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Investigation of the Effect of Various Types and Features of Grooved Barrels on the Range of Firearms

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ABSTRACT

The research has focused on the innovations which can be performed in order to increase the range of cannons and howitzers. The most important parameter affecting the range of a weapon system is the velocity distribution in the barrel and finally the initial muzzle velocity. On the other hand, the most important parameters affecting the initial muzzle velocity of the bullet are the internal barrel pressure, internal barrel friction, mass of the bullet and weight of the bullet. Taking these parameters into consideration, it has been revealed that improvements could be made by designing and manufacturing new types of barrels, ammunition and certain parts. The advantages and disadvantages experienced after such changes have been determined and studied theoretically and experimentally.

Keywords: Groove; Howitzer; Barrel; Internal ballistics; Bullet

NOMENCLATURE

m_m	Mass of the bullet (kg)
m_b	Mass of the gunpowder (kg)
A	Internal section area of the barrel (mm^2)
F_s	Total friction force (N)
P_k	Wedge pressure (MPa)
P_m	Bullet base pressure (MPa)
$V_m(x)$	Velocity of the bullet along the barrel (m/s)
Q	Combustion temperature of propellant charge (kcal/kg)
B_a	Combustion coefficient of propellant charge (1/s)
δc	Intensity of the propellant charge (kg/m^3)
C	Fixed number for the same weapon, ammo and gunpowder
Ψ	Velocity variable dependent on φ
φa	Velocity variable dependent on ψ
γ	Specific heats ratio of propellant charge
D	Weapon diameter (m)
N_z	Number of grooves
α	Helix angle (right helix) (^{0}C)
B_z	Groove width (m)
t	Groove depth (m)
σ_K	Breaking strength of barrel material (MPa)
σ_A	Yield strength of barrel material (MPa)
S_m	Interrupter coefficient
V_0	Bullet initial velocity (m/s)
X_m	Maximum Range (m)
Δ	Loading Density (kg/dm^3)

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1. INTRODUCTION

Primitive weapons launched by human power in the years when technology and science were not yet developed were developed over time, and systems such as slingshots, bows and catapults allowed men to throw objects more effectively and accurately. In particular, new weapons were invented by utilizing the pressure created by the high amount of gas produced by the burning of gunpowder. Studies on firearms basically aim to ensure that the ammunition launched from the weapon system hits the target in the most effective way and to give the weapon system the ability to shoot at longer distances. The barrel is one of the most important parts of the firearm system, and besides being very expensive, it involves very complex design and manufacturing processes. Basically, it is divided into two groups as fluted and non-fluted.[1] Grooved barrels are used in weapon systems such as cannon and howitzer.

The main purpose of barrel weapon systems is to send the projectile to the desired target at maximum speed. The force required by the weapon system to launch the projectile at maximum speed is provided by the high pressure created as a result of the gunpowder burning behind the bullet, that is, in the barrel. The pressure value occurring in the weapon system is one of the important ballistic parameters taken into account in the design of the weapon systems. The most important parameter affecting the range of a weapon system is the velocity distribution in the muzzle and finally the initial muzzle velocity. The most important parameter affecting the initial muzzle velocity of the bullet is the internal barrel pressure. Other parameters can be listed as follows; internal barrel friction, bullet mass and bullet weight. When the fired gunpowder starts to burn, a very high temperature and pressure is created in the barrel. This high pressure affects the walls of the combustion chamber and the bottom of the projectile. When the force exerted by the pressure applied to the bottom of the bullet is greater than the frictional force between the bullet and the barrel, the bullet begins to move rapidly inside the barrel and then leaves the barrel at a high velocity.

When the literature studies are examined, it is seen that there is not enough research on this subject because it is specific to the defense industry. However, the studies carried out are as follows. Akçay M. in his study on external ballistics in the development of classical artillery weapons, determined that three types of problems arise in external ballistic solutions.[1] Gök, Ş. & he did the effect of the internal dynamics of the 7.62 mm NATO bullet on the target accuracy was investigated using experimental methods, and for this, a certain amount of gunpowder was loaded into a predetermined standard NATO bullet and test. Trials were held at a special shooting range.[2] Çelikel[3], A. conducted a research on the effect of barrel length on bullet distribution. For this purpose, he fired at linen targets from 9 different distances with a 12-caliber shotgun with a 70 cm barrel, without a barrel, without a grip and without impact, using cartridges containing 3.5 and 7.5 mm bullets.[3] In the study of Alim, Y., a comparison was made in order to evaluate the empirical analysis and archiving results and to reveal the usefulness and reliability of the 3D imaging system ballistic analysis and archiving. These systems. The 3D imaging has been compared with data from the IBIS system. In this study, a new model was developed to determine the gas pressure distribution and projectile velocity along the barrel.

In addition, numerical solutions were made with ANSYS. The aim of this thesis is to determine the possible cause of failure by analysing the transient behavior of a 105 mm gun barrel in the section where high explosives are detonated.[4] In this study, some issues that should be considered in the optimal design of a modern gun barrel are examined. Then the analytical solution results were compared with a numerical model and the result obtained was used to calculate the radial expansion rate and compression. In the study, the viscous effects of unstable bullet aerodynamics were investigated by Computational Fluid Dynamics (CAD) to simulate the pressure burst of a bullet fired from the barrel and to investigate the pressure distribution and sound pressure level (dB) along different positions from the barrel. It was concluded that for a mathematical model, viscous terms should be included. The mortar of the present invention weighs significantly less than currently available mortars and is provided with an unloading mechanism that significantly reduces the movement of the entire mortar assembly during the firing of the projectiles. In his research, the strength, fracture toughness, Vickers hardness, thermal conductivity, specific heat and linear thermal expansion coefficient of materials containing three silicon carbide and two silicon nitride and alumina, zirconia and SiAlON were investigated. In this study, ceramics were used to determine the optimum gun barrel designs and for further evaluations. Thus, databases for performance estimation have been developed to be used in probabilistic modeling and design studies of the program.

However, there are several studies in the literature on barrel internal ballistics. Sönmez studied the howitzer barrel in his dissertation. The mathematical model of the stresses affecting the combustion chamber where the highest stress in the barrel occurs during firing was put forward in this study.[5] In this study, the instantaneous barrel internal pressure values obtained from shots using different propellant gunpowders were taken into consideration and the stress values affecting the combustion chambers of the barrels produced from different materials and the total deformation values in the combustion chambers were tried to be revealed as a result of time-based analyses. In his dissertation named Özyılmaz, studied the selection of ammunition type, barrel type and mechanisms affecting the design of light weapons as well as the thermodynamic effects observed at the time of explosion and the efficiency of these variables was authenticated with the help of experimental studies and according to the results, it was expressed that the most important variable in weapon design is the choice of ammunition.[6]

On the other hand, Esen, İ.; investigated the dynamic behavior of an anti-aircraft barrel with a diameter of 35 mm and a length of 3240 mm in their study named. In the study, the shock waves generated at the moment of explosion were excluded and the dynamic interaction of the bullet core and the barrel was limited and a program was written in Matlab software for the mentioned dynamic interaction and the motion equation of the accelerated bullet and the barrel was solved with the finite elements method as well as Newmark's direct time integration method and thus the dynamic displacements were obtained. The solid model of the barrel was created with the SOLIDWORKS program. The natural frequencies and mode shapes of the barrel were obtained in ANSYS and MATLAB programs Yazıcı, Z., investigated the numerical simulations and experimental studies of internal ballistics of the barrel guns. In this dissertation, Yazıcı created two digital simulation software for internal ballistics preliminary design.[8] Finally, in his dissertation named Akbulut, M., concluded that when shoots are performed one after another in heavy gun barrels, a large amount of heat transfer occurs from the gases released as a result of the combustion of the propellant charge to the inner surface of the barrel and thus the amount of wear and erosion in the barrel increases and he also expressed that the barrels coolled only naturally would be insufficient for the multi-fire tasks.[9]

2. MODELING OF CANNONS AND HOWITZERS

The preparation of a howitzer for firing is as follows: the bullet is driven rapidly into the grooved barrel and the propulsion ring on the bullet is placed in the grooves. Sufficient gunpowder is put into the combustion chamber (behind the bullet) according to the target where the bullet will be launched and the wedge mechanism is turned off (Fig. 1).

When the weapon system is oriented into the target, the firing is performed. The ignited fuze ignites the gunpowder and increases its internal pressure and temperature in the combustion chamber. The pressure generated begins to act on the walls of the combustion chamber and the bullet base. As soon as the pressure force acting on the base of the bullet overcomes the friction force between the bullet propulsion ring and the barrel grooves, the bullet starts to move inside the barrel[10]. While the bullet moves in the barrel, the gunpowder continues to burn at the same time and a double-phase flow occurs which is composed of unburned gunpowder particles behind the bullet and gases formed after burning the complete combustion of gunpowder ends before the bullet leaves the barrel. The bullet moves in the barrel by accelerating in a very short time and reaches the maximum speed value in the muzzle (Fig. 2).[11] The technical incidents that take place inside the barrel after the fire become complex due to the very high temperature and pressure values.The energy amounts generated by burning of the gunpowder are spent as given in Table 1.

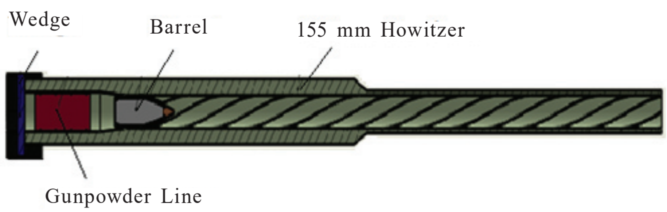

Figure 1. Ready-to-fire weapon system section.

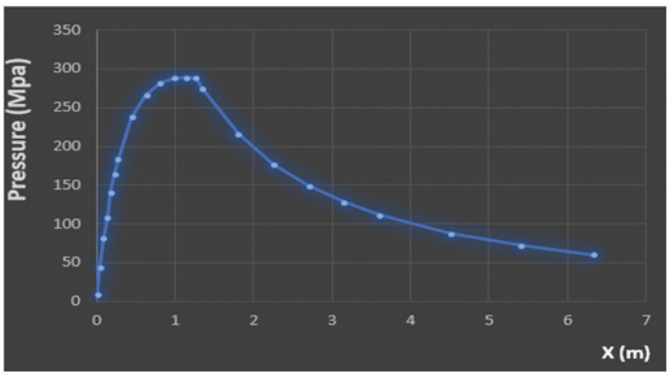

Figure 2. Pressure distribution graph along a "MKE" 155 mm howitzer barrel.[6]

Table 1. Points where the energy obtained by burning the gunpowder is spent[6]

Use of Gunpowder Energy	Amount
Energy spent for the bullet's motion	%32,4
Energy spent for the bullet's rotation	%0,14
Energy spent for recoil	%0,12
Energy spent with the heat loss of the barrel	%22,4
Energy warming the bullet	%2
Energy released with gunpowder gases without being used	%43

Some of the parameters that affect the movement of the bullet inside the barrel are: mass of the bullet, type and amount of gunpowder and friction between the bullet and the barrel.[12] These parameters naturally affect the muzzle velocity of the bullet. The aim of this study is to reduce the amount of friction between the bullet and the barrel by making some alterations on the parameters that affect the bullet's movement.[13] It will be investigated theoretically and experimentally how much the target range can be improved by delaying the initial movement of the bullet and obtaining higher pressures. When the gunpowder is ignited, the high pressure created by the combustion gases enables the bullet to move up to the muzzle of the barrel with a velocity of $V_m(x)$.[14] The forces acting on the bullet, wedge and combustion chamber are shown in Fig. 3. The combustion of gunpowder inside the barrel and the movement of the bullet are related to thermodynamics, fluid mechanics and heat transfer. The motion of the core inside the barrel is in compliance with Newton's Law of Motion.[15]

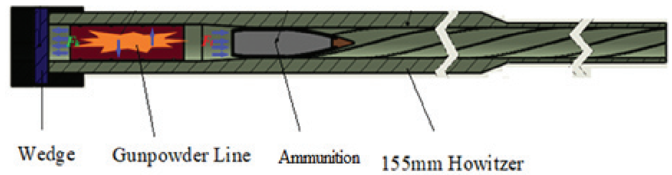

Figure 3. Surfaces affected by the pressure in the combustion chamber after the gun is fired.

2.1 Calculation of General Values of Barrels

The ballistics of the barrel should be examined in order to calculate the strength needed by the gun barrels. In order to obtain the pressure required by the weapon system, the propellant charge is burned and very high pressures are obtained as a result of this combustion. Some theses and formulas are used to calculate this pressure. This study will make use of the data for a 155mm cannon.[16]

Combustion temperature of propellant charge, Q=758 kcal/kg

Combustion coefficient of propellant charge, $B_a = 0{,}07931 / s$

Intensity of the propellant charge, $\delta_c = 1660 \text{ kg} / \text{m}^3$

Specific heats ratio of propellant charge, $\gamma = K = \dfrac{Cp}{Cv}$

Mass of propellant charge, $M_c = 14{,}380$ kg

Mass of bullet, $M_p = 43{,}092$ kg

Weapon diameter, $D = 0{,}155$ m

Maximum gas pressure, $P_m = 281{,}2$ MPa

Number of grooves, $N_z = 48$

$Tg\alpha = \dfrac{\pi}{25}$

$\alpha = 7°9'$ Helix angle (right helix)

Groove width, $B_z = 6.10^{-3}$ m

Groove depth, $t = 1{,}27.10^{-3}$ m

Breaking strength of barrel material, $\sigma_K = 1039{,}70$ MPa

Yield strength of barrel material, $\sigma_A = 860$ MPa

Interrupter coefficient, $S_m = 1{,}80 \sim 2$

Bullet initial velocity, $V_0 = 857$ m/s

Maximum Range, $X_m \sim 23600$m

Loading Density, $\Delta = 0{,}55 \text{ kg} / \text{dm}^3$

Surface area of the bullet exposed to pressure,

$$A = \frac{\pi D^2}{4} + n_z.b_z.t$$

$$A = \frac{\pi 0{,}155^2}{4} + 6.10^{-3}.1{,}27.10^{-3}.48 = 0{,}0192235\text{m}^2 \qquad (1)$$

Hub Volume, $V_B = (m^3) = 26\ dm^3$

$$Xe = \frac{(G+0,5L)}{(2g\eta p_m q)} V_0^2 = \frac{50,282.857^2}{2.9,81.28.2.192,35.0,55} = 6,327m \quad (2)$$

Ratio of average pressure to max pressure, $\eta = \frac{p}{p_m}$ (3)

$$\varphi_e = \frac{A.x_e}{V_B^x} = \frac{0,019235.6,327}{0,01733734} = 7,01952 \quad (4)$$

φ = The ratio of the volume formed behind the bullet to the net volume of the combustion chamber during the movement of the bullet in the barrel.[17]

when, $X = X_e$,

$$\text{then } \varphi = \varphi_e.m^x = m_p + 0,5m_c = 43,092 + 0,5.14,380 = 50,282\ kg \quad (5)$$

2.2 Calculation of Certain Values Until the Propellant Charge is Completely Burned

$$\theta b = \frac{P_0^2 A^2}{2B_a^2 m^x m_c Q_{ex}} = \frac{(9,80665.10^4)^2}{2.0,0793^2.50,282.14,380.Q_e x} \quad (6)$$

θ_b

$$Q_e x = Q\frac{kcal}{kg}.\frac{10^4}{2,38846} = 3173559\frac{Nm}{kg}$$

$$\theta_b = 0,12329$$

Normal air pressure, $P_0 = 9,80665.10^4$ Pa

2.3 Bullet Velocity in the Barrel

$$X' = V = \frac{2.B_a.m_c.Q_{ex}}{P_0 A}.\theta \quad (7)$$

$V = 3837,076.\theta$ (velocity variable dependent on $\theta = \varphi$)

$$\theta = 1 - \frac{1}{(1+\varphi)^{\frac{k-1}{2}}} = 1 - \frac{1}{(1+\varphi)^{0,15}} \quad (8)$$

Calculations are made by giving values at appropriate intervals starting from 0.01 to φ.

2.4 Calculation of Combustion Rate

The combustion rate expressed in Z indicates the ratio of the amount of gunpowder that burns every moment with the combustion of the propellant charge to the total amount of propellant gunpowder. Its value ranges from 0 to 1. When the propellant charge is completely burned, the value of Z will Table 1. The expression depending on the speed of the bullet inside the barrel is as follows:

$$Z = \frac{B_a m^x}{P_0 A} v$$

$$Z = \frac{0,0793.50,282}{9,80665.10^4.0,019235}.v = 2,113843665.10^{-3}.v \quad (9)$$

2.5 Calculation of Maximum Gas Pressure

$$\theta p_m = \frac{k-1}{2k} = \frac{1,30-1}{2.1,30} = 0,1153846 \quad (10)$$

$\theta p_m < \theta_b$ is checked.

$\theta_b = 0,12329$ was calculated before.

0,1153846<0,12329 shows that the situation is normal. Failure to maintain this condition means that the maximum pressure is not normal.

$$p_m = \frac{2(k-1)m^X \beta_a m_c Qex}{V_B^x P_O^2 A^2}.\left(\frac{\theta-\theta^2}{1+\varphi}\right)_{p_m} \quad (11)$$

$$p_m = 64050,45236.\left(\frac{\theta-\theta^2}{1+\varphi}\right)_{p_m}$$

$$\theta p_m = 0,1153846$$

$$(\theta-\theta^2)_{pm} = 0,10207099$$

$$\theta = 1 - \frac{1}{(1+\varphi)^{0,15}}$$

From the formula, $\theta = \theta p_m$

$$0,1153846 = 1 - \frac{1}{(1+\varphi)^{0,15}}$$

$$\frac{1}{(1+\varphi)^{0,15}} = 1 - 0,1153846$$

$$1+\varphi = 2,264488031$$

$$\left(\frac{\theta-\theta^2}{1+\varphi}\right)_{p_m} = 0,045074643$$

$$P_m = 64050,45236 \text{ x } 0,045074643$$

$$P_m = 2887\ Bar = 294,3\ MPa$$

2.6 Calculation of Muzzle Velocity of the Bullet

$$V_e = \sqrt{\frac{2m_C Q_{ex}\varphi_a}{m^x}} \quad (12)$$

φ_a demonstrates the situation after the propellant charge is completely burned.

2.7 Formula of the Combustion Coefficient at the Maximum Pressure Detected

$$\frac{V_B^x p_0^2 A^2 p_m}{2(k-1)m^x m_c^2 Q_{ex}{}^2}\left(\frac{1+\varphi}{\theta-\theta^2}\right)_{Pm} \quad (13)$$

2.8 Formulas Required for Calculating the Values Occurring After the Propellant Charge Is Completely Burned

Φ starting from 1,40414 will continue until it becomes 1,50-2, 00-2,50 which makes X=Xe.

$$X = \frac{V_B^x}{A}.\varphi \quad (14)$$

$$C = \frac{1}{1-\theta_b} \quad (15)$$

$$\psi = \frac{1}{(1+\varphi)^{k-1}} \quad (16)$$

$$\varphi_a = 1 - C.\psi \quad (17)$$

$$V^2 = \frac{2m_c.Q_{ex}}{m^x}.\varphi_a \quad (18)$$

$$V = \sqrt{\frac{2m_c.Q_{ex}}{m^x}.\varphi_a} \quad (19)$$

$$P = \frac{(k-1).(m_c.Q_{ex} - \frac{1}{2}m^x v^2)}{V_B^x + A_x} \quad (20)$$

Table 2. Certain values resulting from the combustion of propellant charge along a 155-mm howitzer barrel[6]

φ	X(m)	φ_a	V(m/s)	$\frac{1}{2}m^x v^2$ (Joule)	$m_c Q_{ex}$ (joule)	(8)-(7) (joule)	P(Bar)
0,01	0,009013	0,001491	5,721	822,86	551742,47	550919,61	94,38
0,05	0,045067	0,007292	27,980	19682,34	2698928,85	2679246,51	441,53
0,1	0,090134	0,014195	54,467	755,65	5254345,68	5179761,03	814,81
0,15	0,1352	0,020746	79,604	159313,41	7679228,99	7519915,58	1084,32
0,2	0,1803	0,026977	103,512	269379,13	9985671,66	9716292,53	1401,02
0,25	0,2253	0,032917	126,305	401073,19	12184427,02	11783353,83	1631,21
0,3	0,2704	0,038590	148,073	551231,84	14284269,11	13733037,20	1827,94
0,5	0,4507	0,059007	226,414	1288810,61	21841517,55	20552706,94	2370,87
0,7	0,6309	0,076509	293,571	2166750,23	28320164,43	26153414,1	2662,13
0,9	0,8112	0,091788	352,197	3118558,19	33975744,67	30857186,48	2810,24
1,1	0,9915	0,105321	404,125	4105953,09	38985237,74	34879284,65	2873,97
1,26449	1,1397	0,115384	442,737	4928039,54	42709613,52	37781573,98	2887,06
1,40414	1,2656	0,123289	473,072	5626480,51	45636267,34	40009786,83	2879,70
1,50	1,3520	0,133513	492,295	6093034,96	45636267,34	39543232,30	2736,99
2,00	1,8027	0,179634	571,029	8197825,25	45636267,34	37438442,00	2159,40
2,50	2,2553	0,216708	627,193	9889749,53	45636267,34	35746517,81	1767,31
3,00	2,7040	0,247466	670,22	11293431,18	45636267,34	34342836,16	1485,66
3,50	3,1547	0,273592	704,72	12485743,06	45636267,34	33150524,20	1274,73
4,00	3,6054	0,296194	733,25	13517183,12	45636267,34	32119084,22	1111,55
5,00	4,5067	0,333656	778,24	15226802,29	45636267,34	30409465,00	876,10
6,00	5,4081	0,363769	812,60	16601059,33	45636267,34	29035208,01	717,73
7,01952	6,3270	0,389199	840,52	17761589,54	45636267,34	27874677,70	601,45

$$C.\psi = \frac{1}{(1-\theta_b)(1+\varphi)^{(k-1)}} \quad (21)$$

2.9 Friction Losses Inside the Barrel

The grooves and sets inside the barrel enable the bullet to be rotated. Grooves and sets are opened into the barrel with precise tolerances and with special methods and it is a costly process. As can be seen in Table 2, very little gunpowder energy is spent on friction. In Table 3, the comparison of the pressure values formed as a result of the combustion of the propellant fuel along the MKE 155 mm howitzer barrel and the combustion of a projectile with a delayed initial motion.[18]

2.10 The Amount of Energy Thrown to the Atmosphere along with the Gunpowder Gas without being used

As seen in Table 2, approximately 43 % of the gunpowder gas energy generated as a result of the firing of the weapon system is thrown into the atmosphere without being used. This ratio indicates that the largest part of the energy is thrown into the atmosphere unused. If the amount of energy that is thrown without use is reduced and transferred to the bullet then the bullet will be fired longer ranges depending on the rate of energy transferred.

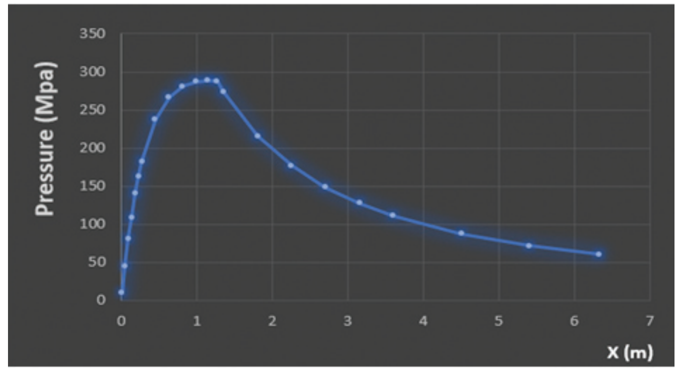

Figure 4. Pressure distribution graph Along a "MKE" 155 mm Howitzer Barrel.[6]

3. CHANGES MADE ON THE BARREL AND BULLET

In order for an ammunition to be launched to longer ranges, the energy loaded on it must be very high. This energy is provided by burning the gunpowder placed behind the bullet. The range of a weapon system can be increased by several methods: for instance, by increasing the barrel length, increasing the amount of gunpowder used, changing the type of gunpowder or using special bullets[19]. In this study, the process which is planned to transfer more energy to the bullet is based on increasing the maximum pressure in the combustion chamber by delaying the initial movement of the bullet in the barrel. The maximum pressure created will cause

Table 3. Comparison of certain values resulting from the combustion of the propellant charge along a MKE 155-mm howitzer barrel and the pressure values resulting from the combustion of a bullet with delayed initial movement[6]

Pressure Values Resulting from the Combustion of the Propellant Charge in a MKE 155 mm Howitzer[6]				Pressure Values Resulting from the Combustion of a 155 mm Howitzer with Delayed Initial Movement			
Line No	X_e m	V (Volume) m3	Pressure (Bar)	Line No	X_e m	V (Volume) m3	Pressure (Bar)
1	0,009013	0,02794	94,38	1	0,009013	0,02794	444,2164746
2	0,045067	0,02811	441,53	2	0,045067	0,02811	834,5208075
3	0,090134	0,02879	814,81	3	0,090134	0,02879	1117,086877
4	0,1352	0,02966	1084,32	4	0,1352	0,02966	1442,115327
5	0,1803	0,03053	1401,02	5	0,1803	0,03053	1677,159577
6	0,2253	0,03139	1631,21	6	0,2253	0,03139	1878,60288
7	0,2704	0,03226	1827,94	7	0,2704	0,03226	2434,808528
8	0,4507	0,03313	2370,87	8	0,4507	0,03313	2940,155047
9	0,6309	0,03659	2662,13	9	0,6309	0,03659	3076,748139
10	0,8112	0,04006	2810,24	10	0,8112	0,04006	3122,913482
11	0,9915	0,04353	2873,97	11	0,9915	0,04353	3117,202389
12	1,1397	0,047	2887,06	12	1,1397	0,047	3054,320106
13	1,2656	0,04985	2879,7	13	1,2656	0,04985	2869,858923
14	1,352	0,05227	2736,99	14	1,352	0,05227	2227,978611
15	1,8027	0,05393	2159,4	15	1,8027	0,05393	2051,429742
16	2,2533	0,0626	1767,31	16	2,2533	0,0626	1691,421537
17	2,704	0,07127	1485,66	17	2,704	0,07127	1429,800985
18	3,1547	0,07994	1274,73	18	3,1547	0,07994	1232,104647
19	3,6054	0,08861	1111,55	19	3,6054	0,08861	962,5136553
20	4,5067	0,09735	876,1	20	4,5067	0,09735	851,470341
21	5,4081	0,11549	717,73	21	5,4081	0,11549	684,0979479
22	6,327	0,13136	601,45	22	6,327	0,13136	591,0982335

the pressure force on the bullet base to increase further ($P_k.A_m$= F=m.a). Thus, it is aimed to accelerate the bullet much more in the barrel and increase the muzzle velocity of the bullet as a result of this high acceleration. In order to obtain these results and achieve our goal, various mechanisms were manufactured on the ammunition in order to delay the initial movement of the existing ammunition.

3.1 Designed and Manufactured Bullet

With this design, it is aimed to increase the range of the bullet by transferring some of the gunpowder energy to the ammunition thanks to the new parts to be included in the existing ammunition. The purpose of this design is to delay the initial movement of the ammunition and increase the gas pressure in the barrel with the help of a new clamping sleeve to be attached to the bullet as seen in Fig. 5 which will load more energy into the bullet.[20]

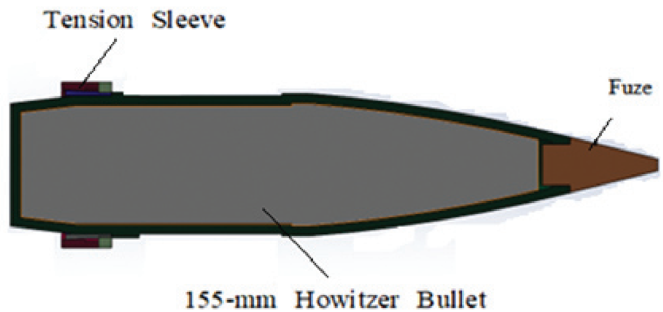

Figure 5. Cross-Section of designed 155-mm Howitzer Bullet.

As the tension sleeve aparts from the bullet as soon as the bullet moves , it won't cause any change in the moving bullet mass.

Thus, thanks to the tension sleeve attached to the ammunition, the initial movement of the ammunition will be able to move at different pressures. As a result, a certain amount of extra energy will be loaded to the ammunition. Placement of the designed ammunition in the weapon system is shown in Fig. 3.

In this study. the effects of a tensioning system attached to bullet without making any change on existing bullet and barrel on the exit speed of a bullet were analysed.

3.2 Theoretical Calculation of Barrel Internal Pressure Distribution in Fires to be Performed with Designed Bullets

Unlike the ammunition used today, it has been shown that the pressures that will occur inside the barrel as a result of firing with the designed bullet will be as follows within the framework of certain assumptions. These assumptions for the technical calculations were made by taking into account the data obtained from MKE publications. Here it is assumed that all gunpowder is burned before the bullet leaves the barrel.[21] Reference values were calculated again with the help of the ideal gas equation and new pressure values were obtained (Fig. 6).

3.3 Designed Experimental Setup and Bullet

The designs of the parts for the prototype experimental setup were made using Solidworks Cad program. With

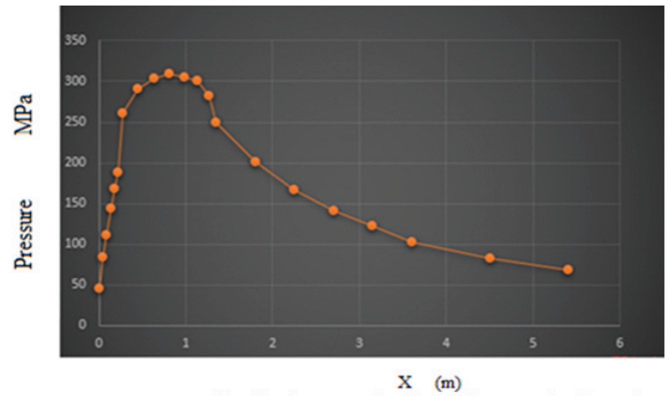

Figure 6. Pressure distribution graph along the barrel of designed 155-mm Howitzer Bullet.

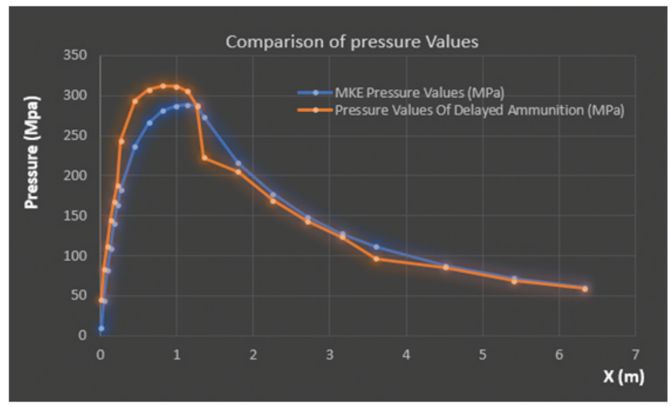

Figure 7. Comparison Graph of Pressure Distributions along a MKE 155-mm Howitzer Barrel as a Result of Firing Under Normal Conditions and Firing with a Delayed Ammunition.

the planned design, it is aimed to increase the range of the bullet by transferring some of the gunpowder energy to the ammunition, thanks to the new parts to be included within existing ammunition. The purpose of this design is to delay the initial movement of the ammunition and to increase the gas pressure in the barrel with the help of a new clamping sleeve to be attached to the bullet as seen in Fig. 9 and thus it aims to load more energy to the bullet. Thanks to the tension sleeve attached to the ammunition, the initial movement of the ammunition will be able to move at different pressures.[22] This will allow a certain amount of extra energy to be loaded to the ammunition. The purpose of this design is to delay the initial movement of the ammunition and increase the gas pressure in the barrel with the help of a new clamping sleeve that will load more energy into the bullet as seen in Fig. 5.

3.4 Manufacturing Stages of the Experimental Setup and Test Firing

After all the drawings required for the manufacturing of the designed project were drawn and the controls were made, the setup was started to be manufactured.

4. TRIAL FIRES MADE WITH EXPERIMENTAL SETUP AND RESULTS OBTAINED

The ambient conditions during the experiment were as follows: Temperature: 20, Altitude: 1044 m. The experiments were conducted using 12-caliber MKE Super Slag cartridges produced by MKE. Initially, test fires were made with five cartridges without making any changes on them and the data obtained were recorded in Table 4 below. The second test fire was made under the same ambient conditions and with cartridges of the same characteristics, but the tension sleeve designed to delay the initial moment of the bullet was attached to the cartridge and the tension sleeve was tightened by applying 30 Nm torque and then placed on the cartridge bed, and in this way five test fires were made and the resulting data are given in Table 4. The third test fire was made under the same ambient conditions and with cartridges of the same characteristics, but the tension sleeve designed to delay the initial moment of the bullet was attached to the cartridge and the tension sleeve was tightened by applying 60 Nm torque and then placed on the cartridge bed, and in this way five test fires were made and the resulting data are given in Table 4.

Expt. No	Fire No	Tightening Torque of Clamping Sleeve (Nm)	Muzzle Velocity of the Bullet (m/sec)	Average Muzzle Velocity for 5 Fires (m/s)
	1	0	390	
	2	0	385	
1	3	0	392	387,2
	4	0	378	
	5	0	391	
	1	30	388	
	2	30	397	
2	3	30	397	395,2
	4	30	389	
	5	30	405	
	1	60	397	
	2	60	412	
3	3	60	409	406
	4	60	413	
	5	60	399	

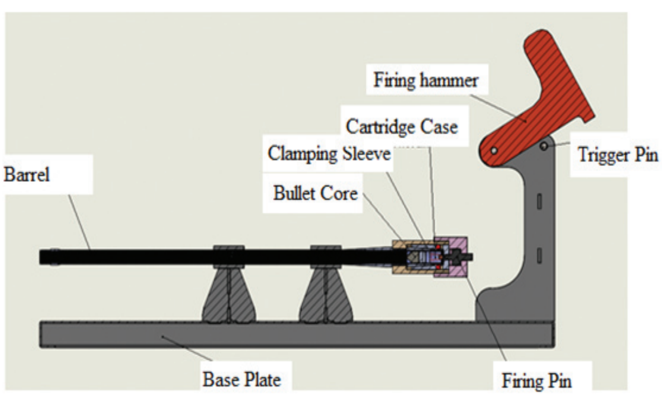

Figure 8. Cross section of the designed experimental setup.

4.1 Design and Manufacturing of the Prototype Experimental Setup

The designs of the parts for the prototype experimental setup were made using Solidworks Cad program.

5. RESULTS ACHIEVED AND THEIR ANALYSIS

In this study, experiments were conducted using 12-caliber Super Slag cartridges produced by MKE (Fig. 4). The

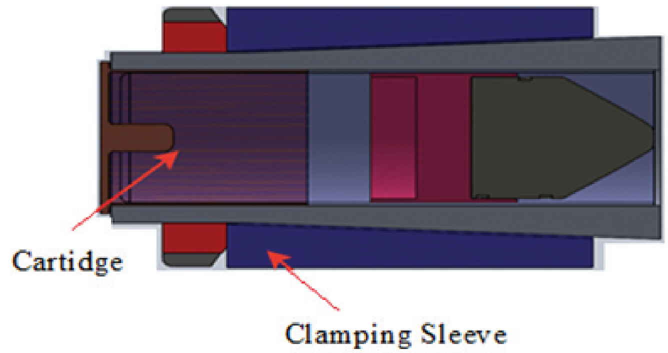

Figure 9. Cross-sections of the shotgun cartridge to be used in the prototype experiment setup and the clamping sleeve to be attached.

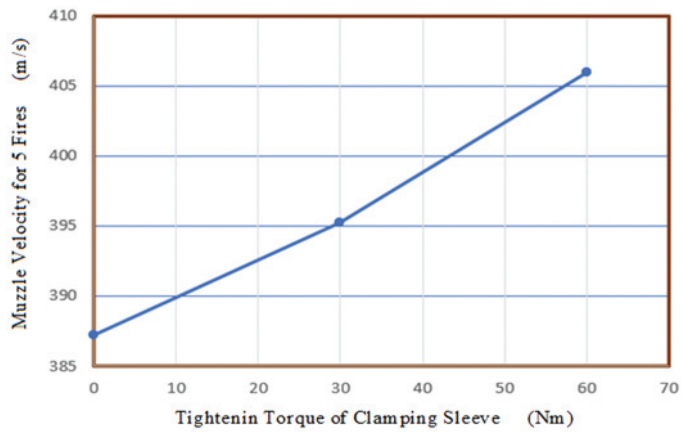

Figure 10. Graph of the change in the barrel exit speed as a result of firing applied to delayed ammunition.

first five cartridges were placed in the chamber as in normal weapons and fires were made and the bullet muzzle velocities were measured and recorded by means of a chronograph device placed in front of the mechanism (Fig. 8). Afterwards, test fires were carried out with a clamping sleeve placed in the cartridge bed by tightening at certain torques for every five fires. The muzzle velocities were measured and recorded again with the help of a chronograph. The bullets placed in the chamber were not tightened in the first five shots and then the bullet core was tightened by applying 30Nm torque in the second five shots and by applying 60Nm of torque in the third five shots (Figure 4 and 6). The muzzle velocity data obtained as a result of these three different shots were measured as 387.2 m/s in the first shot, 395.2 m/s in the second shot and 406 m/s in the third shot (Figure 7). According to the data obtained as a result of these test fires, it was revealed that the method followed was accurate and increased the muzzle velocity of the bullet (Figure 10). In this study, the changes that a bullet may cause inside the barrel, whose initial movement is delayed compared to existing bullets, have been investigated. It has been observed that a bullet whose initial movement is delayed causes an increase in the amount of gas released due to the combustion of gunpowder and thus the internal pressure is increased. It has been demonstrated that depending on the amount of pressure that increases in the barrel, the force applied to the base of the bullet will increase and thus cause the bullet to accelerate further[23]. In the light of these data, it has been shown that a bullet whose initial movement is delayed can go to longer ranges with a lower amount of gunpowder. As a result, this study will be original, innovative and will bring a high added value when it is implemented. In addition, this product which shall be designed and produced for the defense industry will be very important in terms of technical and scientific aspects (Fig.10).

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CONTRIBUTORS

Dr Haşim Pıhtılı obtained PhD in 1991 from Firat University, Turkey and is working as Associate Professor. His areas of interest include: Wear, composite materials and construction of machines.
His contributions in the current study include: Making solid modeling of the existing Grooved Barrels using the technical drawing information in the Solid Works program, the transfer of solid modeling to Ansys Workbench program, applying the values that affect the barrel on this program, comparing the results with the standard barrel and the barrel whose geometry (designing and manufacturing new types of barrels) has been changed, and helped in the study on the analysis of the results.

Mr Ramazan Yildirim obtained Master of Science from Firat University, Turkey and working as a Mechanical Control Engineer in the Republic of Turkey Court of Cassation since 2018.
His contributions in the current study include: Literature review, drawing of technical drawings, writing and editing the publication, and assisted in the study on the analysis of the results.