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Research Article

Effect of the Same Sized Holes with Different Geometries and Angles in the Gun Silencer Diffusers on the Acoustic Power Level

Dilsad AKGUMUS GOK[1*], Serkan GOK[2], Serkan KILICTEK[2]

[1] Mechanical Engineering Department, Istanbul Aydin University, Istanbul, Türkiye

[2]Machine and Metal Technologies Department, Istanbul Aydin University, Istanbul, Türkiye

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Abstract
The bullet, which is activated by the firing of the gunpowder in the gun silencer, comes out of the gun's barrel. In the meantime, an irritating muzzle blast sound is heard that lasts for a few milliseconds. With this explosion, acoustic sound waves are formed that are independent of the bullet's path of motion. In this study, silencer that can be attached to a low-power 9 mm firearm is modelled. Afterward, the impact of holes with the same area drilled in different geometries and angles on the diffusers (compartments) of the silencer are compared. The Computational Fluid Dynamics (CFD) analysis method is used for this comparison. In addition, the dynamic mesh model is used where the ballistic field changes over time. This mesh model is analyzed for imperforate, circular-holed, square-holed, and triangular-holed profiles with the same area. Depending on the analyses, the pressure, velocity, and dB results obtained for the silencer outlet area are compared with each other.

Keywords: Silencer diffusers, Acoustic power, CFD analysis

Silah Susturucu Difüzörlerinde Aynı Boyuttaki Farklı Geometri ve Açılardaki Deliklerin Akustik Güç Seviyesine Etkisi

Öz
Silah susturucusunda barutun ateşlenmesi ile harekete geçen mermi silahın namlusundan çıkmaktadır. Bu esnada birkaç milisaniye süren rahatsız edici namlu ağzı patlama sesi duyulmaktadır. Bu patlama ile merminin hareket yolundan bağımsız olan akustik ses dalgaları oluşmaktadır. Bu çalışmada düşük güçlü 9 mm'lik bir ateşli silaha bağlanması gereken susturucu modellenmiştir. Sonrasında susturucunun difüzörlerine (bölmelerine) aynı alana sahip olan farklı geometrilerde ve açılarda açılan deliklerin etkileri karşılaştırılmıştır. Bu karşılaştırma için Hesaplamalı Akışkanlar Dinamiği (CFD) analiz yönteminden yararlanılmıştır. Ayrıca balistik alanın zamanla değiştiği yerlerde de dinamik ağ modeli kullanılmıştır. Bu ağ modeli aynı alana sahip olan deliksiz, dairesel delikli, kare delikli ve üçgen delikli profiller için analiz edilmiştir. Analizler bağlı olarak susturucu çıkış alanı için elde edilen basınç, hız ve dB sonuçları birbirleri ile kıyaslanmıştır.

Anahtar Kelimeler: Susturucu difüzörleri, Akustik güç, CFD analizi

Corresponding Author: dilsadakgumus@aydin.edu.tr
Dilsad AKGUMUS GOK, https://orcid.org/0000-0003-3403-3815
Serkan GOK, https://orcid.org/0000-0003-3238-6705
Serken KILICTEK, https://orcid.org/0000-0001-6325-7055

1. Introduction

With the development of technology, the means of attack and defense have also progressed correspondingly. In the early ages, people used stones, sticks, or sharpened tools to protect themselves, and with the discovery of gunpowder, firearms replaced them. Soysal examined the effects of silencers on gunshot residues in his study. As a result of this study, it was observed that with silencer, weapon residues spread to lower ranges than without silencer [1]. In her thesis study, Mutlum changed the location of the blades and made changes in the number of partitions in a reactive silencer with flat baffles. She analyzed the sound losses of the different models obtained in the Matlab program and then reached the experimental data with an acoustic impedance test tube [2]. Özkan et al. must be investigated the effects of a reactive silencer interior design on acoustic and flow. The acoustic and flow performance of the silencer was observed by changing only the perforation length measurements without making any changes in the outer dimensions of the silencer. In the interior design of the silencer, perforation length, hole diameter, and number were used as parameters [3]. Zengin focused on the correct design of the sections in the silencer. It was aimed to model the silencer without incurring pressure losses [4]. Arslan et al. designed a silencer system to prevent exhaust noise. The effects of the position and number of the silencer baffles on the sound transmission loss were investigated theoretically [5].

Decibel is defined as the change in sound on a logarithmic scale. The sound frequency range that a healthy person can hear is between 20 – 20000 Hz. The hearing of the person exposed to high decibel sound may be damaged and even hearing loss may occur [6]. The appropriate hearing frequency is 1200 Hz. Noise reaching a frequency of 140 Hz in sudden bursts of sound causes permanent hearing loss in a normal person [7]. The equation expressing the sound pressure level in decibels is given in Equation 1.

$$Lp = 10 \log \left[\frac{P}{P_0}\right]^2 \tag{1}$$

Firing of the gunpowder causes high pressure and as a result, high noise occurs when the bullet leaves the barrel [8]. This high frequency sound is undesirable in some special cases and silencers are used to reduce it.

In this study, a silencer that can be connected to a 9 mm firearm is modelled. Holes with different geometries and angles are drilled on the modelled silencer diffuser and the design with the lowest noise level is determined with the help of computational fluid dynamics.

2. Material And Methods

2.1. Weapon Silencers

Firearms are one of the important examples of sound pressure waves that occur during the explosion of weapons. With the emergence of firearms, many types of weapons have been invented. With the firing of these guns, a great noise arises. This noise includes firing sound, orbital sound, and explosion sound at target. For the firearms to be effective, the design of the firing mechanism and the prevention of pressure losses are very important [9]. For firearms, the bullet must come out of the barrel at a certain speed to cause the necessary damage. The gunpowder fired inside the barrel ensures this speed.

The basic principle of firearms is based on the conversion of chemical energy into kinetic energy. The gunpowder that provides the ignition creates the chemical energy in the gun. With the explosion of gunpowder inside the barrel, rapid gas expansion occurs in the barrel. These gases cause an increase in pressure and temperature inside the barrel. With this pressure, the bullet starts its first movement and this movement continues along the barrel by increasing its speed [10]. The sudden sound frequency emanating from the weapon during the explosion varies between approximately 140 - 180 Hz. There are two main reasons for this sound, which occurs with a pressure wave, as the short-term formation and high amplitude [11].

The silencer is defined as the apparatus attached to the end of the barrel in order to reduce the loud sound produced by the gun during firing. With the use of the silencer, it becomes difficult to detect the point where the gun is fired [12]. Silencers are generally divided into three classes as dispersive, reactive, and hybrid. Dispersive silencers work according to the principle of reducing acoustic pressure fluctuations by converting sound energy into heat energy. Reactive silencers reduce noise depending on the geometric shape of the perforated pipes and expansion chambers inside. Today, reactive silencers are widely preferred [14]. Hybrid silencers, on the other hand, consist of a combination of reactive and dispersive silencers. This type of silencer has perforated pipes, expansion chambers, and insulation materials, thereby reducing the resulting ignition noise [13]. When choosing a silencer, it is necessary to pay attention to the sound frequency range, interior design, and purpose of use of the silencer.

Silencers need an expansion chamber and extra chambers to prevent the resulting noise [15]. In order for the silencers used in firearms to fulfill their aims, their volume should be approximately 20-30 times the barrel length and diameter of the weapon. In this way, sudden gas escape is prevented by reducing the high-pressure gas coming out of the barrel in the chambers inside the silencer. In addition, the volume and geometric shapes of the pressure inlet holes are also important factors in preventing noise [8]. The desired effect of silencers is not only dependent on the design of the silencer. The barrel length and diameter of the gun are directly related to the type of ammunition, amount, and type of gunpowder, namely the technical features of the gun used. Although silencers are very effective in reducing noise, they have a negative effect on the muzzle velocity of the bullet [16]. The following formulas are used to calculate the barrel pressure and bullet velocity in weapon systems [17]. Equations 3 and 4 are obtained by making Newton's second law of motion, which is equation 2, applicable to weapon systems.

$$\sum F = 0 = ma = m\frac{d^2x}{dt^2} \tag{2}$$

$$F = ma = PA \rightarrow F = m\frac{d^2x}{dt^2} = m\frac{dv}{dt} \tag{3}$$

$$\frac{d^2x}{dt^2} = \frac{dv}{dt}\,, \qquad \frac{dv}{dt} * \frac{dx}{dx} = \frac{dx}{dt} * \frac{dv}{dx} = V\frac{dv}{dx} \tag{4}$$

Newton's second law of motion formula in Equation 5 is developed and the energy formula in Equation 6 is derived.

$$F = m\frac{dv_p}{dt} = mv_p\frac{dv_p}{dx_p} = P_pA \tag{5}$$

$$mv_p\frac{dv_p}{dx_p} = P_pA \;\rightarrow\; mv_p\,dv_p = P_pAdx_p \tag{6}$$

$$\int mv_p\,dv_p = \int_{i=0}^{L} P_pAdx_p \tag{7}$$

Equation 8, equation 9, and equation 10 are formed by drawing the average pressure value from equation 7.

$$\frac{1}{L}\int_{i=0}^{L} P_pdx_p = Average\ Pressure = \bar{P} \tag{8}$$

$$\frac{1}{2}mv_p^2 = A\int_{i=0}^{L} P_pdx_p = A\bar{P}_p\,L \tag{9}$$

$$\bar{P}_pL = \int_{i=0}^{L} P_pdx_p \tag{10}$$

Finally, the formulas of barrel pressure and bullet velocity are obtained as in equation 11 and equation 12.

$$V_p = \left(\frac{2\bar{P}AL}{m}\right)^{1/2} \tag{11}$$

$$\bar{P} = \frac{mv_p^2}{2AL} \tag{12}$$

A verification factor is applied to the equation in order to show results close to the true value without including other variables that will affect the results such as bullet friction, rotational energy, and heat transfer into the equation [17]. The formulas with the verification factor are shown in equation 13 and equation 14.

$$V_p = \left(\frac{2P_mAL}{C_fm}\right)^{1/2} \tag{13}$$

$$P_m = \frac{C_f m v_p^2}{2AL} \tag{14}$$

The average pressure is approximately 25% of the maximum pressure. SAAMI maximum bullet pressure (Pm) or maximum pressure is used in the equations. Therefore, a correction factor of 0.25 is applied to the equations. The maximum pressure equations, adjusted using a correction factor of 0.25, are given in equation 15 and equation 16 [17].

$$V_p = 2\left(\frac{2P_m AL}{m}\right)^{1/2} \tag{15}$$

$$P_m = \frac{m v_p^2}{8AL} \tag{16}$$

2.2. Design and Analysis

In this study, the Solidworks program is used for silencer design and Solidworks Flow Simulation for analysis. The designed silencer has expansion chambers. Expansion chambers are separated from each other by diffusers. The silencer design is shown in Figure 1. In the design, 8 diffusers are used and there are 10 expansion chambers.

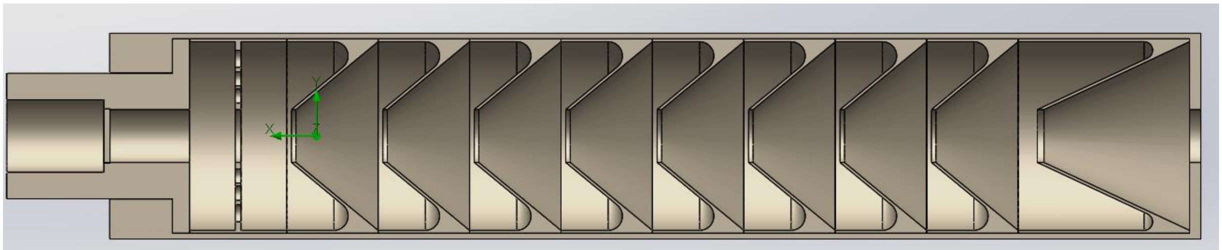

Figure 1. Analyzed silencer design

Square, circular, and triangular profiled holes with an area of 16 mm^2 are drilled perpendicularly to the angled area of the designed diffusers. These holes are drilled to examine their effects on acoustic power levels. In Figure 2, the designs of diffusers with different geometries are shown.

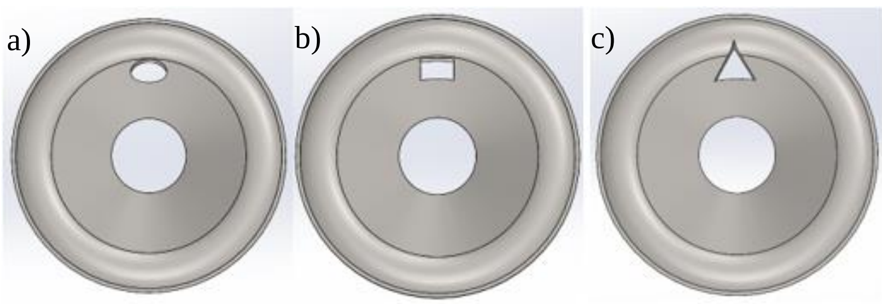

Figure 2. View of a) circle, b) square and c) triangular holes on the designed diffusers

Configurations are created in the silencer assembly so that the drilled holes are aligned, 30° and 45° angled. Figure 3 shows these configurations.

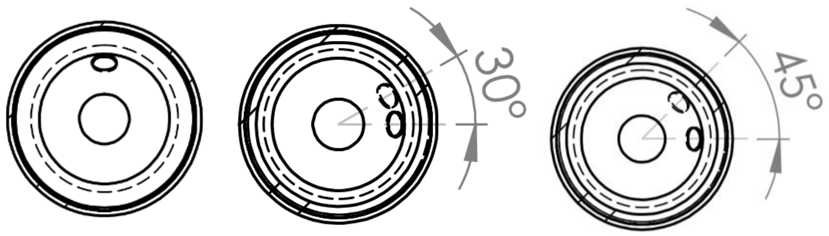

Figure 3. Configurations of holes at different angles

The maximum pressure formed in the barrel of a 9 mm firearm within 0.05 seconds is determined as 2,4x10^{-8} Pa, as seen in Figure 4. In the study, the effects of the diffuser configurations in the silencer design and the original configuration without holes on the acoustic power level (dB) are compared and examined in the findings section.

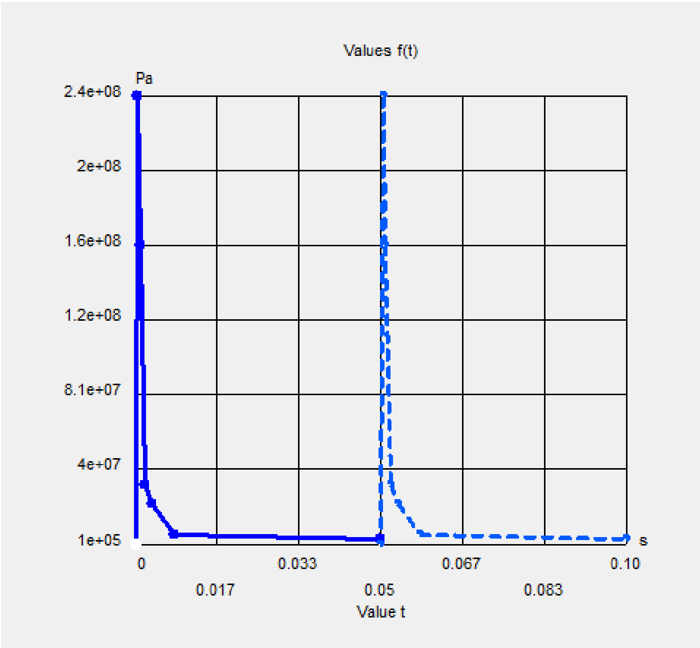

Figure 4. The change of the pressure coming out of the barrel over time

3. Results and Discussion

Within the scope of the study, a silencer design with expansion chambers used in 9 mm firearms is made in the Solidworks program. The cutaway view of the designed silencer is shown in Figure 5.

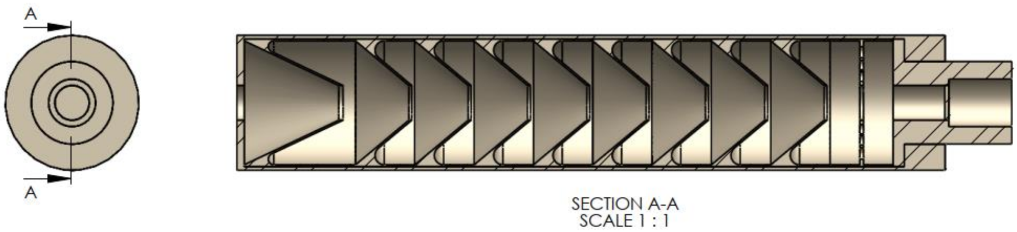

Figure 5. Cutaway view of the designed silencer

Holes in three different geometric shapes with an area of 16 mm^2 are drilled onto the diffusers of the designed silencer model, and different mounting configurations are created so that these holes are aligned and at different angles (30° and 45°). Pressure values that will occur within 0.05 seconds at the muzzle for 10 silencer models, including the imperforate silencer design, are entered with the Solidworks Flow Simulation program depending on time. The silencer outlet is treated as ambient pressure.

As a result of the analysis applied to the design of the silencer without holes on the diffusers, the cutaway view of the acoustic power level inside the silencer is shown in Figure 6.

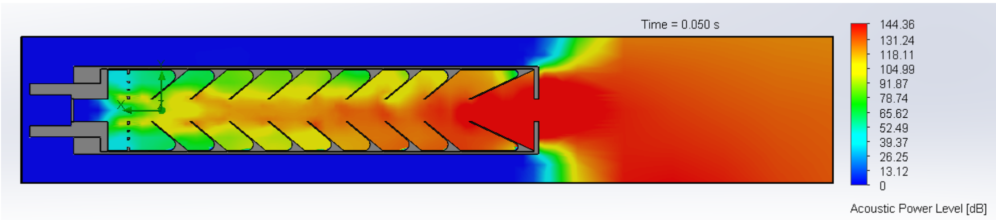

Figure 6. Acoustic power level analysis of the silencer without holes on its diffusers over time

The time-depended acoustic power level analysis of the silencer design with no holes on the diffusers is given in Figure 7. The maximum acoustic power level at the silencer output was 144.36 dB in 0.003 sec, and the minimum acoustic power level was 129.88 dB in 0.002 sec. The average acoustic power level within 0.05 seconds was determined as 138.14 dB. After 0.01 sec, there was not much fluctuation in the acoustic power level, it remained at the average acoustic level.

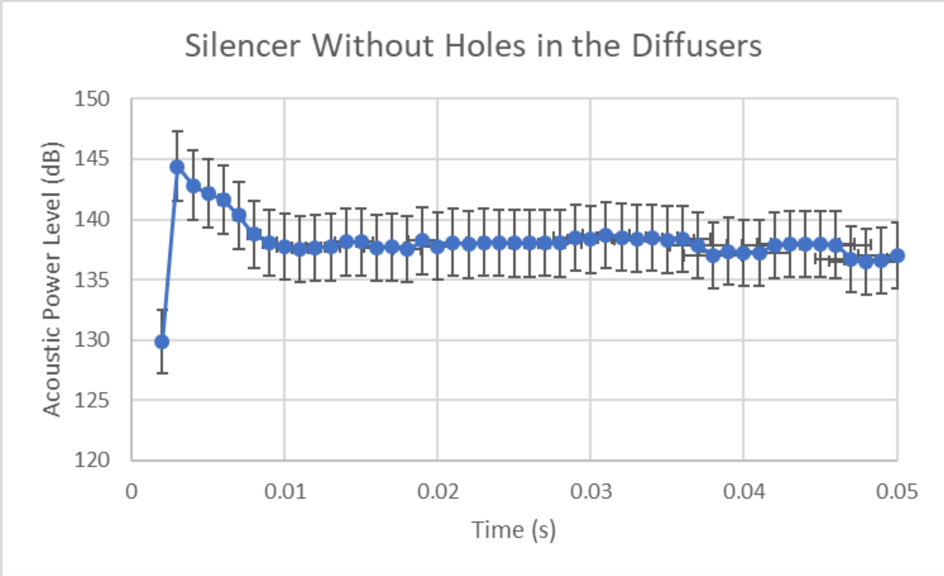

Figure 7. Imperforate diffuser analysis

Diffusers with circular holes of the same area are placed in the silencer at 30º and 45º angles. The diffuser analysis results of this silencer are compared in Figure 8. The maximum acoustic power level of the silencer with circular and aligned holes on its diffusers is 144.18 dB in 0.003 sec, the minimum acoustic power level is 116.29 dB in 0.002 sec, and the average acoustic power level is 139.22 dB. The maximum acoustic power level of the silencer with diffuser holes that are placed at an angle of 30º is 143.98 dB in 0.006 sec, the minimum acoustic power level is 109.57 dB in 0.002 sec, and the average acoustic power level is 137.85 dB. The maximum acoustic power level of the silencer with diffuser holes that are placed at an angle of 45º is 140.74 dB in 0.01 sec, the minimum acoustic power level is 113.39 dB in 0.002 sec, and the average acoustic power level is 138.02 dB. According to the data obtained from the silencers with circularly perforated diffusers and holes placed at different angles, the maximum and minimum acoustic power levels occur between 0 and 0.01 seconds. When the average acoustic power level is considered, it is seen that the sound level of the silencer with non-angled circular holes on its diffusers is at least 1 dB higher than the others. While the acoustic power levels in silencers with circular diffuser holes that are placed at an angle of 45º and 30º are close to each other, they have a lower dB level than the silencer without holes on their diffusers. The silencer with circular diffuser holes that are placed at an angle of 30º is at the lowest dB level.

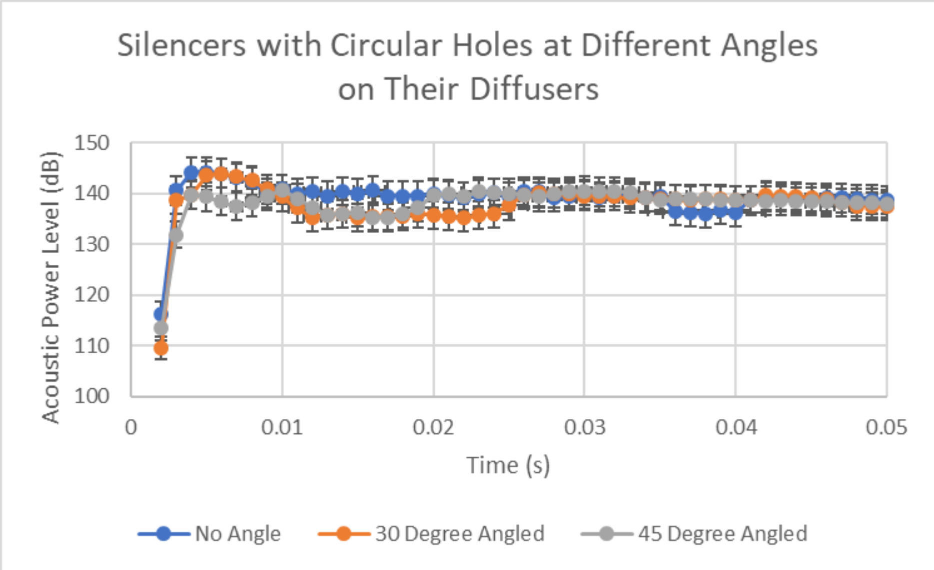

Figure 8. Analysis of circular-holed diffusers with angles of 30°, 45° and non-angled

Diffusers with square holes of the same area are placed in the silencer at 30^o and 45^o angles. The diffuser analysis results of this silencer are compared in Figure 9. The maximum acoustic power level of the silencer with square and aligned holes on its diffusers is 143.90 dB in 0.004 sec, the minimum acoustic power level is 122.30 dB in 0.002 sec, and the average acoustic power level is 139.35 dB. The maximum acoustic power level of the silencer with square diffuser holes that are placed at an angle of 30^o is 144.36 dB in 0.004 sec, the minimum acoustic power level is 111.28 dB in 0.002 sec, and the average acoustic power level is 135.86 dB. The maximum acoustic power level of the silencer with square diffuser holes that are placed at an angle of 45^o is 140.55 dB in 0.007 sec, the minimum acoustic power level is 110.80 dB in 0.002 sec, and the average acoustic power level is 136.43 dB. According to the data obtained from the silencers with squarely perforated diffusers and holes placed at different angles, the maximum and minimum acoustic power levels occur between 0 and 0.007 seconds. When the average acoustic power level is considered, it is seen that the sound level of the silencer with square diffuser holes that are placed at an angle of 30^o is approximately 3.5 dB lower than the silencer with aligned diffuser holes.

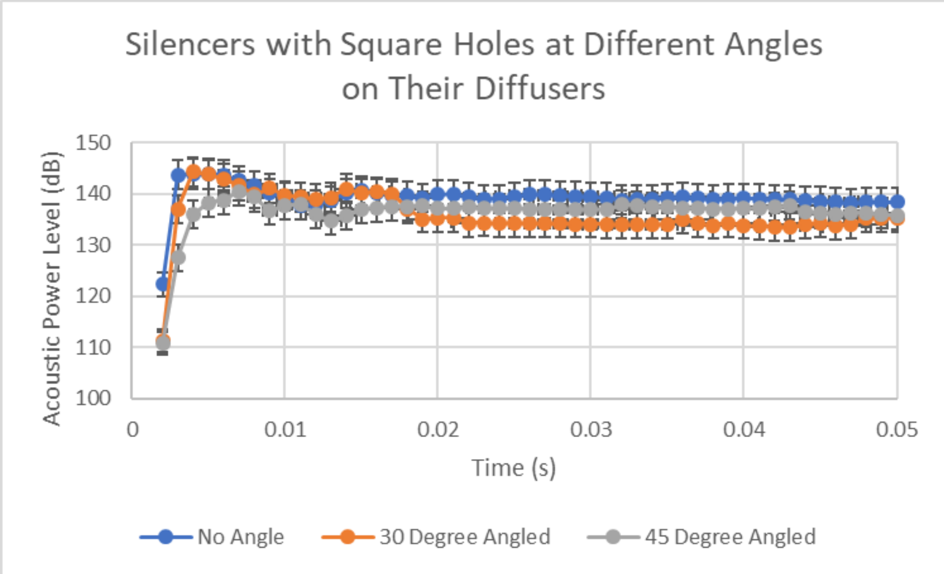

Figure 9. Analysis of square-holed diffusers with angles of 30°, 45° and non-angled

Diffusers with triangle holes of the same area are placed in the silencer at 30º and 45º angles. The diffuser analysis results of this silencer are compared in Figure 10. The maximum acoustic power level of the silencer with triangle and aligned holes on its diffusers is 144.04 dB in 0.003 sec, the minimum acoustic power level is 121.13 dB in 0.002 sec, and the average acoustic power level is 138.96 dB. The maximum acoustic power level of the silencer with triangle diffuser holes that are placed at an angle of 30º is 144.31 dB in 0.004 sec, the minimum acoustic power level is 109.04 dB in 0.002 sec, and the average acoustic power level is 134.64 dB. The maximum acoustic power level of the silencer with triangle diffuser holes that are placed at an angle of 45º was 142.95 dB in 0.006 sec, the minimum acoustic power level is 120.07 dB in 0.002 sec, and the average acoustic power level is 134.84 dB. According to the data obtained from the silencers with triangularly perforated diffusers and holes placed at different angles, the maximum and minimum acoustic power levels occur between 0 and 0.006 seconds. When the average acoustic power level is considered, it is seen that the sound level of the silencer with triangular diffuser holes that are placed at an angle of 30º is lower than the others. However, there is a difference of 0.19 dB between the silencer with triangular diffuser holes placed at an angle of 45º, and the silencer with the same holes placed at an angle of 30º.

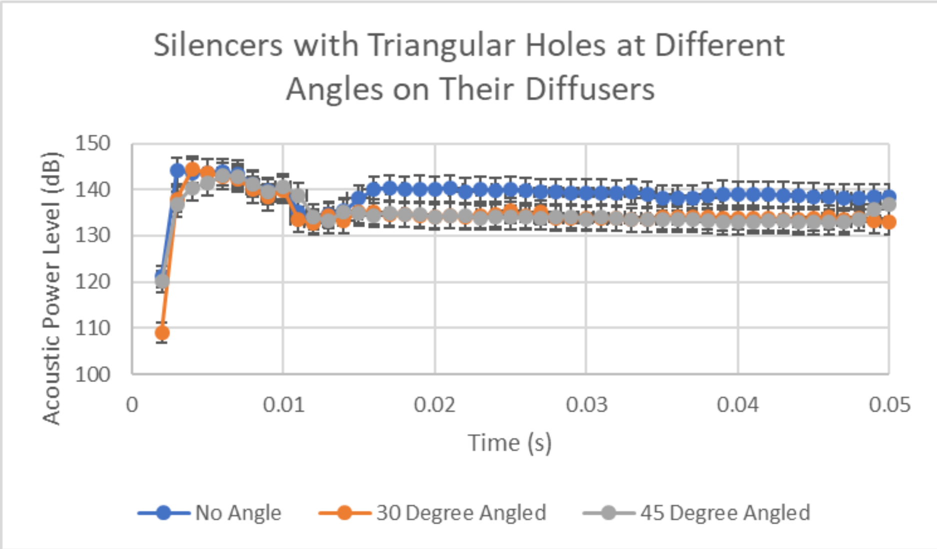

Figure 10. Analysis of triangular-holed diffusers with angles of 30°, 45° and non-angled

4. Conclusion

When the analysis results of the silencers with different diffuser holes are compared with the analyzes of the silencer without holes on the diffusers, it is seen that the average acoustic power levels of the silencers with diffuser holes that are aligned without an angle are higher. Acoustic power levels in silencer designs with angled holes on the diffusers are lower than the acoustic power level obtained from the silencer design without holes on the diffusers. When silencers with their diffuser holes placed at a certain angle are considered, it is seen that the silencers with diffuser holes that are placed at an angle of 30° have the lowest average acoustic power level. The average acoustic power levels of diffusers without holes, with different holes and with different angles are compared in Figure 11.

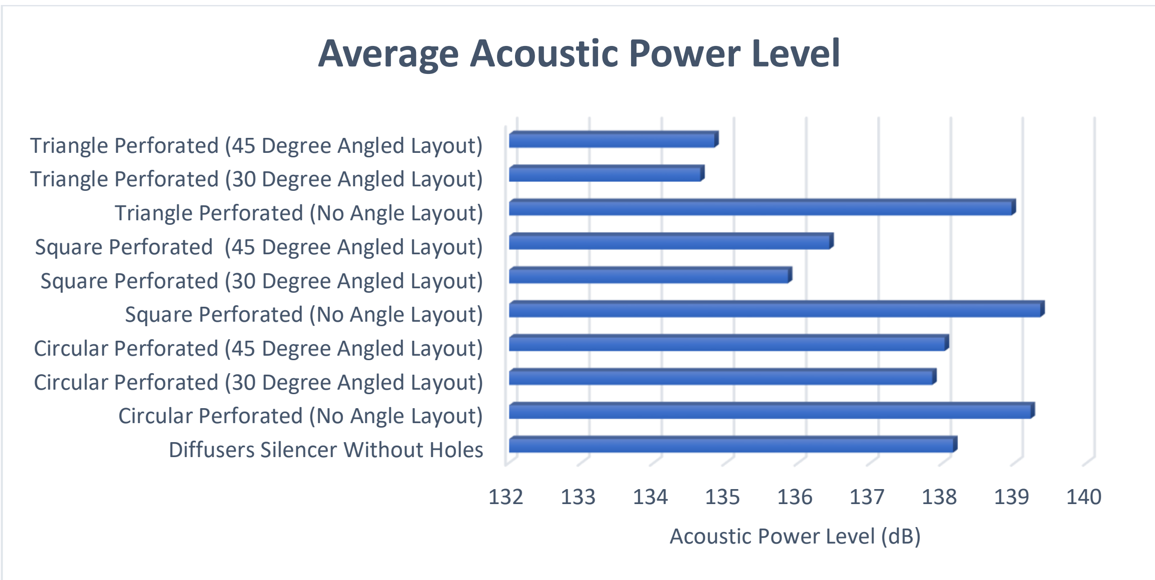

Figure 11. Comparison of average acoustic power levels

As a result, the lowest acoustic noise level is obtained from the silencer design with triangular diffuser holes that are placed at an angle of 30º. The acoustic power level of this silencer design is 3.5 dB lower than the silencer without holes on the diffusers. Considering that a value of 1 dB increases the sound level 10 times, it is concluded that this sound level is $10^{3.5}$ times lower than the silencer without holes on its diffusers. It has been concluded that the angled placement of the holes on the diffusers and the triangular perforation of the diffuser holes in the silencer design reduce the acoustic power level. Numerical simulations of this study are expected to be a guide for solving other weapon problems with three-dimensional and complex geometries.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

D.A.G: contributed to the creation of the idea and design of the study,
S.G: contributed to the determination of the analysis method of the data and the analysis presented idea of the study,
S.K: contributed to the literature review. All authors discussed the results and contributed to the final manuscript.

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