*ISSN 1392-1207. MECHANIKA. Vol. 30, No. 1, 2024: 57–65*

# Performance Analysis of Different Firearm Suppressor Structures

**Vytautas GIEDRAITIS*, Artūras KILIKEVIČIUS****
**Department of Mechanical and Material Engineering, Faculty of Mechanical Engineering, Vilnius Gediminas Technical University, Plytinės st. 25, LT-10105 Vilnius, Lithuania, E-mail: vytautas.giedraitis@vilniustech.lt*
***Institute of Mechanical Science, Faculty of Mechanical Engineering, Vilnius Gediminas Technical University, Plytinės st. 25, LT-10105 Vilnius, Lithuania, E-mail: arturas.kilikevicius@vilniustech.lt*

https://doi.org/10.5755/j02.mech.35196

## 1. Introduction

Today, most hunting and military firearms are equipped with a type of sound suppressor. If a weapon is fired without any type of suppression system like a muzzle break, flash suppressor, or any type of sound suppressor a lot of harm may be induced to the shooter and the surrounding environment. However, most of the development of suppressors has been done to reduce the negative effects of firearm-induced sound and embrace stealth [1, 2]. The most common and probably easiest measure to reduce firearm-induced impulse sound waves is to use personal hearing protection devices. Information we have on hunting rifle suppression is very fragmented and inconclusive. Studies also look at suppression effects on the environment, whereas known suppression effects on the shooter are vague. More information on how each individual change in design affects suppression efficiency is needed. The industry standard now is to eliminate or replace the process that produces hazardous soundwaves and only then should the shooter depend on personal hearing protection as a safe alternative [3, 4].

Firearm induced sound can be classified into three categories: the explosion inside the firearm barrel, the velocity of the bullet, which, depending on the ammunition can overcome the speed of sound, and the sound of the bullet hitting the target [1, 4, 5]. The duration of the explosion in the firearm barrel takes up only a small part of a second, but the pressures are vast as is the intensity. Such very high intensity sound waves pose a significant risk to lose one's hearing [3, 6]. The general levels of impulse noise induced by firearms range from 140 dB for small rifles, 155-160 dB for medium rifles, to 160-180 dB for large rifles [3, 4, 7]. Safe levels of firearm soundwave exposure are 140 dB to adults and 120 dB to children [4].

A flash suppressor, also called a flash guard, flash eliminator, flash hider, flash cone is used to cool and dissipate gasses exiting the rifle barrel [8]. As the name suggests, it hides the flash signature of the shooter differently than a muzzle break, which is mainly used to compensate for the high recoil caused by the gun powder explosion in the firearm. We see different suppression systems being developed for all kinds of firearms like pistols, rifles, or machine guns [9]. Scientists are even evaluating possible suppression systems for tanks [10].

Usually, to achieve better acoustic results and to muffle the sound, multichambered suppressors are used. A baffle design with angled cones is the gold standard in the industry. Suppressors of this type have proven their operational reliability and shot suppression efficiency in all types of environments from professional service when using automatic rifles to light small arms of different types [11]. However, suppressor geometries can become complex, consequently making computer simulated models hard to produce [12]. Making computer simulated models proves the design much faster and cheaper and is considered a standard practice at this point. Although numerical models and simulations are widely used to prove sufficient design ideas, there are very little guidelines on how such models should be constructed [13]. Nevertheless, designs proved by computational tools may still end up not exactly matching the prototypes tested in an experiment from 1.5% to by as much as 17% [1, 14], therefore, this must be accounted in the effectiveness calculations of the suppressor.

To understand how a suppressor works and how different suppressor designs influence the ability to suppress sound is the goal to solve the problem about loud noise produced by firearms. Different features and design ideas for internal components have different effects on operating efficiency and effect [9]. Therefore, to build an efficient suppressor, one must first consider different suppressors, different design choices, advantages, and caveats before developing something truly operational and worthwhile [11, 15]. A silencer is a metal weapon attachment consisting of a shell with a whole for the bullet to pass thru and a type of baffle arrangement that muffles the sound inside of a large volume chamber to reduce the energy of exiting gasses [3, 16, 17]. Usually, we can see a silencer made from metal, aluminium, titanium [9, 11, 18]. Firearm suppressors, like all things, fall under the natural laws of physics, therefore making them larger and providing much larger surface areas to dissipate gasses, lowering the temperature and energy levels of exiting gases is a straightforward process. However, since suppressors are firearm attachments that "add to" the very end of a firearm's barrel, they carry heavy downsides, literally. If a suppressor is too long, too heavy, too big, the firearm can become cumbersome and unwieldy. Sometimes even very specific requirements such as very short length for special operation specific units are stated upfront [19].

Different possible designs of firearm silencers are considered each time an operational requirement needs to be met. However, without knowing which design choices serve the needed purposes may end up evaluating random and vastly different design choices looking for the best performing design. Usually when designing a suppressor, one must decide on the number of expansion chambers and their dimensions, baffle type and angles, gas flow type, and gas flow rates [2, 11].

During the gunshot, the bullet rapidly exits the firearm and the suppressor at the end of the barrel, leaving a hot trail of expanding gases behind it. The strong pulse sound is directional and can travel great distances harming the shooter as well as anyone or anything standing nearby [20-

22]. Studies show that suppressors can have a pulsed sound suppression effect of 17-36 dB [4, 5, 7, 9, 11, 14, 18, 19]. If coupled with personal hearing protection that offers an additional suppression effect of as much as 30 dB, even the largest of the rifles can be safely used without risk of hearing loss [3].

Studies show that suppressors sometimes have no effect on weapon automatics and regimes, as well as shot grouping characteristics, but some studies show a reduction in shooting distance of as much as 30% [1, 9, 23]. Therefore, additional research on suppressor influence on shooting at greater than 300 m. distances is warranted. Firearm suppressors, apart from dampening pulse sound waves, also eliminate muzzle flash which can cover the shooters target as well as be fatal in an armed conflict [14, 24, 25, 26]. Scientific literature indicates that bullet trajectory is affected as well as noise suppression of a non-military firearm when a suppressor is used, but insufficient evidence is provided for firearms that are not meant for military application.

A well-made, operationally proved suppressor performs in all but the worst conditions in salt fog, rain, dust, snow, icing, and in temperatures ranging from -50 degrees to as much as +50 degrees Celsius without any effect on operational performance.

Current research of suppressor efficiency is very fragmented. Even if some studies research suppressor efficiency when parameters like the number of baffles are changed, the results of suppression efficiency are inconclusive and require a larger sample size and a broader range of different parameters to be able to determine geometry traits that ensure high efficiency. The scientific novelty of this study is the broad analysis of different baffle designs with clear design indications that make the suppressor more effective. Different baffle numbers, placement angles, bending angles, and different number of separators, thus different expansion volumes are used to determine the best possible configuration. General suppressor volume, the casing were kept the same during the whole study. The article presents a computational study of more than 162 different suppressor arrangement designs. The final prototype of the most efficient suppressor is developed through CFD simulation in SolidWorks.

After the computational part of the study, a similar suppressor under the same setting is modelled and simulated. The same model is then made from 3 parts of aluminium with an actual suppressor and tested in an open shooting range. Experimental studies of the most efficient suppressors are done to evaluate and confirm the results as well as to suggest the most efficient suppressor baffle arrangement.

## 2. Computational and experimental bench methodology

Relevant available literature shows that a broader simulation of different baffle designs is required. Suppressor production and testing can be expensive, therefore computer simulation is done to narrow down the best designs. The study consists of two parts where the first one covers the computational work done with many different suppressor configurations: different number of baffles, angles, and different sizes of chamber for gas expansion. The second part aims to verify the results by creating a model with the same settings as in the computational part, making the suppressor and testing it in an open range.

The sound pressure $p$ was calculated using the Helmholtz Eq. (1) [4, 23, 27]:

$$\nabla\left(\frac{1}{\rho_0}\nabla p - q\right) + \frac{k^2 p}{\rho_0}, \quad (1)$$

where $k = 2\pi f/c$ is the wavelength, $\rho_0$ is air density, $f$ is the frequency, $c$ is the speed of sound, $p$ is sound pressure, $q$ is acceleration per unit volume. For this equation, using a parametric solver, a solution can be determined. The transmission loss of a suppressor is calculated in Eq. (2) [28]:

$$TL = 10\,log\frac{P_{in}}{P_{out}}. \quad (2)$$

$P_{in}$ and $P_{out}$ determine acoustics at the start and outlet of the suppressor. Eqs. (3) and (4) produce the acoustic effect of a suppressor [4, 23]. In is for incident wave, out is for transmitted wave:

$$P_{in} = \int \frac{p_0^2}{2\rho c_0} dA, \quad (3)$$

$$P_{out} = \int \frac{p_{tr}^2}{2qc_0} dA. \quad (4)$$

Eqs. (2) - (4) can have a varying result and the input pressure value ($p_i$) was assumed to be 101325 Pa. Sonic boundary conditions at the solid boundaries are used and further shown in Eq. (5) [28]:

$$\left(-\frac{\nabla p}{\rho}\right)n = 0. \quad (5)$$

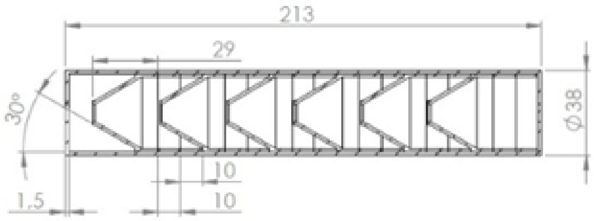
First, the computational part of this study is done using Solidworks Computational fluid dynamics (CFD) solution embedded within the Solidworks application. The goal of this paper is to strictly study unique designs and their effects on suppression efficiency. Solidworks CFD environment does all calculations automatically. Mathematical calculations are correct and well proven in the scientific community. The general idea of this study is to test as many as possible configurations while retaining some ease of interchangeability. The making of completely unique configurations may result in a small pool of test variants or take up too much time to commit to a single study. A plan for this is drawn with a total of 189 configurations (Table 1). 162 different configurations are done, where 27 possible configurations did not fit in to a given casing of the suppressor (Fig. 1, a). Table 1 is important to understand the whole scope of which ideas were tested. A broader test of multiple different ideas and their comparison to a level field, preferably in a scientific manner was needed to have a clear picture of the most important approaches to designing a suppressor. The suppressor casing was 213 mm in length and 38 mm in diameter, which is 8.5 inches and 1.5 inches respectively. Fig. 1 shows the possible design of a suppressor. Made in the typical setting that all further suppressors were modelled in. The wall thickness was set to something that can be typically found at 1.5 mm. Cones and separators mount each other on a specially made edge (it’s grinded to 90 degrees to ensure a perfect fit for all parts inside the casing. The diameter at 38 mm is typical. A larger diameter should provide more efficient suppression at the lower end of the frequency but could be problematic to the end user due to its sheer size.

The possible configurations are coded for ease of use, where the letter A followed by a number indicates the number of baffles used in the configuration, meaning A9 has a 9-baffle design, A8 has 8 baffles, A7 has 7 baffles and so on. The second component determines the angle of the baffle placed inside the suppressor, where B30 stands for a 30-degree baffle placement design, B45 stands for a 45-degree baffle placement, B60 stands for a 60-degree baffle placement (Fig. 2, c). BR1 determines that the baffle is rounded at 10 mm radius, BR2 is rounded at 20 mm radius and BR3 is rounded at 30 mm radius (Fig. 1, b). The third component from 8 to 12 determines the length of the angled or rounded part of the baffle being 8 mm or 12 mm (Fig. 1, b). The last component means the number of separators being used between each baffle. A separator is a ring with a length of 10 mm shown in Fig. 2, b. The goal of the separators is to easily lengthen or shorten the volume of each baffle enclosed space inside the suppressor. T0 means no separators are used, T1 means 1 separator is used after each baffle, T2 means that 2 separators are used after each baffle (a T2 configuration in shown in Fig. 1, a). An example would be A9B3010T0 means a 9-baffle, which are angled at 30 degrees, with a 10 mm angled part, with no separators design. All non-typical baffle designs and the separator are in Fig. 1, b.

The coding for the suppressor design configurations shown in Table 1 were made according to their physical properties and arrangement. Firstly, the number of baffles had to be indicated, together with the angle at which the baffle wall was tilted. Then a set length of 8 mm, 10 mm or 12 mm of the cone was chosen to simulate slightly non-typical design approaches and different volumes. Moreover, a non-typical approach to easily change chamber volumes was introduced from 0 to 2 units per chamber and was standardized across all tests.

This selection of design and configurations is selected due to the current solutions we see in the market. Designs with 6-9 baffles are very standard and more baffles may only be used with much bigger suppressors. Moreover, having observed that a big first expansion chamber has a great effect on suppression, baffles were placed at the end of the suppressors. This meant that the less baffles were used, the initial expansion chamber got bigger (this design trend can be seen in Fig. 2). Using less than 3 baffles is considered not efficient as is not used in the industry.

Some currently available baffle design suppressors also use bent or rounded baffles, therefore testing designs




a

b

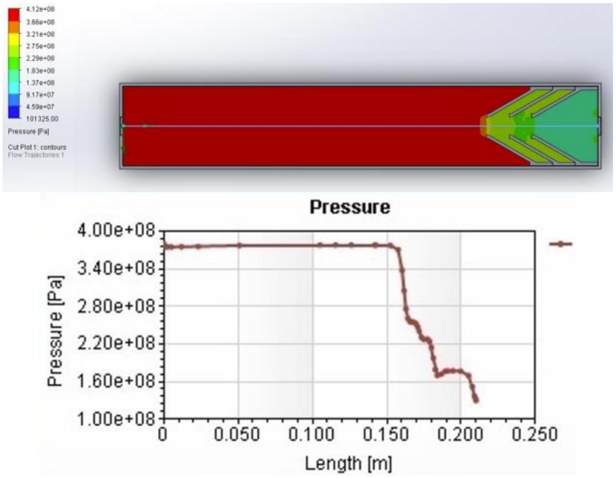
Fig. 1 Design of a 6-baffle suppressor angled at 30 degrees with 2 separators (a) and 3D model of separators and all bafflers (b)

Table 1

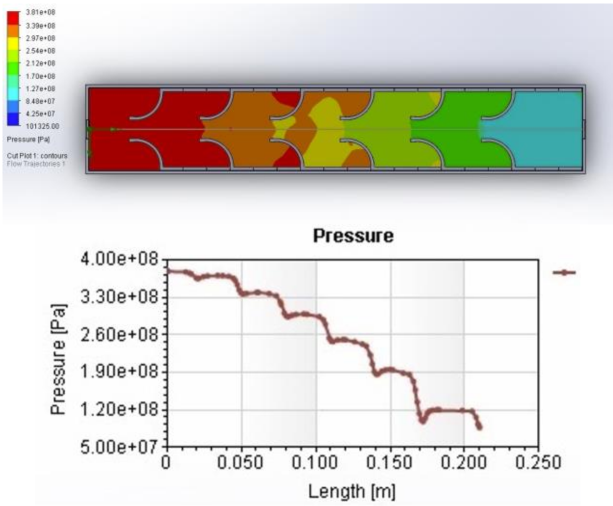
Computational test plan

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A9 | B30 | 10 | T0 | A8 | B30 | 10 | T0 | A7 | B30 | 10 | T0 | A6 | B30 | 10 | T0 | A5 | B30 | 10 | T0 | A4 | B30 | 10 | T0 | A3 | B30 | 10 | T0 |
| A9 | B30 | 10 | T1 | A8 | B30 | 10 | T1 | A7 | B30 | 10 | T1 | A6 | B30 | 10 | T1 | A5 | B30 | 10 | T1 | A4 | B30 | 10 | T1 | A3 | B30 | 10 | T1 |
| A9 | B30 | 10 | T2 | A8 | B30 | 10 | T2 | A7 | B30 | 10 | T2 | A6 | B30 | 10 | T2 | A5 | B30 | 10 | T2 | A4 | B30 | 10 | T2 | A3 | B30 | 10 | T2 |
| A9 | B45 | 10 | T0 | A8 | B45 | 10 | T0 | A7 | B45 | 10 | T0 | A6 | B45 | 10 | T0 | A5 | B45 | 10 | T0 | A4 | B45 | 10 | T0 | A3 | B45 | 10 | T0 |
| A9 | B45 | 10 | T1 | A8 | B45 | 10 | T1 | A7 | B45 | 10 | T1 | A6 | B45 | 10 | T1 | A5 | B45 | 10 | T1 | A4 | B45 | 10 | T1 | A3 | B45 | 10 | T1 |
| A9 | B45 | 10 | T2 | A8 | B45 | 10 | T2 | A7 | B45 | 10 | T2 | A6 | B45 | 10 | T2 | A5 | B45 | 10 | T2 | A4 | B45 | 10 | T2 | A3 | B45 | 10 | T2 |
| A9 | B60 | 10 | T0 | A8 | B60 | 10 | T0 | A7 | B60 | 10 | T0 | A6 | B60 | 10 | T0 | A5 | B60 | 10 | T0 | A4 | B60 | 10 | T0 | A3 | B60 | 10 | T0 |
| A9 | B60 | 10 | T1 | A8 | B60 | 10 | T1 | A7 | B60 | 10 | T1 | A6 | B60 | 10 | T1 | A5 | B60 | 10 | T1 | A4 | B60 | 10 | T1 | A3 | B60 | 10 | T1 |
| A9 | B60 | 10 | T2 | A8 | B60 | 10 | T2 | A7 | B60 | 10 | T2 | A6 | B60 | 10 | T2 | A5 | B60 | 10 | T2 | A4 | B60 | 10 | T2 | A3 | B60 | 10 | T2 |
| A9 | BR1 | 8 | T0 | A8 | BR1 | 8 | T0 | A7 | BR1 | 8 | T0 | A6 | BR1 | 8 | T0 | A5 | BR1 | 8 | T0 | A4 | BR1 | 8 | T0 | A3 | BR1 | 8 | T0 |
| A9 | BR1 | 8 | T1 | A8 | BR1 | 8 | T1 | A7 | BR1 | 8 | T1 | A6 | BR1 | 8 | T1 | A5 | BR1 | 8 | T1 | A4 | BR1 | 8 | T1 | A3 | BR1 | 8 | T1 |
| A9 | BR1 | 8 | T2 | A8 | BR1 | 8 | T2 | A7 | BR1 | 8 | T2 | A6 | BR1 | 8 | T2 | A5 | BR1 | 8 | T2 | A4 | BR1 | 8 | T2 | A3 | BR1 | 8 | T2 |
| A9 | BR2 | 8 | T0 | A8 | BR2 | 8 | T0 | A7 | BR2 | 8 | T0 | A6 | BR2 | 8 | T0 | A5 | BR2 | 8 | T0 | A4 | BR2 | 8 | T0 | A3 | BR2 | 8 | T0 |
| A9 | BR2 | 8 | T1 | A8 | BR2 | 8 | T1 | A7 | BR2 | 8 | T1 | A6 | BR2 | 8 | T1 | A5 | BR2 | 8 | T1 | A4 | BR2 | 8 | T1 | A3 | BR2 | 8 | T1 |
| A9 | BR2 | 8 | T2 | A8 | BR2 | 8 | T2 | A7 | BR2 | 8 | T2 | A6 | BR2 | 8 | T2 | A5 | BR2 | 8 | T2 | A4 | BR2 | 8 | T2 | A3 | BR2 | 8 | T2 |
| A9 | BR3 | 8 | T0 | A8 | BR3 | 8 | T0 | A7 | BR3 | 8 | T0 | A6 | BR3 | 8 | T0 | A5 | BR3 | 8 | T0 | A4 | BR3 | 8 | T0 | A3 | BR3 | 8 | T0 |
| A9 | BR3 | 8 | T1 | A8 | BR3 | 8 | T1 | A7 | BR3 | 8 | T1 | A6 | BR3 | 8 | T1 | A5 | BR3 | 8 | T1 | A4 | BR3 | 8 | T1 | A3 | BR3 | 8 | T1 |
| A9 | BR3 | 8 | T2 | A8 | BR3 | 8 | T2 | A7 | BR3 | 8 | T2 | A6 | BR3 | 8 | T2 | A5 | BR3 | 8 | T2 | A4 | BR3 | 8 | T2 | A3 | BR3 | 8 | T2 |
| A9 | BR1 | 12 | T0 | A8 | BR1 | 12 | T0 | A7 | BR1 | 12 | T0 | A6 | BR1 | 12 | T0 | A5 | BR1 | 12 | T0 | A4 | BR1 | 12 | T0 | A3 | BR1 | 12 | T0 |
| A9 | BR1 | 12 | T1 | A8 | BR1 | 12 | T1 | A7 | BR1 | 12 | T1 | A6 | BR1 | 12 | T1 | A5 | BR1 | 12 | T1 | A4 | BR1 | 12 | T1 | A3 | BR1 | 12 | T1 |
| A9 | BR1 | 12 | T2 | A8 | BR1 | 12 | T2 | A7 | BR1 | 12 | T2 | A6 | BR1 | 12 | T2 | A5 | BR1 | 12 | T2 | A4 | BR1 | 12 | T2 | A3 | BR1 | 12 | T2 |
| A9 | BR2 | 12 | T0 | A8 | BR2 | 12 | T0 | A7 | BR2 | 12 | T0 | A6 | BR2 | 12 | T0 | A5 | BR2 | 12 | T0 | A4 | BR2 | 12 | T0 | A3 | BR2 | 12 | T0 |
| A9 | BR2 | 12 | T1 | A8 | BR2 | 12 | T1 | A7 | BR2 | 12 | T1 | A6 | BR2 | 12 | T1 | A5 | BR2 | 12 | T1 | A4 | BR2 | 12 | T1 | A3 | BR2 | 12 | T1 |
| A9 | BR2 | 12 | T2 | A8 | BR2 | 12 | T2 | A7 | BR2 | 12 | T2 | A6 | BR2 | 12 | T2 | A5 | BR2 | 12 | T2 | A4 | BR2 | 12 | T2 | A3 | BR2 | 12 | T2 |
| A9 | BR3 | 12 | T0 | A8 | BR3 | 12 | T0 | A7 | BR3 | 12 | T0 | A6 | BR3 | 12 | T0 | A5 | BR3 | 12 | T0 | A4 | BR3 | 12 | T0 | A3 | BR3 | 12 | T0 |
| A9 | BR3 | 12 | T1 | A8 | BR3 | 12 | T1 | A7 | BR3 | 12 | T1 | A6 | BR3 | 12 | T1 | A5 | BR3 | 12 | T1 | A4 | BR3 | 12 | T1 | A3 | BR3 | 12 | T1 |
| A9 | BR3 | 12 | T2 | A8 | BR3 | 12 | T2 | A7 | BR3 | 12 | T2 | A6 | BR3 | 12 | T2 | A5 | BR3 | 12 | T2 | A4 | BR3 | 12 | T2 | A3 | BR3 | 12 | T2 |

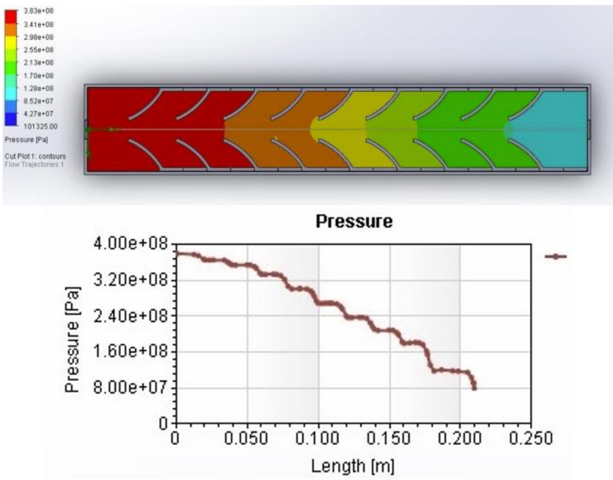
where baffles were cut with a radius of 10-30 mm were added (coded BR1 to BR3 in Table 1). Different baffle lengths as well as the addition of separators were introduced to easily expand the chambers between each baffle and to test whether the bigger chambers have a great effect on sound suppression.




a




b




c

Fig. 2 Examples of different design simulations: a - 3-baffle, 30-degree, 10 mm length without spacer; b - 6-baffle, rounded at 10 mm, 12 mm length with 2 spacers; c - 9-baffle, rounded at 30 mm, 12 mm length with 1 spacer

The drawings for the study were produced with Solidworks, the computational CFD study was also done in the Solidworks environment. The produced suppressor was made from 3 parts: the baffled part, the end, and the case. The suppressor is made from solid aluminium with a precise CNC type machine.

The experimental test was done in an open shooting range. Firearm from Steyr Mannlicher, Austria, in the 223 Rem caliber was used, together with Swarovski magnified optics. The firearm was placed on a table with two sandbags and 6 shots were attempted with and without the suppressor. The results were taken at 1 meter distance on the side from the tip of the firearm. Results were measured using a GRAS 46AC microphone. The ammunition used in the experiment were .223 Rem caliber made by GGG. Characteristics are shown in Table 2, where $V_0(E_0)$-$V_{300}(E_{300})$ are velocity and energy parameters for various distances in meters.

With this configuration of different suppressor designs, a CFD simulation in Solidworks was played. To resemble the pulse sound effect, a 380 MPa sound pressure

Table 2

Characteristics of bullets used in the research (.223 Rem; source https://www.ggg-ammo.lt/)

| Bullet weight, g/gr | | Ballistic coefficient | |
|---|---|---|---|
| 3,56 / 55 | | 0,272 | |
| Velocity, m/s | | | |
| *V* (0 m) | *V* (100 m) | *V* (200 m) | *V* (300 m) |
| 1015 | 890 | 775 | 670 |
| Energy, J | | | |
| *E* (0 m) | *E* (100 m) | *E* (200 m) | *E* (300 m) |
| 1835 | 1410 | 1075 | 800 |

a


b

Fig. 3 Measuring sound pressure when shooting with 223REM calibre bullets: a - measuring 1 m to the right of the rifle at 1 m height, b - 3 new suppressor system used during testing wave was set at the inlet of the suppressor as well as a 101325 Pa. After each simulation, a photo of the pressure displacement, as well as a chart with pressure data was saved (Fig. 2).

A Danish portable sound pressure meter model 2250 from „Bruel&Kjaer“ with a wide-range microphone model 4189 was used (Fig. 3, a). Images of the suppression systems used during shots made with 223REM caliber bullets are shown in Fig. 3, b. When measuring, 3 newly developed suppressors were used: 1 – 8-baffle, angled at 60 degrees; 2 – 7-baffles, angled at 60 degrees; 3 – 9-baffle, angled at 45 degrees.

## 3. Results of the computational and experimental study

The general differences between different suppressor performance characteristics are down to the number of baffles used, the angle at which they are placed, and the volume of each chamber the baffle produces. The larger the volume exhausting gases must lose their energy and the more effective they are caught into these chambers, the better and more efficient the suppressor becomes. Bigger overall volumes produced by a bigger overall suppressor as well as more exotic materials, special chambers made specifically for cooling purposes or to increase the overall length gasses must travel, unique configurations or shapes such as produced by artificial intelligence may result in a more efficient suppressor but are not the aim of this study.

In this study, 162 different simulations are done using the CFD solution embedded in Solidworks. All non-typical constructions have produced better results than using no suppressor in this setting, thus proving that any suppressor is better than none. The concept that CFD study is done only in the suppressor, as is not the result we observe when we measure the pulse sound with a microphone during a shot, should also be considered. Tests for all baffles were carried out and the best results achieved for different baffle designs (30-degree; 45-degree; 60-degree; rounded at 10 mm, at 8 mm and 12 mm lengths; rounded and 12 mm, at 8 mm and 12 mm lengths; rounded at 10 mm, at 8 mm and 12 mm lengths are shown in Table 3. Table 3 provides the most important information for all critical design choices. Easily understood ,at a glance, the results are shown to provide sufficient information for further analysis or for rapid design modelling or prototyping applications.

The test with a 9-baffle, angled at 30 degrees, with a 10 mm angle length and 1 separator after each baffle A9B3010T1 achieved the best result dampening the pressure from 380 MPa to 63.4Mpa, meaning from 265.575 dB to 250.021 dB respectively. This results in a 15.55 dB delta (Fig. 4).

The graph in Fig. 4 indicates that the bigger the first chamber is, the more efficiently it can suppress the large initial sound pressure wave. However, further down the suppressor, a larger number of expansion chambers prove to be more efficient than their volume.

Fig. 5. present different graphs of sound pressure, in the time and frequency domain for all 4 suppression scenarios.

Table 3

Best results achieved for different baffle designs

| Type | Arrangement | Result |
|---|---|---|
| Baffles angled at 30 degrees | A9B3010T1 | 15,55 dB |
| Baffles angled at 45 degrees | A8B4510T1 | 13,75 dB |
| Baffles angled at 60 degrees | A8B6010T1 | 14,42 dB |
| Baffles rounded at 10 mm, with a length of 8 mm | A8BR18T1 | 13,93 dB |
| Baffles rounded at 10 mm, with a length of 12 mm | A9BR112T1 | 14,10 dB |
| Baffles rounded at 20 mm, with a length of 8 mm | A6BR28T1 | 14,09 dB |
| Baffles rounded at 20 mm, with a length of 12 mm | A9BR212T1 | 14,32 dB |
| Baffles rounded at 30 mm, with a length of 8 mm | A9BR38T1 | 12,63 dB |
| Baffles rounded at 30 mm, with a length of 12 mm | A9BR312T1 | 13,63 dB |

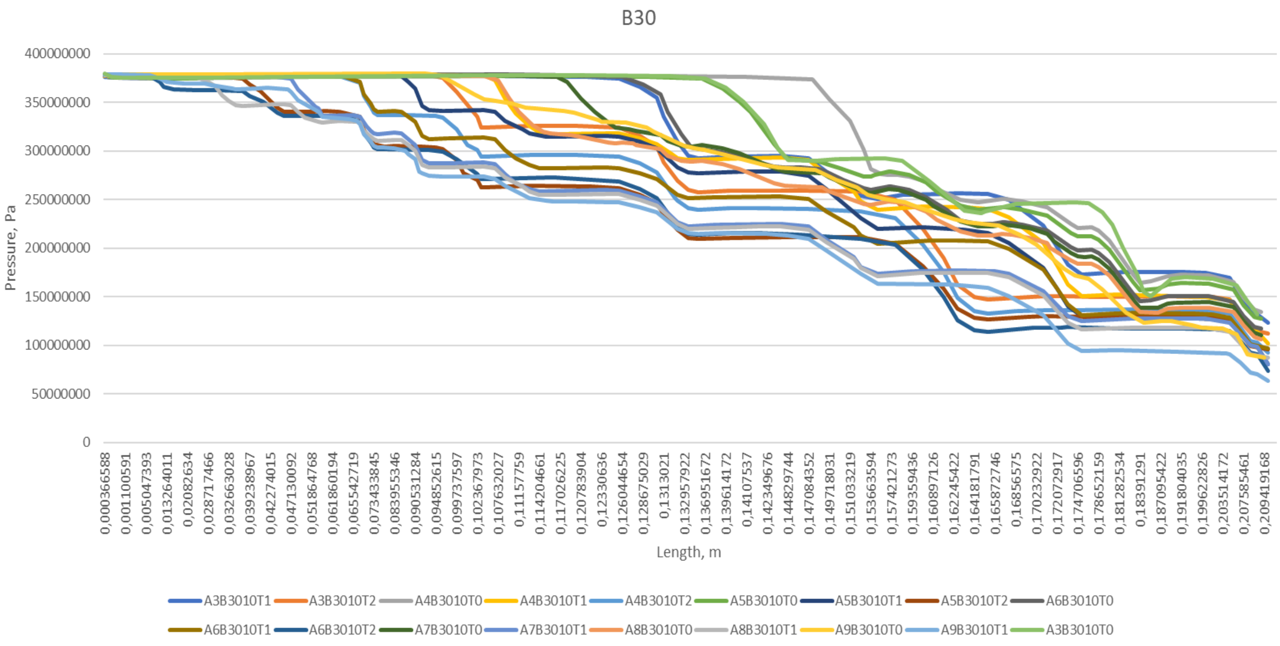
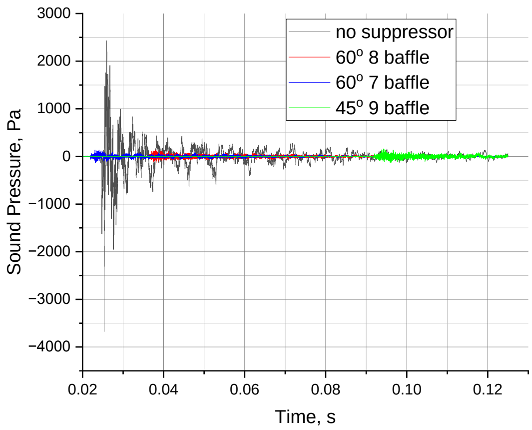
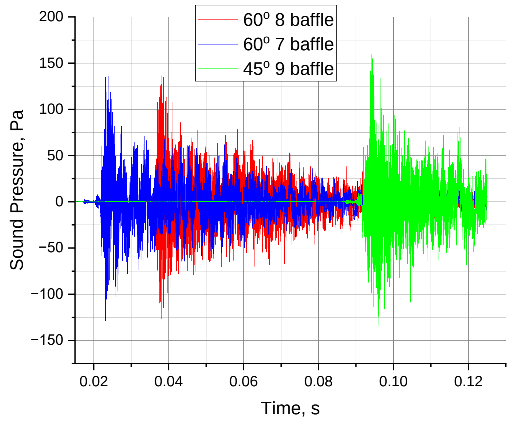



Fig. 4 Test results graph for the 30-degree angled baffle design suppressor

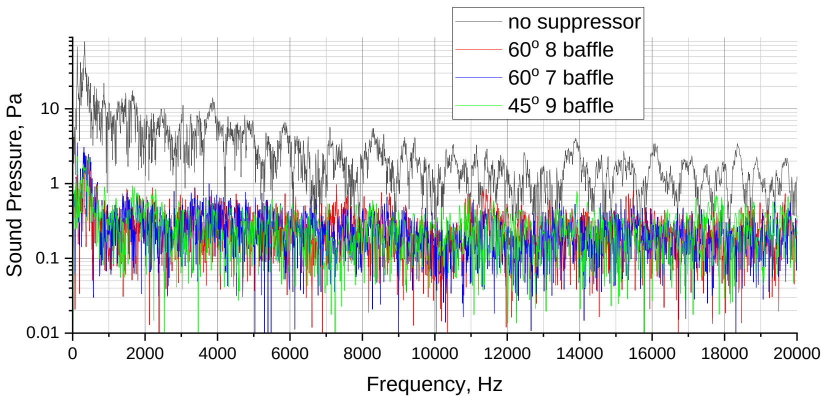
In Fig. 5, b, the sound suppression scenario without a suppressor is taken out and the sound pressure scale is narrowed out to better reflect the differences in sound suppression effectiveness using different sound suppressor geometries over a period of time. Fig. 5, c shows different sound pressure displacement in the frequency domain when all 4 suppression scenarios are present. In Fig. 5, d sound suppression scenario without a suppressor is taken out and the frequency range is shortened from 20 kHz to 2 kHz. to better reflect the differences in sound suppression effectiveness using different sound suppressor geometries over a specific frequency range. Different color lines shown in Fig. 5 show 4 different sound pressure measurement scenarios: 1 – when no suppressor is used (black curve); 2 – when an 8-baffle, angled at 60° suppressor is used (red curve); 3 – when a 7-baffle, angled at 60° suppressor is used (blue curve); 4 – when a 9-baffle, angled at 45° suppressor is used (green curve).



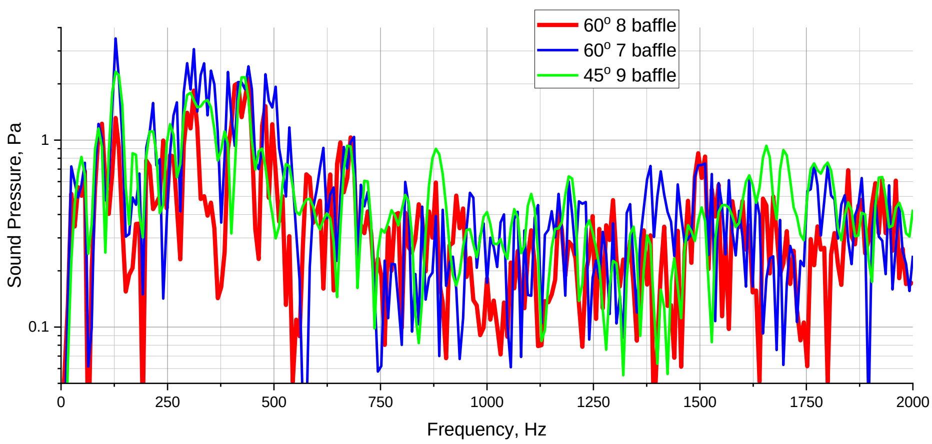

a




b




c




d

Fig. 5 Graphs of sound pressure distribution in the suppressor: a - distribution of sound pressure in the time domain for various scenarios, b - distribution of sound pressure in the time domain without the data of the unsuppressed shot, c - distribution of sound pressure in the frequency domain for various scenarios up to 20 kHz and d - distribution of sound pressure in the frequency domain for various scenarios up to 2 kHz without the data of the unsuppressed shot

Judging by the sound pressure results shown in Fig. 5, in the frequency band up to 20000 Hz, the main high values of sound pressure amplitudes (without suppressors) are in the frequency range up to 4000 Hz. The maximum values are in the frequency range from 0 to 400 Hz and reach up to 81.0 Pa. When evaluating the obtained sound pressure amplitude values, the three frequencies (128, 216 and 328 Hz) with the highest amplitudes were determined. Corresponding to the set frequencies, when using an 8-baffle, angled at 60° suppressor, the decrease in sound pressure values, compared to shots done without a suppressor, were 87.6 (at a frequency of 128 Hz), 104.5 (at a frequency of 216 Hz) and 157.6 (at a frequency of 328 Hz) times lower. When a 7-baffle, angled at 60° suppressor is used, the decrease in sound pressure amplitudes, compared to the case without a suppressor, were 19.3 (at a frequency of 128 Hz), 26.1 (at a frequency of 216 Hz) and 30.3 (at a frequency of 328 Hz) times lower. When 9-baffle, angled at 45 degrees suppressor is used, the reduction of sound pressure amplitude, compared to the case without a suppressor, was 29.1 (at a frequency of 128 Hz), 26.1 (at a frequency of 216 Hz) and 52.5 (at a frequency 328 Hz) times lower. Evaluating the reduction of the sound pressure amplitudes in the time graph when suppressors are used, of the newly developed 8-baffle, angled at 60°, the suppressor was found to have the greatest effect on the sound pressure values and a decrease of 23.2 times compared to the case without a suppressor. Using the newly developed 7-baffle, angled at 60° suppressor, a very similar reduction of 23.1 times was obtained. Accordingly, using the newly developed 9-baffle, angled at 45 degrees suppressor, a very similar reduction of 20.7 times was obtained. Most of the pressures that can be observed at frequencies over 5000 Hz are not that important since hearing loss or other damage usually happens below this threshold. Correctly, the unified sound pressure values and sound pressure values in the 20 Hz to 4000 Hz frequency zones are most important. The dampened sound pressure values at the lower frequency range indicate the correct decision for great overall sound suppression results. In this case, the 8-baffle, angled at 60° suppressor at the high peak frequency range from 0 Hz to 400 Hz proved to be the most effective.

The initial, large scope non-typical modelling study in Solidworks CFD was done separately. They provide ample information for further research of hunting rifle suppressors. To prove the results achieved with the Solidworks CFD simulation, separate CFD suppressor models of the tested engineering samples were made with the same settings as in all other CFD models. Engineering samples were made earlier than the Solidworks CFD modelling study and was the proof that we could produce highly effective, non-typical hunting firearm suppressors. According to the CFD simulation embedded in Solidworks, the newly developed suppressor engineering samples should dampen the exhaust pressure from 380 MPa to 10.96 MPa which would result in suppression from 265.57 dB to 234.77 dB respectively with a delta of 30,8 dB. Such results, achieved in the same environmental conditions are in line with the efficiency results that were expected from these types of designs. A suppression efficiency of more than 30 dB makes most non-military rated rifles safe to use in a leisure environment (only for adults). Engineering samples for suppressor testing were made according to previous research results. The Solidworks CFD study had great insights with a large enough sample size of non-typical designs , therefore a way of confirming the concept with additional Solidworks CFD models was chosen.

According to the measurements recorded with the GRAS 46AC microphone during the shooting in an open shooting range, the result was 155 dB unsuppressed and 122,76 dB with the suppressor, averaged from 6 shots taken with the suppressor with a delta of 32,24 dB. This puts the delta of 30,8 dB from the computational part by 4,67% of one another, as in line with the results shown in previous studies and articles.

The suppressor created in this study is intended for hunters and people who shoot for pleasure. The suppressor positively effects the recoil, kickback, and noise levels. Most of the suppression effects the shooter but not the environment in front of the barrel. The suppression effect on the direct environment is about 30 %, which may classify this suppressor not for use in a military application. Producing the whole line of CFD simulated suppressor models would be highly inefficient, therefore a prototype proof of concept is a sufficient approach to achieve high suppression research results.

The best result achieved by CFD simulation of the 162 design configurations was 15,55 dB, but the results achieved with the new suppressor was 30,8 dB and 32,24 dB (CFD simulation and experiment respectively). This discrepancy is due to a design difference in the initial part of the silencer. Fig. 3 clearly shows how the newly developed suppressor has an initial chamber, extends even backwards to the firearm barrel, and has an additional cone covering the entrance to the chamber (Fig. 3). Fig. 5 clearly shows a massive 170 MPa drop in pressure due to the initial chamber effect. Therefore, a combination of the best design configuration in CFD simulation with the large initial chamber extending over the firearm barrel would probably produce the best result but must be confirmed with further research.

## 4. Conclusions

Out of all CFD models made to understand the effects to suppression efficiency when certain geometry changes are made, the suppressor model with a 9-baffle, angled at 30 degrees and 1 separator after each baffle achieved the best results, dampening the sound pressure from 380 MPa to 63.4 MPa inside the suppressor, or from 265.575 dB to 250.021 dB respectively. To verify the suppression results of the large-scale CFD model study, a suppressor model in the same CFD environment and an actual prototype were made and tested. The highest achieved suppression result of the new CFD modelled suppressor was 30.8 dB. Sound pressure results of the prototype taken from a microphone, placed at a 1-meter distance to the side of the tip of the firearm measured 122.76 dB (averaged out after 6 shots). 32.24 dB effectiveness of the suppressor prototype was achieved and was only 4.67 % different than the result presented by the CFD model, which was 30.8 dB, respectively. CFD model and live fire testing research indicates that first, the large initial suppressor chamber is very efficient. Research also shows, when using a 8-baffle, angled at 60° suppressor, decrease in sound pressure values up to 400 Hz, compared to shots done without a suppressor, were 87.6 (128 Hz), 104.5 (216 Hz) and 157, 6 (328 Hz) times lower and proved the most effective.

## References


1. **Huerta-Torres, J.; Silva-Rivera, U.; Verduzco-Cedeño, V.; Flores-Herrera, L.; Sandoval-Pineda, J. M.** 2021. Numerical and Experimental Analysis of Sound Suppressor for a 5.56 mm Calibre, Defence Science Journal 71: 12-17. https://doi.org/10.14429/dsj.71.14957.
2. **Li, Y.; Xu, H.; Gu, G.; Guo, Y.; Wang, B.** 2023. A review of stability control algorithms for weapon platforms. Journal of Physics: Conference Series. 2460. 012025. https://doi.org/10.1088/1742-6596/2460/1/012025.
3. **Tasko, S.M.; Murphy, W.J.; Flamme, G.; Deiters, K.K.; Finan, D.S.; Meinke, D.K.; Lankford, J.E.; Stewart, M.** 2022. When is a firearm suppressor like a hearing protector?, The Journal of the Acoustical Society of America 152: A162. https://doi.org/10.1121/10.0015888.
4. **Murphy, W.; Flamme, G.; Campbell, A.; Zechmann, E.; Tasko, S.; Lankford, J.; Meinke, D.; Finan, D.; Stewart, M.** 2018. The reduction of gunshot noise and auditory risk through the use of firearm suppressors and low-velocity ammunition, International Journal of Audiology 57:sup1, S28-S41. https://doi.org/10.1080/14992027.2017.1407459.
5. **Pääkkönen, R.; Jussila, J.** 2011. A suppressor for indoor shooting sites, Applied Acoustics 72(9): 684-687. https://doi.org/10.1016/j.apacoust.2011.02.004.
6. **Tasko, S.; Deiters, K.; Finan, D.; Flamme, G.; Lankford, J.; Meinke, D.; Murphy, W.; Stewart, M.** 2023. Approaches to Measuring Noise Reduction of Firearm Suppressors. Poster in National Hearing Conservation Association (NHCA) Annual conference.
7. **Murphy, W.; Campbell, A.; Flamme, G.; Tasko, S.; Lankford, J.; Meinke, D.; Finan, D.; Stewart, M.; Zechmann, E.** 2018. Developing a method to assess noise reduction of firearm suppressors for small-caliber weapons, Proceedings of Meetings on Acoustics 33(1): 040004. https://doi.org/10.1121/2.0001132.
8. **Tatiya, H.; Jadhao, V.; Taware, A.; Bandgar, A.** 2016. Patterned Injury Due to Flash Suppressor: A Case Report, Indian Journal of Forensic Medicine & Toxicology 10(1): 126-128.
9. **Pylypenko, O. V.; Konovalov, N. A.; Kovalenko, V. I.; Semenchuk, D. V.** 2020. Monoblock silencers for pistols, Technical mechanics 3: 3-11. https://doi.org/10.15407/itm2020.03.003.
10. **Rehman, H.; Hwang, S.H.; Fajar, B.** 2011. Analysis and attenuation of impulsive sound pressure in large caliber weapon during muzzle blast, Journal of Mechanical Science and Technology 25: 2601–2606. https://doi.org/10.1007/s12206-011-0731-2.
11. **Pylypenko, O.V.; Konovalov, N.A.; Kovalenko, V.I.; Semenchuk, D.V.** 2021. Compact silencers with discrete baffle elements for new-generation light small arms, Technical mechanics 4: 18-28. https://doi.org/10.15407/itm2021.04.018.
12. **Chiu M.C., Chang Y.C.** 2023. Numerical assessment of gun mufflers using finite element method, neural networks, and a genetic algorithm, Noise & Vibration Worldwide 54(4-5): 224-234. https://doi.org/10.1177/09574565231161651.
13. **Kyaw Oo D'Amore, G.; Morgut, M.; Biot, M.; Mauro, F.** 2022. Numerical study on the influence of porous baffle interface and mesh typology on the silencer flow analysis, Marine Systems & Ocean Technology 17: 71-79. https://doi.org/10.1007/s40868-022-00114-1.
14. **Pylypenko, O.V.; Konovalov, N.A.; Kovalenko, V.I.; Semenchuk, D.V.** 2019. Submachine gun and rifle silencers with a type Multi-Y front cover, Technical mechanics 3: 5-15. https://doi.org/10.15407/itm2019.03.005.
15. **Kovalchuk, O.; Skorohvatov, O.; Galkin, A.** 2019. Sound suppressors for small arms with an advanced expansion camera. Collection of scientific works of Odesa Military Academy 1: 19-29. https://doi.org/10.37129/2313-7509.2019.12.1.19-29.
16. **Murphy, W.; Campbell, A.; Flamme, G.; Tasko, S.; Lankford, J.; Meinke, D. Finan, D.; Zechmann, E.; Stewart, M.** 2018. The attenuation of firearm suppressors as a function of angle and bullet velocity, Presentation to National Hearing Conservation Association. https://doi.org/10.13140/RG.2.2.16091.87842.
17. **Murphy, W.; Flamme, G.; Tasko, S.; Finan, D.; Meinke, D.; Lankford, J.; Stewart, M.** 2022. Comparisons of auditory risk metrics with suppressed and unsuppressed civilian firearms, The Journal of the Acoustical Society of America 152: A161-A161. https://doi.org/10.1121/10.0015887.
18. **Pylypenko O. V; Konovalov N. A.; Kovalenko V. I.; Semenchuk D. V.** 2019. Silencers for flowback pistols. Technical mechanics 1: 5-15. https://doi.org/10.15407/itm2019.01.005.
19. **Pylypenko, O.V.; Konovalov, N.A.; Kovalenko, V.I.; Semenchuk, D.V.** 2020. Small-size silencers for stub-barreled arms, Technical mechanics 4: 3-12. https://doi.org/10.15407/itm2020.04.003.
20. **Selech, J.; Kilikevičius, A.; Kilikevičienė, K.; Borodinas, S.; Matijošius, J.; Vainorius, D.; Marcinkiewicz, J.; Staszak, Ž.** 2020. Force and Sound Pressure Sensors Used for Modeling the Impact of the Firearm with a Suppressor, Applied Sciences 10(3): 961. https://doi.org/10.3390/app10030961.
21. **Suyadnya, K.; Tarwidi, D.; Setiawan, E.; Umbara, R.** 2019. Numerical Modeling of Heat Transfer in Gun Barrel with Experimental Validation, International Journal of Engineering & Technology 8(1.9): 62-66.
22. **Hristov, N.; Kari, A; Jerković, D.; Savić, S.** 2018. Application of a CFD Model in Determination of the Muzzle Blast Overpressure in Small Arms and Its Validation by Measurement, Tehnicki Vjesnik 25(5): 1399-1407. https://doi.org/10.17559/TV-20180321135212.
23. **Elsayed, A.; Bastien, C; Jones, S.; Christensen, J.; Medina, H.; Kassem, H.** 2017. Investigation of baffle configuration effect on the performance of exhaust mufflers, Case Studies in Thermal Engineering 10: 86-94. https://doi.org/10.1016/j.csite.2017.03.006.
24. **Badurowicz, P.; Wiśniewski, A.; Jasiński, M.; Pacek, D.; Szczurowski, K.; Wolinski, M.; Bartkowiak, T.** 2022. Analysis of Ignition Capability of Flammable Gases from Small Arms Propellant Gases, Problems of Mechatronics. Armament, Aviation, Safety Engineering 13(4): 39-50. https://doi.org/10.5604/01.3001.0016.1455.

25. **Krieg, J.; Eisele, C.; Seiffer, D.** 2016. Electro-optical muzzle flash detection, ELECTRO-OPTICAL AND INFRARED SYSTEMS: TECHNOLOGY AND APPLICATIONS XIII, Proceedings of SPIE, 9987: 9987A. https://doi.org/10.1117/12.2240777.
26. **Yan, C.G; Zhu, C.G** 2023. Quantitative assessment method of muzzle flash and smoke at high noise level on field environment, Scientific Reports 13(1): 1480. https://doi.org/10.1038/s41598-023-27722-0.
27. **Zeynep P.; Şengül A.; Rıfat Y.; Erdem Ö.; Arda K.** 2013. Acoustic and Flow Field Analysis of a Perforated Muffler Design, World Academy of Science, Engineering and Technology: 11998. https://doi.org/10.5281/zenodo.1078334.
28. **Amuaku, R.; Amoah A. E.; Edward, A.; Bright G. G.** 2019. Effects of Chamber Perforations, Inlet and Outlet Pipe Diameter Variations on Transmission Loss Characteristics of a Muffler Using Comsol Multiphysics, Advances in Applied Sciences 4(6): 104-109. https://doi.org/10.11648/j.aas.20190406.11.


V. Giedraitis, A. Kilikevičius

PERFORMANCE ANALYSIS OF DIFFERENT FIREARM SUPPRESSOR STRUCTURES


S u m m a r y

A powerful soundwave from shooting a firearm can travel great distances harming the shooter as well as anyone or anything standing nearby. To address this, a non-typical firearm suppressor is used. A suppressor muffles the soundwave to a level that is usually safe for the shooter and its environment. A suppressor usually has 3-4 main parts that highly influence its effectiveness. The study aims to investigate how non-typical baffle design and placement selection influence the suppressor effectiveness. The study consists of 162 different non-typical baffle design configurations. Suppressors with 3 to 9 baffles, angled from 30 to 60 degrees as well as rounded from 10 mm to 30 mm radius, are simulated in a CFD environment. Suppressors with the best designs were then produced and evaluated on a firing range. At the firing range, a result of 32.24 dB delta was achieved and was only 4,67% different than the result presented in the CFD study, which was 30.8 dB, respectively. The 9 straight geometry baffle, angled at 30 degrees, suppressor, with an average chamber volume proved to be the most efficient and combined with a large initial chamber was the most efficient design in this study.



**Keywords:** suppressor, baffle, firearm suppression, suppressor structure.

Received September 25, 2023
Accepted February 15, 2024