Paper: ASAT-14-172-AF

14th International Conference on
AEROSPACE SCIENCES & AVIATION TECHNOLOGY,
ASAT - 14 – May 24 - 26, 2011, Email: asat@mtc.edu.eg
Military Technical College, Kobry Elkobbah, Cairo, Egypt
Tel: +(202) 24025292 –24036138, Fax: +(202) 22621908

Ballistic Comparative Study of Three Automatic Rifle Calibers

A. Fayed*, O. Ramy* and H. Yakout*

Abstract: Calibers 7.62×39 mm and 5.56×45 mm are the two famous automatic rifle calibers used worldwide by infantry soldiers. Several years ago, most of European and American countries already changed from 7.62×39 mm to 5.56×45 mm, while other countries still using caliber, 7.62×39 mm and refusing the change. To optimize the advantages of both calibers, a new automatic rifle caliber 6.8×43 mm emerges.

The purpose of this study is to perform a ballistic comparative study of the three mentioned calibers. Interior ballistic calculations were performed using modified Charbonnier semi-empirical model to estimate the weapon interior ballistic parameters. While, the main task of exterior ballistics (i.e., projectile trajectory parameters and energy dissipation during projectile flight at different firing angles) was performed using point-mass two-degree-of-freedom trajectory model.

It was found that the value of maximum pressure of gases inside the rifles barrel were almost the same, while three different muzzle energies were obtained. They are 2.45 kJ for 6.8×43 mm, 2.1 kJ for 7.62×39 mm, and 1.55 kJ for 5.56×45 mm. The highest energy dissipation along the trajectory was found with 6.8×43 mm projectile. The lowest one was found with 5.56×45 mm projectile all over the range of angles of fire.

Introduction

Solution of the direct task of interior ballistics is to estimate the ballistic parameters of a weapon through the solution of a proper mathematical model of its firing process. Among these parameters are the gas pressure and temperature histories, and projectile velocity down the barrel. This task is usually accomplished during the process of designing a new weapon, improving the performance of an existing one, and/or solving problems with weapons and ammunition in service.

Numerous interior ballistic models have been developed for classical guns, which can generally be classified into empirical, semi-empirical and analytical ones [1-7]. The empirical models are normally obtained by fitting arbitrarily proposed equations including weapon characteristics to firing test data. They are used for rough estimation of the ballistic parameters of a weapon. The semi-empirical models represent the dynamics of the weapon firing process by two classes of equations. The first class models the physical reality of the process, and includes the equation of projectile motion, mass and energy conservation equations. The second class of equations is empirical formulation of propellant rate of burning, energy losses, projectile frictional losses and gradients down the barrel.

The semi-empirical models neglect the fluid dynamics aspects of the problem, and the combustion chamber is treated as well-stirred so that it may be characterized by a lumped

* Egyptian Armed Forces.

parameter formulation. Through a proper choice of empirical equations, they can provide excellent predictions of the ballistic parameters of classical weapons [2, 3]. Analytical models simulate the ignition and flame spreading in the packed propellant bed. The fluid dynamics aspects of the two-phase-reacting flow down the barrel tube are completely introduced [7].
One of the well-established semi-empirical models is Charbonnier's [1]. The model was subsequently modified by considering the propellant grain relative burnt out thickness to be the independent parameter during the burning period of propellant [8]. As such, the model was considerably simplified and is, therefore, used herein.
The point-mass two-dimensional projectile trajectory model was applied to predict the trajectory parameters for the three aforementioned projectile calibers. The necessary variation of aerodynamic total drag coefficients, versus Mach number were predicted using Siacci empirical model [9]. In such model, the drag- Mach number functional relation for a given projectile shape is considered to have the same form of the chosen law of air resistance for a model projectile differs by a constant multiplier called the projectile shape coefficient. Such model is used in this work because of its availability, simplicity and practicability, in addition to the acceptable results it provide.

Interior Ballistic Model

The modified Charbonnier model is centered on a Lagrangian frame of reference. A number of simplifying assumptions were introduced in formulating the model [2, 4], which considerably reduce computational time. They do not enable, however, the prediction of internal phenomena, such as the ignition process and gas pressure oscillations.
The model consists of the following equations: (i) Equation of burning of propellant, (ii) Equation of projectile motion inside the barrel, (iii) Equation of energy conservation, (iv) Equation of state of propellant gas mixture, in addition to two kinematical equations. The weapon firing process is divided into three intervals: (1) Ignition and burning under constant volume conditions, (2) Burning with volume change, and (3) Gas expansion.
The first interval is basically solved by applying the Nobel-Abel equation of state. In the second interval, the aforementioned equations can be combined to yield analytical expressions for velocity, pressure, and temperature as well as ordinary differential equations for projectile travel and duration. For completing the solution until the projectile leaves the barrel muzzle, adiabatic expansion of propellant gas is assumed. Complete set of the model equations is available in Refs. [2, 8].

Exterior Ballistic Model

A point-mass two-degree-of-freedom projectile trajectory model is chosen for the present study [10]. The basic assumptions of this model are: (a) the projectile motion is limited to the x-y plane; the gravitational force $\vec{Q}$ and the aerodynamic drag $\vec{R}$ are the only forces acting on the projectile during its flight in air. (b) The projectile mechanical axis coincides with the trajectory tangent at the projectile center of gravity, and the aerodynamic drag acts in the same direction, but opposite to the projectile motion. (c) The gravitational acceleration is considered to be constant in magnitude and direction, and normal atmospheric conditions are considered.
The system of differential equations represents the projectile trajectory parameters can be solved numerically employing any numerical integration scheme such as the second-order Runge-Kutta scheme. The change of atmospheric elements (e.g. specific mass of air δ_∞, atmospheric pressure p_∞ and air temperature T_∞) is given as function of height y in Ref. [11].

Results and Discussions

Interior and exterior ballistic input data for the three calibers (i.e. 7.62×39 mm, 6.8×43 mm, and 5.56×45 mm) are listed in Table 1, in which projectile mass, initial combustion volumes, propellant characteristics, and projectile shape coefficient are indicated.

Table 1 Ballistic input data

Input Data	5.56×45 mm	7.62×39 mm	6.8×43 mm
Projectile mass, grams	3.9	7.8	7.45
Initial combustion volume, cm^3	1.85	2.1	2.2
Barrel length, m	0.4	0.4	0.55
Propellant mass, grams	1.2	1.65	1.67
Initial pressure, MPa	40	35	35
Propellant force factor, MJ/kg	1.045	0.87	0.996
Propellant specific mass, kg/m^3	1570	1600	1550
Unit Burning rate, m/s. Pa	15×10^{-10}	13.5×10^{-10}	11.3×10^{-10}
Specific heat ratio	1.28	1.27	1.27
Explosion temperature, K	3000	3200	2950
Propellant covolume, m^3/kg	1.1×10^{-3}	1.05×10^{-3}	0.928×10^{-3}
Grain half-web size, mm	0.2	0.16	0.18
Projectile muzzle velocity, m/s	896	737	798
Projectiles Siccci's shape coefficient	0.5	0.5	0.5

The obtained results of gas pressure inside the weapon barrel are illustrated in Figs. 1 and 2. The values of gas pressure, projectile velocity, projectile travel and corresponding time of projectile motion at the point of maximum pressure and at the muzzle section are listed in Table 2.

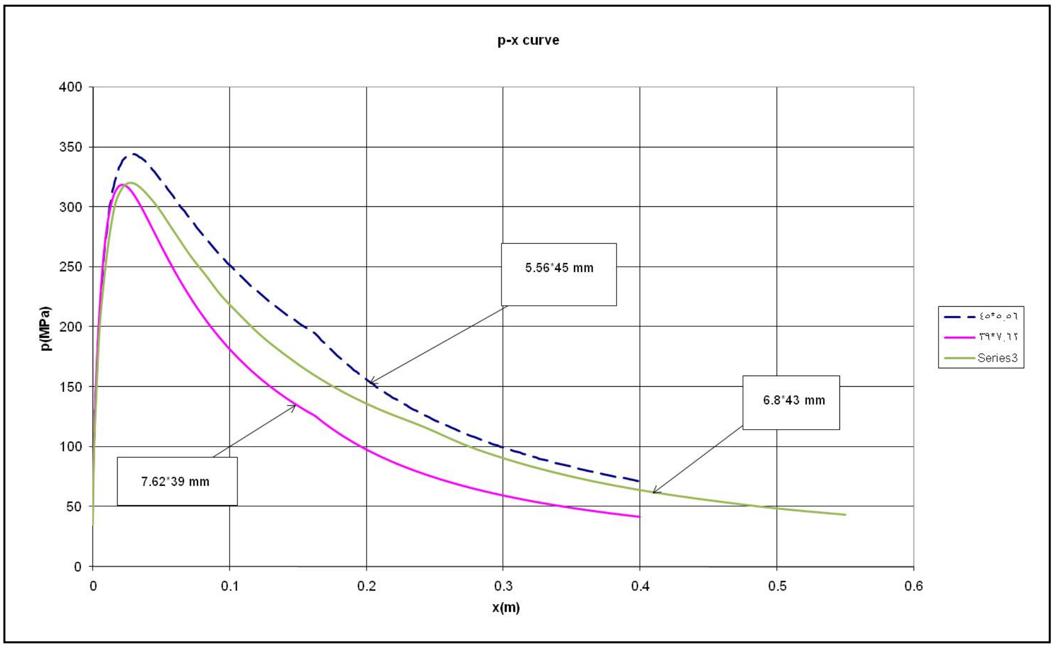

Fig. 1 Gas pressure vs. projectile travel for the three calibers.

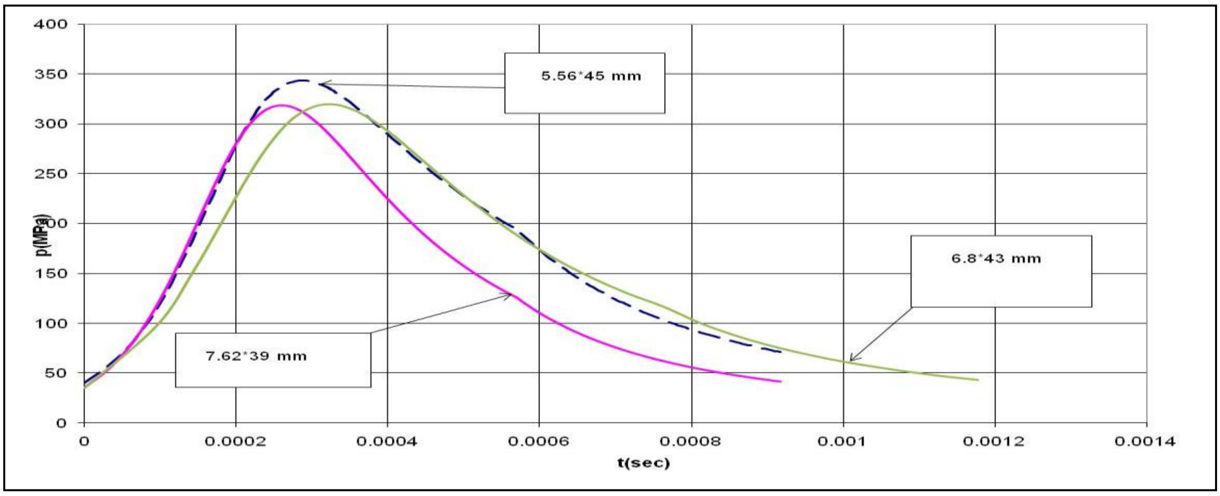

Fig. 2 Gas pressure vs. time of projectile travel for the three calibers.

Table 2 Calculated values of velocity, pressure and travel at main points.

Parameter	Position	Weapon caliber		
		7.62×39 mm	5.56×45 mm	6.8×43 mm
t, ms	Point of maximum pressure	0.261	0.321	0.331
	Muzzle point	0.918	0.844	1.177
v, m/s	Point of maximum pressure	245	340	268
	Muzzle point	737	896	798
p, MPa	Point of maximum pressure	319	344	320
	Muzzle point	42	72	43
x, m	Point of maximum pressure	0.022	0.038	0.03
	Muzzle point	0.4	0.4	0.55

The above results indicates that caliber 7.62×39 mm needs lower specific kinetic energy and specific impulse from the used propellant to get its maximum energy at the muzzle compared with the calibers 5.56×45 mm and 6.8×43 mm. This means lower barrel thickness and hence less barrel and weapon relative weights. According to published date, the expected muzzle energy of the new automatic rifle caliber 6.8×43 mm is about 2.45 kJ. In order to reach such muzzle energy using the other two calibers, the barrel length should be increased by nearly 15 cm (see Fig. 1).

The maximum pressure of the two calibers 7.62×39 mm and 6.8×43 mm are much closed, this means the two barrels thickness are nearly the same, but the new expected caliber, 6.8×43 mm has a longer barrel length. The muzzle pressures of the same two calibers are also the same, this means low efficient and dimension muzzle adaptor is needed for these two weapons compared by the third caliber 5.56×45 mm. The masses of the two bullets of calibers 7.62×39 mm and 6.8×43 mm enables the designers to get more powerful cartridges than that of the 5.56×45 mm caliber, where the masses of the bullets are 7.8, 7.45 and 3.9 grams respectively.

In order to study the exterior ballistic behaviors of the three calibers, three firing angles are selected. They are 0.1, 0.3 and 0.5 degrees. Figure 3 illustrates the projectile trajectories for the three calibers at the chosen angles of fire.

It is clear that the two calibers 6.8×43 mm and 5.56×45 mm reaches nearly the same range at the same angle of fire, this is due to longer length of the barrel caliber 6.8×43 mm, and higher muzzle velocity of caliber 5.56×45 mm. Caliber 7.62×39 mm reach less distance for the same angle of fire, that is because of the bullet mass and the value of the muzzle velocity.

From Fig. 3, it is noticed that the trajectory maximum height at different angles of fire for projectile caliber 6.8×43 mm is always less than those for the projectile caliber 5.56×45 mm and higher than for the projectile caliber 7.62×39 mm. This is due to the fact that the projectile mass of caliber 7.62×39 mm is heavier than that of calibers 6.8×43 mm and 5.56×45 mm. On other hand, caliber 7.62×39 mm can reach the same distance by proper adjusting the sight mechanism of such weapon. Actually the more important factors are the projectile muzzle energy, the energy dissipation along the trajectory at different firing angles and the kinetic energy of bullets at maximum distance.
Figure 4, shows that the muzzle kinetic energies of caliber 6.8×43 mm are always higher than the values of kinetic energies of calibers 5.56×45 mm and 7.62×39 mm. This is due to its mass and value of muzzle velocity (nowadays demands). In the same time caliber 7.62×39 mm still has higher kinetic energy than the caliber 5.56×45 mm.

For further investigation of velocities and kinetic energies values along longer ranges, the velocity and energy drop along the trajectory at 5 degrees angle of fire for the three calibers are plotted in Figs. 5 and 6.

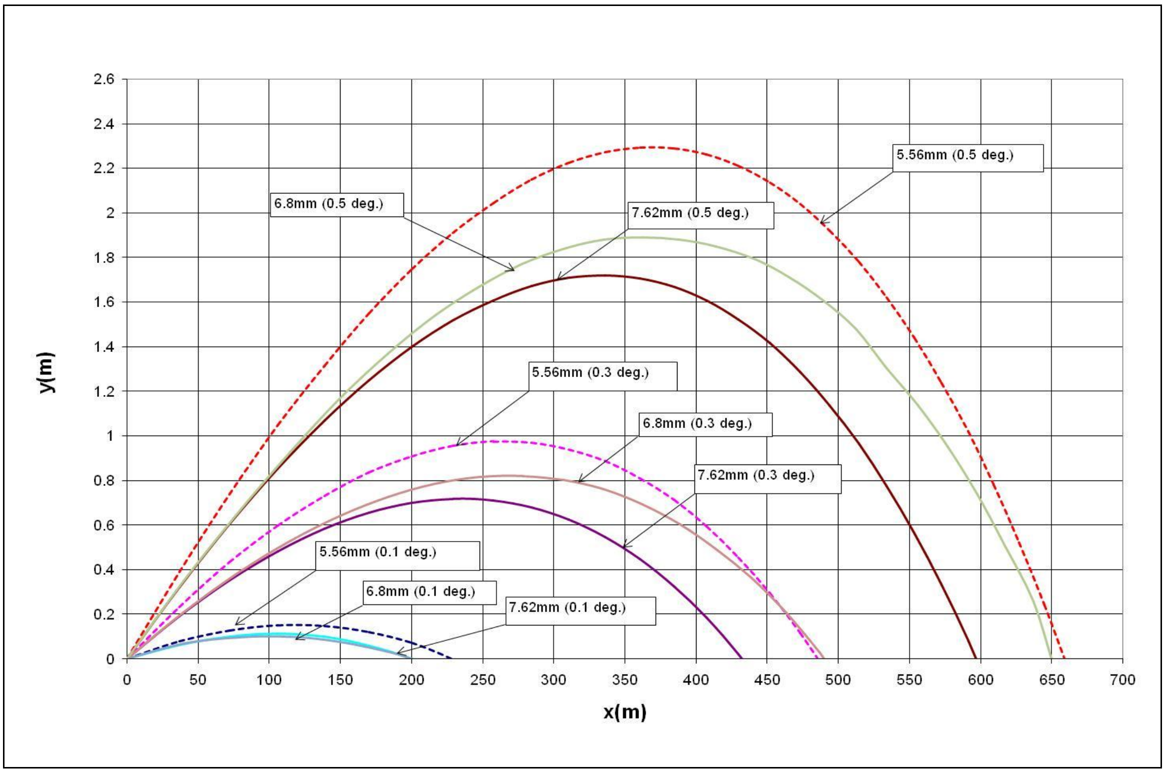

Fig. 3 Trajectories of the three calibers at different angles of fire.

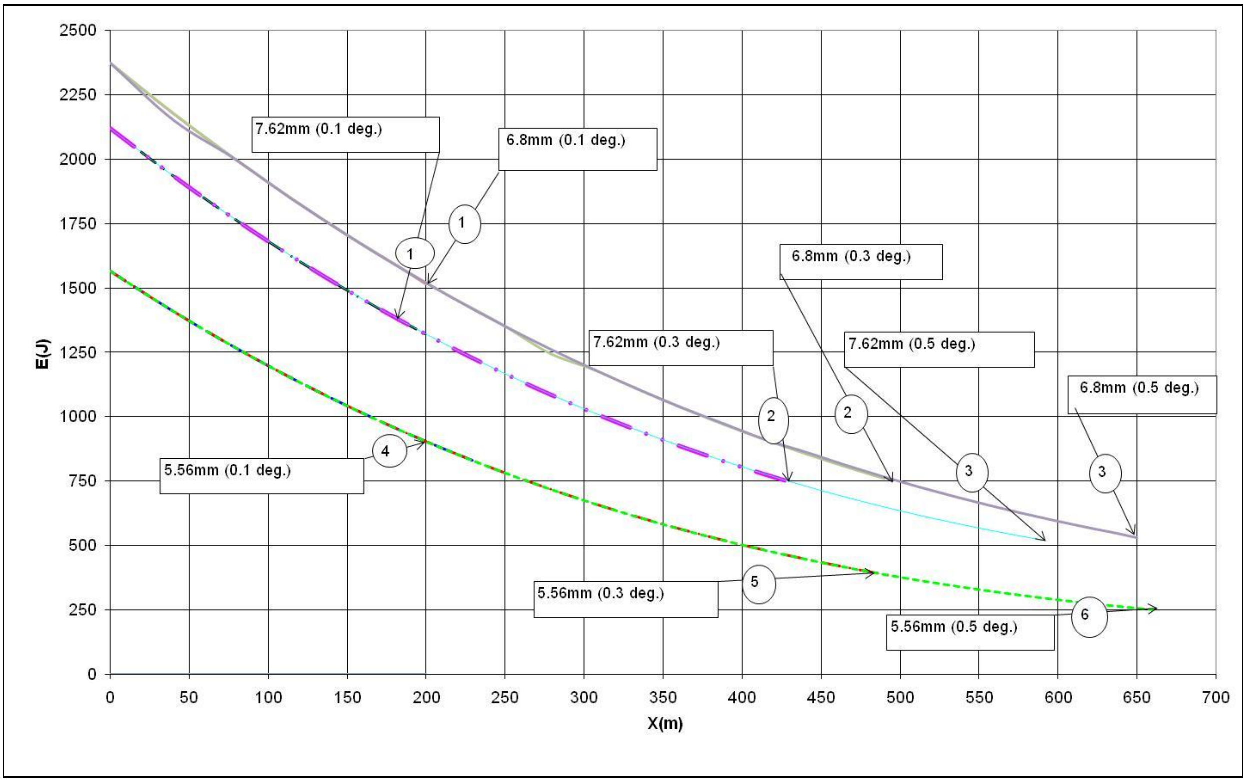

Fig. 4 Energy dissipation of the three calibers at different angles of fire.

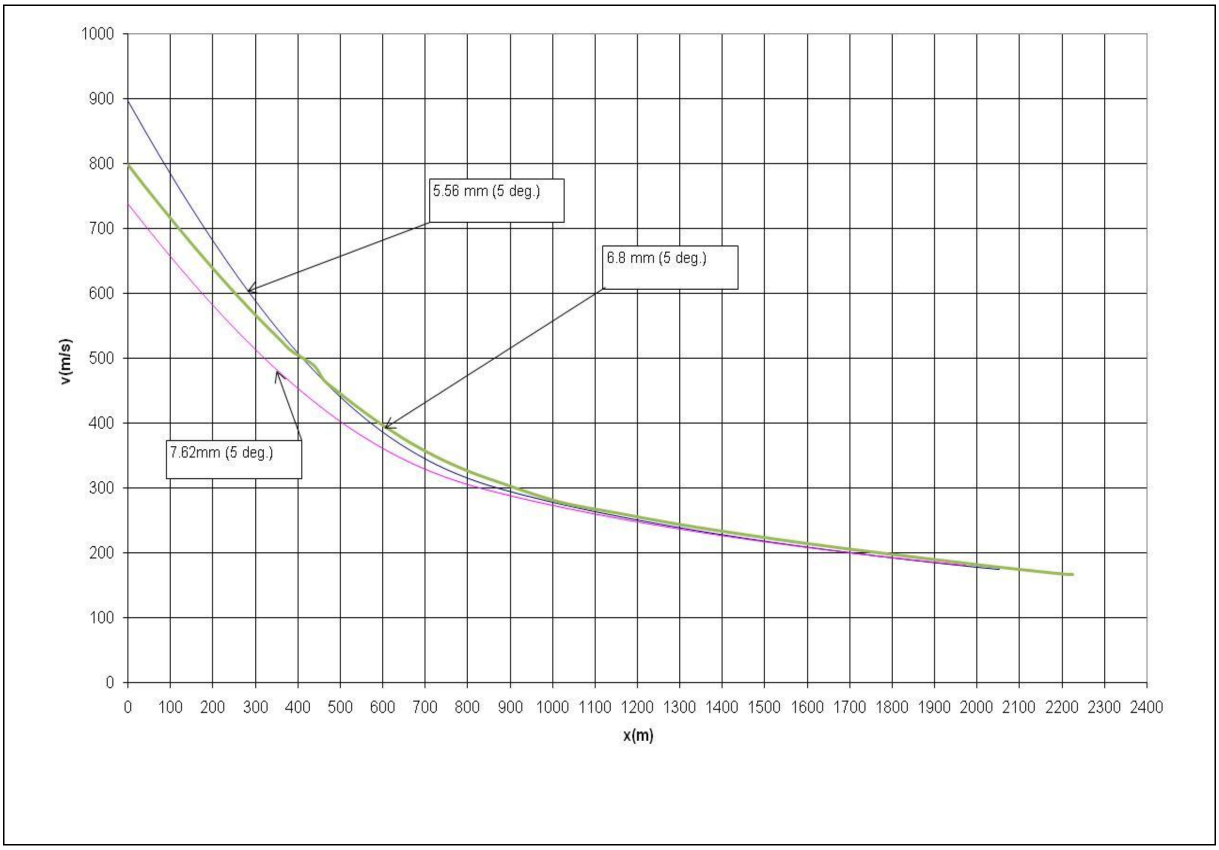

Fig. 5 Projectiles velocity vs. displacement at 5 degrees angle of fire.

It can be seen in Fig. 5 that the three caliber projectile velocities are converging to the velocity value at about 1000m range. Before such distance, projectile caliber 5.56×45 mm has the highest value, while projectile caliber 7.62×39 mm has the lowest value.
Figure 6 presents the kinetic energies of the three calibers. It is shown that the kinetic energy of the 6.8×43 mm caliber are always higher than that of the 5.56×45 mm and 7.62×39 mm calibers all over the trajectory, which means that the power of the projectile caliber 6.8×43 mm is always higher than the of power of the projectile calibers 5.56×45mm and 7.62×39 mm.

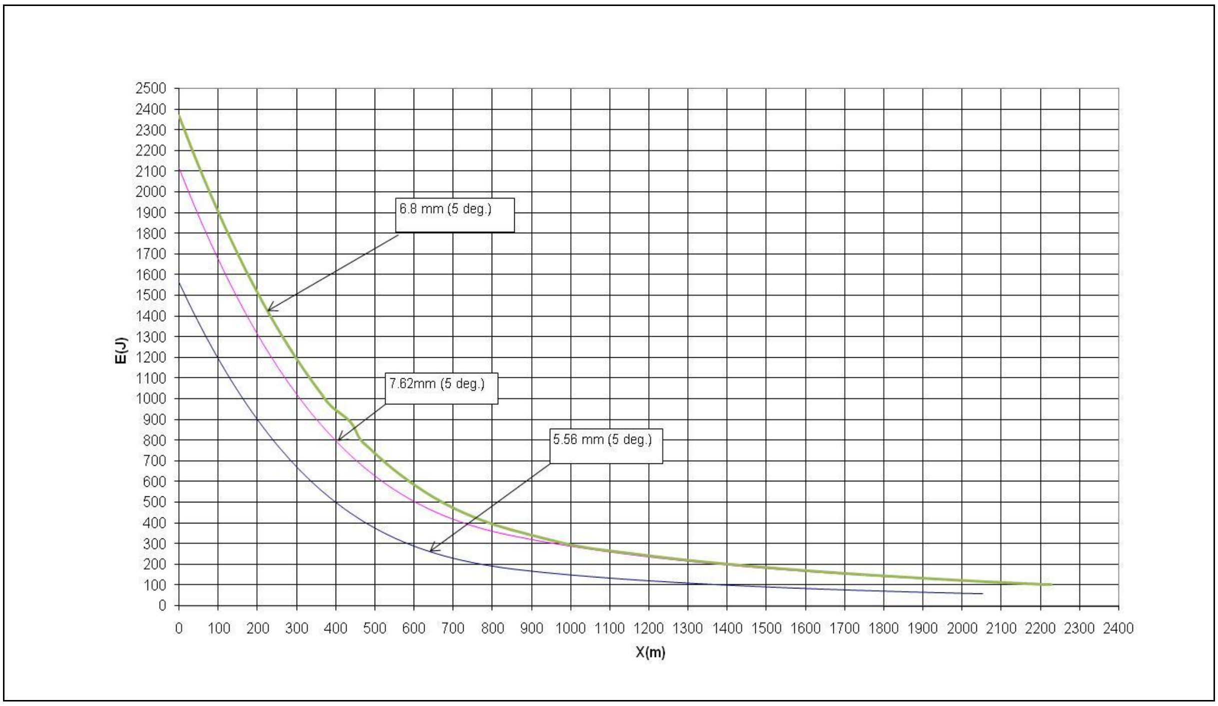

Fig. 6 Energy dissipation vs. displacement at different angles of fire.

Conclusions

The interior and exterior ballistic main tasks are solved by using the modified Charbonnier's model and two-degree-of-freedom (point mass) trajectory model consequently to present a comparative study between the most famous infantry weapons calibers (7.62×39 mm, 5.56×45 mm and 6.8×43 mm) .
The study highlighted the new direction towards the changes in the infantry armament. It is basically increasing the out energy of new generation weapons, this means, a new generation in body armors are going to rise near future for protection against the ammunition of the new generation. The caliber 7.62×39 mm can still play a reasonable rule, but with some changes, since the difference in its output energy is about 14% less than the new caliber 6.8×43 mm. While the caliber 5.56×45 mm has about 37% difference in energy than the caliber 6.8×43 mm.
As a future development for the caliber 7.62×39 mm, it is necessary to calculate its performance, and make some modification on its ammunition to compensate the 14% kinetic energy difference.

References

[1] Rebicek, V., "Principal Problems of Theoretical Interior Ballistics", MTC No. 717, Cairo (1967).

[2] Yakout, H., "Analysis of Different Methods Used for Solving the Main Task of Interior Ballistics", M. Sc Thesis, MTC, Cairo (1979).

[3] Baer, P.G., "Practical Interior Ballistic Analysis of Guns", Prog. Astro. and Aero. , AIAA, Vol. 66, pp 37-66, New York (1979).

[4] Krier, H. and Adams, M.J., "An Introduction to Gun Interior Ballistics and a Simplified Ballistic Code", Prog. Astro. and Aero. AIAA, Vol. 66, pp 1-36, New York (1979).

[5] EL-Naggar, M., Aboul, M. and Kresha, Y., "Interior Ballistics: Design, Testing and Optimization", 2nd AME Conf., MTC, Cairo (1986).

[6] East, J.L. and McClure, D.R., "Projectile Motion by Solid/Gas Flow of Interior Ballistic Model", 10th JANNAF Combustion Meeting, 243 (1973).

[7] Gouph, P.S. and Zwarts, F.J., "Modeling Heterogeneous Two-Phase Reacting-Flow ", AIAA J., Vol. 17, pp 17-25 (1979).

[8] Yakout, H. and Abdel-Kader, M.S., "Numerical Solution of Interior Ballistic Model for a Classical Weapon", 3rd ASAT Conf., MTC, Cairo (1989).

[9] Anon, "External Ballistics: Part I", Military Technical College Printed Lectures No. 208, MTC, Cairo (1967).

[10] Kandil, S.A., Abdel-Kader, M.S. and Yakout, H., "Artillery Projectile Drag

[11] Modeling", 6th ASAT Conf., MTC, Cairo (1995).

[12] Anon, "Incompressible Aerodynamics", Military Technical College Printed Lectures No. 1504, MTC, Cairo (1967).