from ShotView™ and documented in a table in Microsoft Excel with unit conversions to metric (ft/s to m/s) (see Supplementary Table S1). An error occurred in the chronograph for the 220gr projectile where one shot was not recorded.

This was then transferred to a table with only metric values for velocity (m/s) (Table 1).

Table 1. Relationship between muzzle velocity (m/s) and projectile mass (gr, kg)

Mass (gr)	Mass (kg)	Velocity (m/s)					
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
220	0.01425576	746.9124	750.3871	742.2794	742.4928		745.5179
200	0.01295978	773.4605	774.2225	767.6388	775.6855	768.6751	771.9365
185	0.01198780	767.1816	780.2880	779.7698	772.8509	780.1966	776.0574
168	0.01088622	787.5727	804.0014	792.0533	801.5021	799.0942	796.8447
155	0.01004383	815.3400	803.3004	807.6286	806.7446	804.7330	807.5493

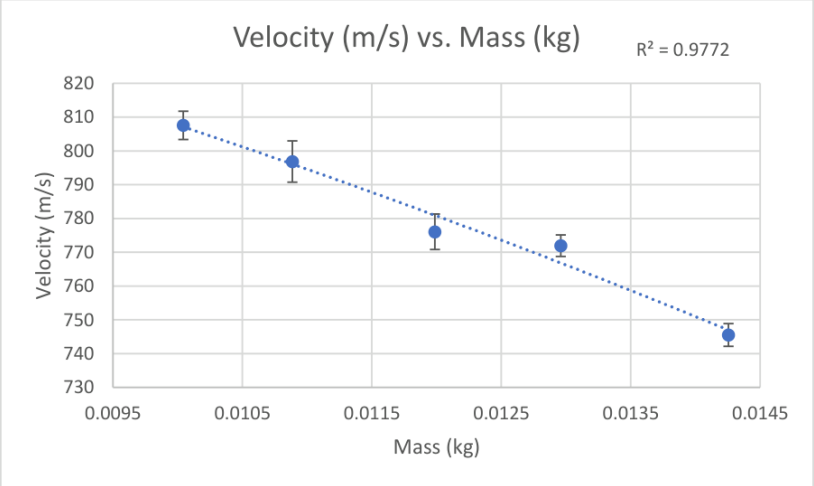


Figure 1. Relationship between muzzle velocity (m/s) and projectile mass (kg). Group sample sizes were $n = 4$ for 220 gr and $n = 5$ for all other projectile masses

ANOVA was used with an alpha value of 0.05 to determine whether there was a statistically significant difference between the means of the velocity of each group (see Supplementary Table S2).

The velocities collected from Table 1 were used to calculate kinetic energy by the formula $KE = \frac{1}{2}mv^2$, where m is the projectile mass in kg and v is the projectile velocity in m/s (Table 2).

Table 2. Relationship between projectile kinetic energy at muzzle exit (J) and projectile mass (gr, kg)

Mass (gr)	Mass (kg)	Kinetic energy (J)					
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
220	0.01425576	3976.488	4013.573	3927.311	3929.569		3961.735
200	0.01295978	3876.537	3884.179	3818.401	3898.873	3828.718	3861.342
185	0.01198780	3527.815	3649.382	3644.536	3580.147	3648.526	3610.081
168	0.01088622	3376.201	3518.525	3414.725	3496.683	3475.705	3456.368
155	0.01004383	3338.466	3240.600	3275.614	3268.448	3252.168	3275.059

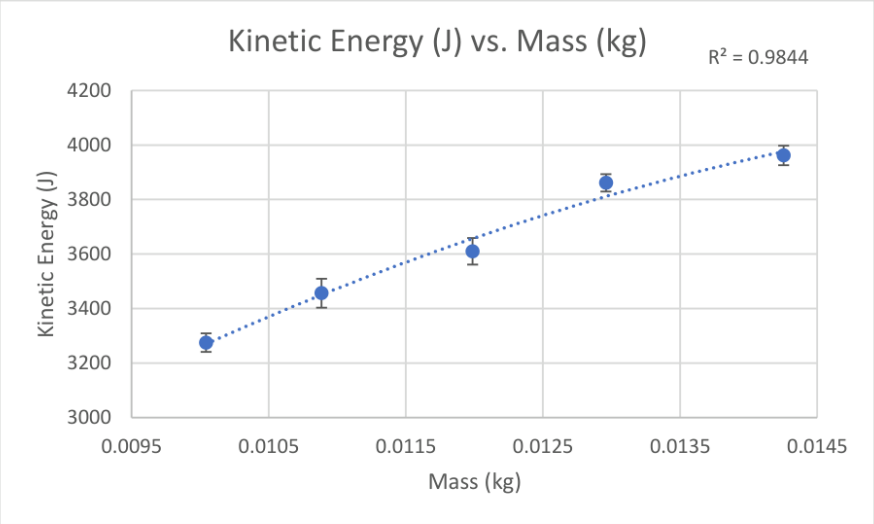


Figure 2. Relationship between kinetic energy of projectile at muzzle exit (J) and projectile mass (kg). Group sample sizes were $n = 4$ for 220 gr and $n = 5$ for all other projectile masses

ANOVA was used with an alpha value of 0.05 to determine whether there was a statistically significant difference between the means of the kinetic energy of each group (see Supplementary Table S3). Since kinetic energy is proportional to the square of velocity, propagated uncertainty can be evaluated as $\Delta KE = KE \cdot 2\frac{\Delta v}{v}$, where $\Delta v = \pm 0.015\ \mathrm{m\,s^{-1}}$ based on chronograph precision.

These values are naturally included in the standard deviation shown in the error bars and contribute a small portion of the total error.

For purposes of discussion, average acceleration of projectile from rest to recorded velocity and the time the projectile takes to travel the length of the barrel were calculated using the following equations:

$a = \frac{v^2-u^2}{2s}$, where a is average acceleration, v is final velocity, u is initial velocity and s is displacement (length of the barrel the projectile travels) (see Supplementary Tables S4 and S5).

$t = \frac{v-u}{a}$, where t is the time the projectile takes to travel the length of the barrel, v is final velocity, u is initial velocity and a is average acceleration (Table 3).

ANOVA statistical tests were performed on both data sets with an alpha value of 0.05 (see Supplementary Tables S5 and S6).

Table 3. Relationship between projectile time in barrel (s) and projectile mass (gr, kg)

Mass (gr)	Mass (kg)	Time in barrel (s)					
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
220	0.01425576	0.001870367	0.001861706	0.001882041	0.001881500		0.001873903
200	0.01295978	0.001806169	0.001804391	0.001819866	0.001800988	0.001817413	0.001809765
185	0.01198780	0.001820951	0.001790365	0.001791554	0.001807593	0.001790574	0.001800207
168	0.01088622	0.001773804	0.001737559	0.001763770	0.001742977	0.001748230	0.001753268
155	0.01004383	0.001713396	0.001739075	0.001729756	0.001731651	0.001735980	0.001729970

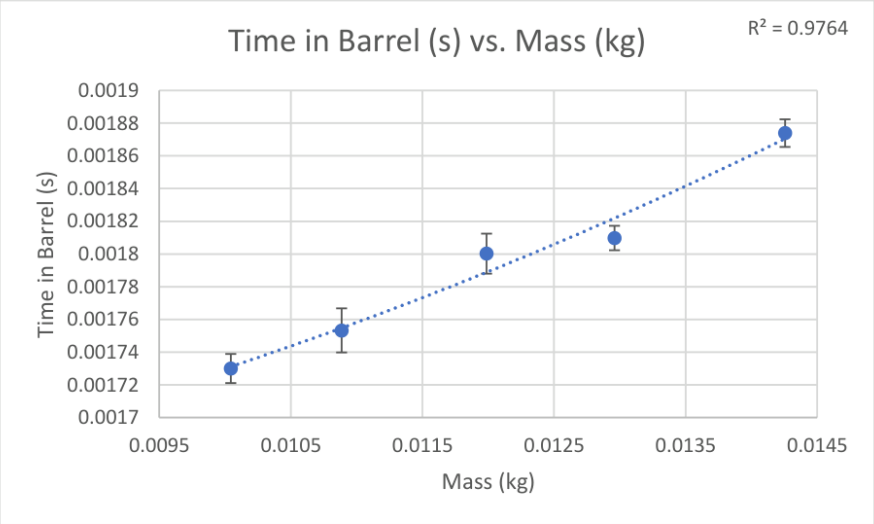


Figure 3. Relationship between projectile time in barrel (s) and projectile mass (kg). Group sample sizes were $n = 4$ for 220 gr and $n = 5$ for all other projectile masses

DISCUSSION

All data gathered was tested using ANOVA with an alpha value of 0.05. The F-critical for all data sets was 2.895107. No injuries occurred during the experiment.

The projectile muzzle velocity as seen in Table 1 and Figure 1 was observed to decrease as mass increases. This is plausible as it adheres to Newton's Second Law, as objects of larger mass experience less acceleration under application of a constant force. This remained true despite factors such as friction on the rifling and the projectile travels through the barrel, which would theoretically have a greater deceleration effect on lighter projectiles. The trend was not linear, as seen in Figure 1, a polynomial trendline with a slight negative concavity fit the data with the greatest R^2 value of 0.9772, indicating that the magnitude of the rate of velocity decrease increases with mass. ANOVA displayed an F-value of 96.74092 and a pvalue of 2.343792×10^{-12} (F-value $>$ F-critical, p-value < 0.05), indicating that there was a statistically significant difference between the means within this data set (the results are unlikely (less than 5% probability) to have been caused by random chance).

Using the velocities calculated from Table 1, the kinetic energy of the projectiles at the instant that the muzzle velocity was calculated (the moment the projectile left the muzzle) using the equation $KE = \frac{1}{2}mv^2$. Theoretically, velocity would have a greater effect on kinetic energy than mass would, due to kinetic energy being directly proportional to the square of velocity, while being directly proportional to mass. Experimentally, as seen in Table 2 and Figure 2, the kinetic energy of the projectile increased with mass, despite lighter projectiles possessing greater velocities. ANOVA displayed an F-value of 168.7801 and a p-value of 1.465494×10^{-14} (F-value $>$ F-critical, p-value < 0.05), indicating that there was a statistically significant difference between the means within this data set. This trend can be explained by the nature of the energy transfer between the potential energy in the gunpowder charge, that being the work done on the projectile being proportional to the force on the projectile integrated over the length of the barrel.

Although not directly related to the work done on the projectile, the time the projectile spends in the barrel affects the rate at which the volume expands behind the projectile, thus affecting the magnitude of pressure generated by the propellant combustion over time and thus being a relevant relationship to examine with respect to projectile mass. In order to calculate the time the projectile spends in the barrel, first the average acceleration of the projectile must be calculated. The barrel length was measured to be 30in, and the cartridge protrudes into the barrel 2.5in when chambered, so a total displacement of 27.5in was converted to metric (0.6985 m) and used in calculations. Using the equation $a = \frac{v^2-u^2}{2s}$, the average acceler-

ation of each data point was calculated (as shown in Supplementary Table S4) and analysed using ANOVA to display an F-value of 94.82958 and a p-value of 2.805423×10^{-12} (F-value > F-critical, pvalue < 0.05), reinforcing a statistically significant difference between the means within the data set.

The average acceleration of each data point was then used to calculate the total time the projectile spent travelling from rest to muzzle exit when fired. This was achieved using the equation $t = \frac{v-u}{a}$ (as seen in Table 3) and was also analysed using ANOVA to display an F-value of 100.4061 and a p-value of 1.675771×10^{-12} (F-value > F-critical, p-value < 0.05), reinforcing a statistically significant difference between the means within the data set. Table 3 and Figure 3 depict time spent in firearm barrel as increasing with mass. The trendline is polynomial with a slight positive concavity, indicating that the rate of increase in time increases with mass. This experimentally and mathematically confirms Newton's Second Law.

Since time spent in firearm barrel increases with projectile mass, and kinetic energy also increases with mass, it can be inferred that the greater kinetic energy in the heavier projectiles is explained by a greater opportunity for the combustion of the propellant to do work on the projectile. When a round is fired, the chemical potential energy stored in the gunpowder is released in a combustion reaction which results in the formation of rapidly expanding gases. The interaction between the rapidly expanding gases and the projectile transfers the potential energy released in the combustion reaction to kinetic energy in the projectile. In all practical applications, some energy is lost in the system in forms such as bearing surface friction, air resistance, heat and sound, therefore not all chemical potential energy is transferred to kinetic energy in the projectile. Thus, the difference in kinetic energy in heavier and lighter projectiles can be determined to be a result of the heavier projectiles travelling at slower velocities, therefore increasing the duration of time spent in the barrel, which results in a lower volume expansion rate behind the projectile, causing higher pressures to be sustained for a longer period of time and thus for a longer portion of the barrel's length. According to the work-energy theorem, $W = \int F\,dx$, a greater force due to pressure over a particular length will result in a greater work done on the projectile, thus explaining the increasing kinetic energy with increasing projectile mass.

It should be noted that this experiment contains limitations. The Ohaus Precision Standard electronic balance has a degree of uncertainty of ±0.01gr (0.000648g), which is almost negligible in this experiment. There was also found to be a deviation of up to 0.22gr (0.0143g) in the weighed projectiles when compared with their manufacturer stated masses. Variables such as neck tension, brass quality, brass wear, gunpowder moisture content, projectile uniformity, primer charge uniformity, recoil resistance, bullet centricity also have effects on the velocity of the projectile, which could explain the variance within groups. Further limitations of this research are extrapolation to other factors in ballistics such as ballistic coefficient and the behaviour of projectiles in long range flight, which have not been considered in this investigation.

CONCLUSION

The aim of this investigation was to determine how .308 projectile mass affected the kinetic energy of projectiles at muzzle exit of a .308 target rifle. The data was consistent with the expected relationship of increased kinetic energy with increased mass, supported by statistically significant results despite limitations such as measurement uncertainty and shot variance. Thus, the hypothesis was supported. These findings reinforce principles of classical physics and its application to ballistics in practice.

SUPPLEMENTARY MATERIAL

Supplementary material accompanying this article contains the raw data and unit conversions, derived acceleration calculations, ANOVA outputs, an additional derived-data figure and detailed supplementary methods.

The supplementary PDF is available with the online article at https://doi.org/10.67642/ar34df81.

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