# Answer to Reviewer A

## **Manuscript**: Analytical and Experimental Investigation on Muzzle Brake Efficiency

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In terms of professional focus, I would recommend at least mention:

1. How the forces measured between the weapon and its mount will change at the sniper, the light combat vehicle, the tank, the vessel?

Answer:

In the case of using a rifle as a sniper rifle, the recoil force, which is largely absorbed by the muzzle brake, is additionally absorbed with the absorber through the buttstock system with a rubber lining. Nevertheless, the force acting on the shooter's shoulder is significant.

In the case of the use of weapons on a vehicle-mounted carrier (the light combat vehicle, the tank, the vessel), the recoil force would primarily reflect the need to install an absorber on the carrier, and to a lesser extent the stability of the gun carriage, carrier and weapon. The impact of the recoil force on the vehicle is less significant than in the case of sniper rifle.

On the other hand, the geometric parameters of the muzzle brake can increase efficiency at the expense of greater impact on the shooter. This means that by automating the weapon system, a greater reactive effect of the muzzle brake could be provided in order to increase efficiency. Weapon systems up to 12.7 mm often do not use the muzzle brake, because the weapon carrier mounted on the combat platform (light combat vehicle and tank) can absorb the energy of recoil.

In any case, the process of weapon recoil, would partly reflect on the initial conditions of projectile motion as the initial disturbances, which we did not consider in this paper.

The excessive muzzle blast wave will harm the soldiers and equipment. Therefore, it is necessary to balance the efficiency of the muzzle brake with the blast wave intensity, and to reduce the blast wave intensity as much as possible based on the assurance that the efficiency meets the demand.

In the manuscript, Chapter 1. Introduction, after fifth Paragraph, we add: “The force that occurs during the firing process and depending on the use of the weapon must be adequately absorbed in order to reduce the load and the impact of the wave on the shooter (in the case of sniper rifle). In the case of integration of weapons on the combat platform (light combat vehicle, tank, vessel), the impact of the recoil force is smaller and can be absorbed by a suitable absorber built into the carrier, to reduce platform load and impact on firing conditions. The use of muzzle brakes depends on the recoil force, the type of weapon and the manner of use or carriage of the weapon.”.

1. What is the relationship between the force of the gas in the barrel and during the aftereffect and the forces in Figure 6, including max. values?

Answer:

The main goal of the research was to determine the efficiency of the muzzle brake, based on the measurement of the force acting on the weapon during the whole process of firing, during combustion and movement of the projectile in the barrel and after leaving the barrel.

Preliminary research and measurements can offer very good agreement of results of recoil force and muzzle brake force, with standard measuring devices (universal receiver and recoil spring system).Due to the direct measurement of the recoil force on the described weapon system, anti-material rifle 12.7 mm, without moving parts of the breech mechanism of the barrel and the impact of that force on the shooter, or possibly on the weapon stand, a force sensor with strain gages was developed and applied. The basic idea was to determine the most reliable value of muzzle brake efficiency, which we obtained by measuring the force during the firing process on weapons with models of muzzle brake in relation to weapons without muzzle brake.

The values of the force during the firing process are lower while the projectile is in the barrel max 14 kN (Fig. 3.), and after the exit (aftereffect) it reaches values of max.18 kN (Fig. 6 of Manuscript and Fig. 3), without a muzzle brake. In the case of firing with muzzle brakes, the force values, while the projectile is in the barrel is max. 12.5 kN, and during after effect it reaches values of max. 15.5 kN for MB type 1 and max. 14 kN for MB type 2. The measured force, while the projectile is in the barrel (about 2.2 ms), in the case without a muzzle brake, is slightly higher than the force in the case of a weapon with a muzzle brake, due to the mass of the muzzle brake.

The recoil force described on the Fig. 6 of Manuscript, represents the force in aftereffect period. The maximum force recorded during the measurement, while the projectile is in the barrel is less than the maximum measured force when the projectile leaves the barrel. The recoil force curve has the same character in all test cases.

In the manuscript, Chapter 3. Experiment, bellow Figure 6 after first Paragraph, we add: “The recoil force described on the Fig. 6 represents the force in aftereffect period. The maximum force recorded during the measurement, while the projectile is in the barrel is less than the maximum measured force when the projectile leaves the barrel.”.

1. Missing the relationship between the time when the shot leaves the muzzle of the barrel.

Answer:

The time of motion of the projectile from firing to exit (muzzle) is about 2.2 ms, which shows the coincidence of the values of the analytical interior ballistics calculation and the values obtained by measurement, as shown in Fig. 2 (analytical results of RF) and Fig. 3 (experimental results of RF). The RF curve in Fig. 3 shows the complete process of measurement force during period in the barrel and after.

The part of the experimental function with the saddle function shape, about 2.2 milliseconds from start, shows that projectile leaves the barrel, Fig. 3.

1. What type of shooting stend was used for the experiment (producer, dimensions, mass, ...)?

Answer:

Within experimental facilities of the Research and Development Department of Zastava Arms Kragujevac, tests was conducted using genuine experimental shooting equipment developed and produced by factory.

In the manuscript, Chapter 3. Experiment, in Paragraph 4, we add: “The measuring shooting equipment was consisted of Zastava Arms Fixed Firing Rest M2 (mass 400 kg, dimensions 1300 x 420 x 830 mm, elevation angle 3° with drift setting device) and Universal Receiver (mass 14 kg, dimensions 300 x 215 x 86 mm with manual and electromechanical triggering).”.

1. It would be interesting to determine the impulse of the measured force and compare it with the impulse of force from the gas during the entire time of action (min. 9 ms)

Answer:

According to the theory, total impulse of the recoil force for weapon with muzzle brake was presented in Fig. 1.



Fig. 1. Total Impulse of Force on the barrel (Z. Ristić, Weapon Mechanics, 2006.)

Analytical results of forces, according to used interior ballistic model, in the barrel and during after effect, used for the analytical model in the research, was presented in Fig. 2. During the period of action of the gas in the barrel, all three force curves coincide.



Fig. 2. Analytical Model of Forces: without MB, with MB1 and MB2

For the purposes of research in order to determine the efficiency of the muzzle brake, the values of the pressure of gunpowder gases were taken into account, i.e. the third period, which is represented by the analytical calculation and results.



Fig. 3. Comparison of Experimental Recoil Forces in total test period (in the barrel, aftereffect, …):
without MB – black, MB1 - blue and MB2 – red

Regarding experimental tests, Figure 6 of Manuscript presents the results of force measurements from the moment the projectile leaves the barrel.

The experimental force impulse for the total period from the firing to 9 ms, (Fig. 3.) in the case of rifle without muzzle brake 63.4432 Ns. In the case of rifle with MB1 the force impulse is 37.5161 Ns, and in the case of weapons with MB2 it is 37.2304 Ns. This represents an force impulse reduction of about 41%. In the case described in the paper, when the force impulse from the moment of leaving the pipe mouth (from 2.2 ms to 9 ms) are directly compared by measuring the force, the reduction of the force impulse would be about 66%.

In the manuscript, Chapter 4. Results and Discussion, after last Paragraph, we add: “In this paper, the impulse of the recoil force in the period when the projectile leaves the barrel was used to determine the efficiency of the muzzle brake. If the total period were observed (from the firing), the difference in the force impulses acting on the weapon with and without the muzzle brake would be due to a longer time, which would lead to a higher value of the muzzle brake efficiency. In period when the projectile is inside the barrel, the measurement results show a certain difference of the impulse of the recoil forces with the muzzle brake in relation to the weapon without the muzzle brake, which is conditioned by the higher total mass of the weapon and muzzle brake, and does not objectively affect the determination of efficiency.”.

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