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4. SECTION : AMMUNITION AND ENERGETIC MATERIALS

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SIMULATION OF WEAPON SILENCER EXITS USING OF FUNCIONAL DECOMPOSITION APPROACH

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Abstract: *The basic approach of this paper considers the blast weapon effects by simulations and experimental research. Silencer of weapon blast is considered as the acoustic dumping transformer and wave conductor. The basic approach of simulation uses directed acoustic point source model. A convenient method for describing the outputs creation of wave transformer is decomposition approach. The electrical acoustic analogies are also used in simulation model. The simulation and experimental results are tested and compared, showing good results agreement and proving accepted approach.*

Keywords: *silencer, simulation, decomposition approach, electrical acoustic analogies.*

1. INTRODUCTION

Phenomena that occur when a gun is fired are the result of high powder gas energy that manifests through high intensity overpressure, high temperatures and high gas flow velocities. The firing sound is a combination of a number acoustic waves formed as a result of four main components: the gunpowder gas flow muzzle wave, the shock wave generated due to the supersonic projectile movement, the wave formed by the air column ejected from the gun barrel in front of the projectile and the acoustic wave generated by collision of gun parts during the firing process.

The main task of a silencer is to neutralize or reduce the first component of the firing sound without affecting the initial projectile velocity. A silencer suppresses the firing sound in several ways: by reducing the inner energy of the powder gases coming out of the barrel, by reducing their output velocity and temperature or by breaking the powder gas flow and by making it whirl.

It is well known that while the projectile accelerates with high temperature and high pressure, the explosion of propellant gases generates the muzzle blast wave [1,2]. A shoot, as an impulse shock wave coming from the weapon, has a lot of negative effects on people and the environment. Unlike other sounds, shock wave has high energy, low frequency, impulsiveness; it is strongly directed and has long-range propagation [3]. Muzzle blast is strongly directed. The design of muzzle brake that would decrease the noise involves theoretic studies of acoustic systems and simulations as well as empirical and experimental data. [3].

The primary objective of this paper is to create a simulation model of a blast wave generated by small arms equipped with a silencer. The simulation model is based on electroacoustic analogies and application of decomposition approach. Measuring parameters on the experimental model yielded correct overpressure values at chosen characteristic points around the muzzle. The analysis of the obtained results has justified the use of the simulation model and its application in designing silencers for different types of small arms.

2. DESCRIPTION OF SILENCERS AS ACOUSTIC DEVICES

A silencer can be considered as a gas-dynamic wave transducer inside which there are some connections and obstacles [4]. The wave transducer basically consists of the volume V_0 with connected acoustic transmitters (Fig.1) that border on the volume V_0 with their cross-sections $S_\beta(\beta = 1,2)$. The volume V_0 has energy connection with the environment only through acoustic transmitters in front of it and behind it. The cross sections

S_1 and S_2 are called input cross-sections.

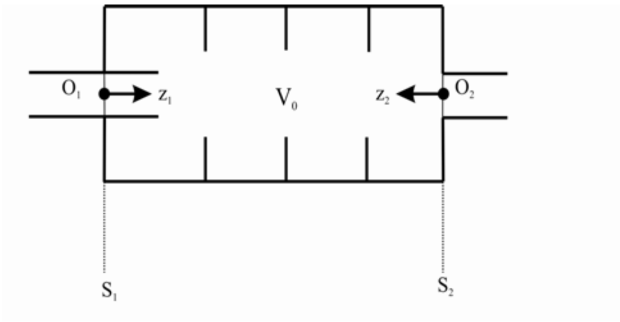

Figure 1: Formalization of an acoustic device

The acoustic field of the wave transducer can be presented as superposition of translational and whirling waves [4]:

$$P_\beta(r,\alpha,z_\beta)=\sum_{k=1}^{\infty}c_{k(\beta)}^{+}P_{k(\beta)}^{+}(r,\alpha,z_\beta)+c_{k(\beta)}^{-}P_{k(\beta)}^{-}(r,\alpha,z_\beta)$$
$$\vec{v}_\beta(r,\alpha,z_\beta)=\sum_{k=1}^{\infty}c_{k(\beta)}^{+}\vec{v}_{k(\beta)}^{+}(r,\alpha,z_\beta)+c_{k(\beta)}^{-}\vec{v}_{k(\beta)}^{-}(r,\alpha,z_\beta) \quad (1)$$

where

P_β - output pressure,

$r,\ a,\ z_\beta$ - cilindrical coordinates,

v_β - output vector of wave velocity,

$P_{k(\beta)}$ - input pressure,

$v_{k(\beta)}$ - input vector of wave velocity,

β - the input cross-section index,

$c_{k(\beta)}^{+}$ - the amplitude of normal waves (decreasing),

$c_{k(\beta)}^{-}$ - the amplitude of reflected waves.

3. DECOMPOSITION APPROACH TO DESCRIPTION OF WAVE PROCESSES IN THE SILENCER

The area of the gas transducer between the input cross-sections S_1 and S_2 (Fig.2a) is divided by imaginary cross-sections into basic elements. The basic elements are regarded as acoustic wave transducers for which elements of the impedance matrix Z and the scattering matrix R are determined [4]. The elements of the scattering and impedance matrices of the wave transducer completely define the final recomposition results. Virtual lines, connected to the output cross-sections of the basic elements are considered to have infinitely small lengths during the recomposition. The recomposition of the basic elements into virtual conductors is performed in accordance with the conditions determined by the continuity of the pressure and the longitudinal component of the gas particles velocity for two adjacent cross-sections connecting the basic elements. A multi-chamber silencer (Fig.2) is used to demonstrate the decomposition approach.

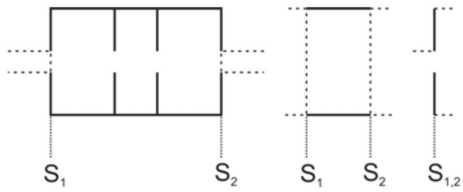

Figure 2: Basic elements of the wave line (a - silencer, b - cutout of the cylindrical conductor, c - a membrane between two cylindrical cutouts)

In order to set a mathematical model of the multi-chamber silencer, a cutout of the cylindrical wave conductor (Fig.2.b) and membranes of two cylindrical lines of different diameters (Fig.2.c) are used as basic elements.

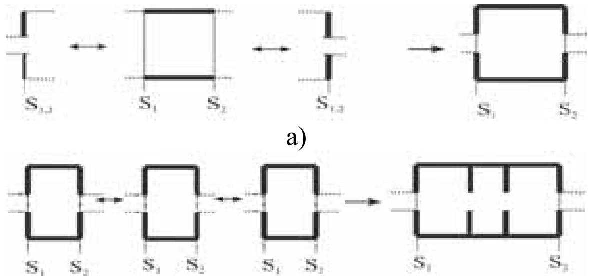

Figure 3: Recomposition of the basic elements:
a – a chamber consisting of connectors and a cylindrical line;
b –a multi-chamber silencer obtained by joining chambers

If two membranes and one cylindrical line cutout are joined a silencer chamber is obtained (Fig.3.a). Joining three chambers (Fig.3.b) yields a multi-chamber silencer.

In Figs.2 and 3, virtual conductors are presented by dashed lines. The membrane of the two cylindrical lines of different diameters has no volume i.e. there is no impedance matrix. The elements of the scattering impedance matrices of the cylindrical cutouts and membranes a method developed in electrical engineering is used [4,5].

4. ELECTROACOUSTIC AND ELECTRO-MECHANICAL ANALOGIES

All the phenomena occurring during the firing of a weapon can be described as acoustic processes hence it is quite simple to register the acoustic pressure (powder gas overpressure) of the sound wave. The silencer can be considered as an acoustic system with input values at the muzzle and output values at the point M (Fig.4).

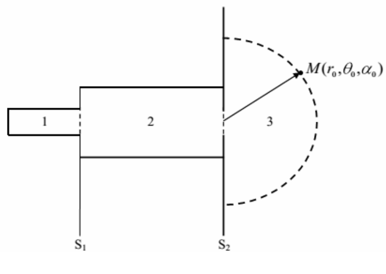

Figure 4: Scheme of overpressure measurement at the point M (S1- muzzle cross-section, S2- output cross-section of the silencer)

Applying electroacoustic analogies [5], the acoustic sound suppressing device can be interpreted using an adequate oscillating electrical circuit decomposed into its constituting components.

The volumes of the chambers (Fig.5b,5c and 5d) represent the acoustic capacitance, C_a, that is obtained by:

$$C_a = \frac{V}{\rho c^2} \,. \qquad (2)$$

where: V – volume of chamber, ρ - destinity of gass in chamber and c – sound velocity.

The chamber capacitance does not depend on its form but only on the volume [5].

The lines connecting the chambers (Fig.5a) have their own inductance, i.e., they represent the mass of the air column to be suppressed. The acoustic inductance is obtained using the expression [5]:

$$m_a = \frac{\rho l'}{S} \,, \qquad (3)$$

where l' is the adjusted length of the air column, i.e. the sum of the length of the line l and the adjusted length Δl in accordance with the connection diameter (Fig.5a).

The length adjustment is performed according to the position of the connection in the acoustic system (Fig.5b, 5c and 5d).

If the distances between the lines of the same cross-section are smaller compared to the adjustment of the cross-section, the air column is considered unique and its whole length is taken (Fig.5e).

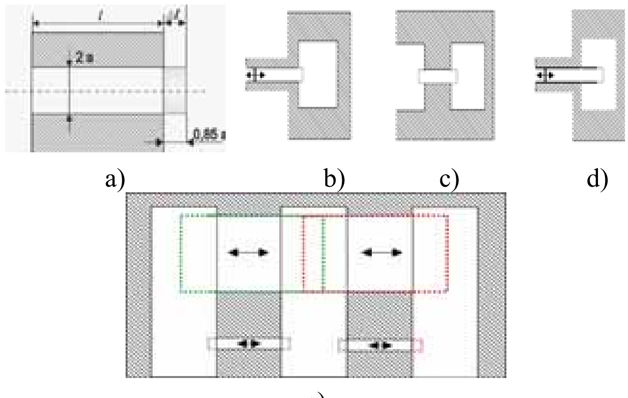

Figure 5: Adjustment of the air column length of the acoustic inductance

5. SIMULATION OF PROCESSES IN ACOUSTIC DEVICES

Using the above stated analogies and applying the decomposition method, the silencer can be interpreted as an electrical oscillating circuit.

The intensity of the powder gasses pressure in the muzzle flow is introduced as an input parameter. The values are obtained by an internal ballistics calculation for a particular weapon. The input signal is introduced by a signal-generator, and the output is recorded on a virtual oscilloscope (Fig. 6).

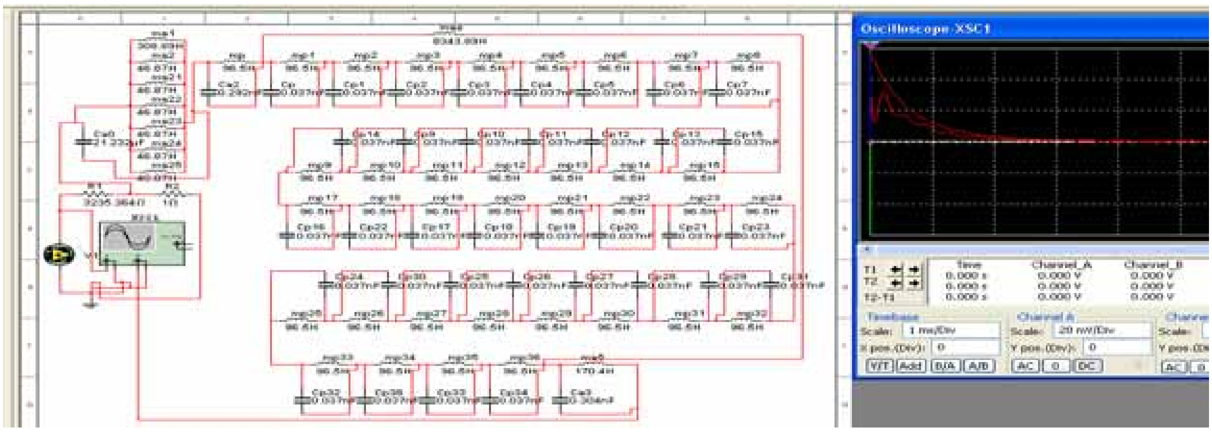

Figure 6: Simulation model of an electro-acoustic system

It is necessary to step the signal function for a time interval needed for the gas particles to travel from the sound way source (muzzle) to the referential point. The nature of the wave propagation after it has left the silencer [5] is identical to the wave propagation generated in an acoustic dotted source of the directed effect (Fig.7).

The final signal values are obtained applying the function of the distance from the referential point to the last opening on the silencer:

$$p = \frac{1}{r}\sqrt{\frac{P_a \rho c}{4\pi}} \qquad (4)$$

where: p – pressure in the reference point, r – reference point distance of sound source, P_a – sound power of sound source, and applying the propagation direction factor:

$$\Gamma_{(\vartheta)} \text{ [5], } \Gamma_{(\vartheta)} = {p_\vartheta}/{p_0} \,, \qquad (5)$$

where: p_0 – pressure in zero direction and p_θ – pressure in direction under angle θ.

Simulations were performed for three cases: overpressure was simulated around a weapon without a silencer, around the weapon equipped first with a silencer Type 1 and then with a silencer Type 2 (Fig.8).

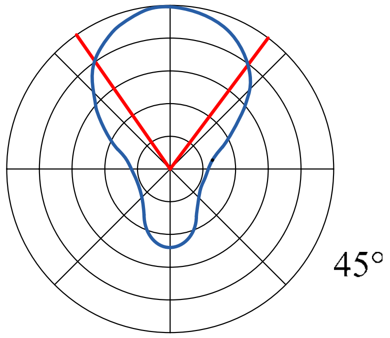

Figure 7: Propagation of the wave generated in an acoustic dotted source of directed effect

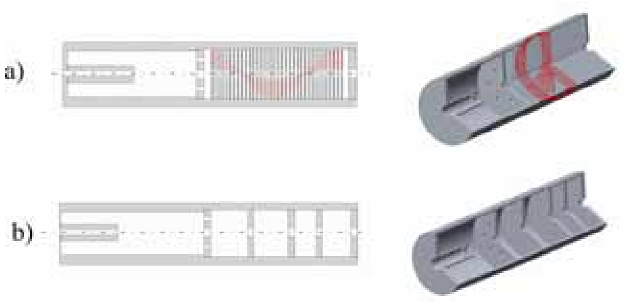

Figure 8: Experimental models of silencers a) Type 1, b) Type 2

Silencer Type 1 (Fig.8a) is with an extended gunpowder gases flow. It consists of two expansion chambers, membrane for flow breaking and extended powder gas flow. The extended flow is formed within the cutout at 36 perforated membranes, which are turned at the angle of 10º, so that the whole flow is 2π. The silencer Type 2 (Fig.8b) has a simpler design. It consists of five expansion chambers mutually separated by a membrane for breaking the flow of gasses and three flat membranes.

Simulation of the overpressure is done at referential points in given directions and distances (Fig.9).

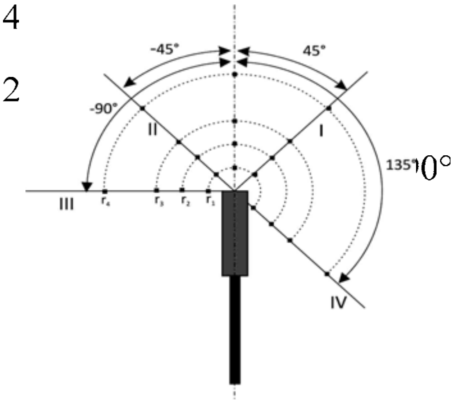

Figure 9: Distribution of referential points (RP)

In order to simplify the data processing only maximum simulation values were taken from all the points.

Table 1: Simulation values of the muzzle blast overpressure in bars

	without a silencer				silencer Type 1				silencer Type 2			
	RP1	RP2	RP3	RP4	RP1	RP2	RP3	RP4	RP1	RP2	RP3	RP4
r	-45°	45°	- 90°	135°	-45°	45°	-90°	135°	-45°	45°	-90°	135°
0,2 m	0,46276	0,46276	0,22831	0,15214	0,0466	0,0466	0,0172	0,0138	0,0409	0,0409	0,0151	0,0121
0,4 m	0,23138	0,23138	0,11415	0,07607	0,0233	0,0233	0,0086	0,0069	0,0204	0,0204	0,0075	0,006
0,6 m	0,15428	0,15428	0,07611	0,05072	0,0154	0,0154	0,0057	0,0046	0,0136	0,0136	0,005	0,004
1,0 m	0,09255	0,09255	0,04566	0,03043	0,0104	0,0104	0,0038	0,0031	0,0092	0,0092	0,0034	0,0027

6. MEASUREMENT METHOD DESCRIPTION

Experiments were carried out to determine the dispersion of the shock wave around the muzzle of weapon, resulting in the firing process, with and without silencer. In experiments are performed measurement decreasing of shock wave around muzzle of weapon in appropriate directions and at appropriate distance of muzzle (Fig.10).

Measuring overpressure in the time base provides not only the peak overpressure values but also some information on the nature of the blast wave. Measurement systems based on the principle of piezoelectric effect are most suitable for the use here. Generated charge (based on the piezo-converter) is introduced into the intermediate unit - amplifier via coaxial cable and then into a special registration device. In order to obtain an entirely physical image of this impulse phenomenon, several sensors are used.

Piezotronics probes PCB 137A23 were used to measure overpressure, while the charge amplifier 494A21 PCB piezotronics was used as an amplifying unit in the measurement system.

The muzzle blast overpressure was measured first without the use of a silencer and then, under the same conditions (atmospheric pressure 998 mbar, temperature 20°C), the overpressure was measured with the use of two types of silencers.

Figure 10: Displaying of measurement methods

Since the same measurement chain was used, the measurement error has no effect on the obtained results.

The overpressure was measured at referential points (Fig.10) in compliance with the scheme identical to the one used for simulation (Fig.9).

In addition to the overpressure intensity, the projectile velocity was measured in order to establish the effect of the silencer on the initial elements of the projectile flight towards the target (Fig.10) [6, 7]. Since there was no decrease in the initial velocity, it can be concluded that the silencers had no effect on the elements of the projectile flight. LabView software was used to record measurement results of overpressure for numerical and graphical processing (Fig.11).

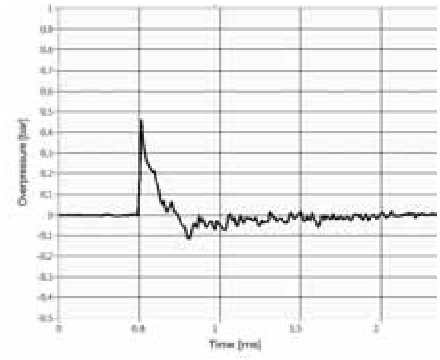

Figure 11: Overpressure measured using the probe PCB137A23 in the time domain

The peak overpressure values at the referential points are shown in Table 2.

Table 2: Values of the measured muzzle blast overpressures in bars

	without a silencer				silencer Type 1				silencer Type 2			
	RP1	RP2	RP3	RP4	RP1	RP2	RP3	RP4	RP1	RP2	RP3	RP4
R	-45°	45°	-90°	135°	-45°	45°	-90°	135°	-45°	45°	-90°	135°
0,2 m	0,4513	0,4405	0,2111	0,1232	0,05388	0,03344	0,01074	0,009757	0,03657	0,04312	0,01365	0,009236
0,4 m	0,2767	0,2828	0,1284	0,0846	0,02522	0,02295	0,00756	0,006801	0,02578	0,02297	0,00834	0,00723
0,6 m	0,1465	0,1573	0,0758	0,0544	0,01978	0,01506	0,00739	0,00653	0,0194	0,01601	0,00704	0,00665
1,0 m	0,0774	0,0794	0,0436	0,0306	0,015502	0,0111	0,00581	0,005216	0,01393	0,0116	0,00635	0,00607

7. ANALYSIS OF THE OBTAINED RESULTS

The diagrams in Figs.12-15 give both the simulation and experimental results for the maximum muzzle blast overpressure values measured first without the use of a silencer, and then with the use of the two types of silencers for different angles depending on the distance.

Simulation curves are fitted curves of the data obtained by simulation and measurements for the chosen points, per a form function:

$$y = Ae^{-Bx}, \qquad (6)$$

where: y – overpressure, x – distance and A, B – constants, which corresponds to the theoretical function of the pressure change during the period of the subsequent powder gases effect. The given coefficients A and B are calculated for each single experiment using the software.

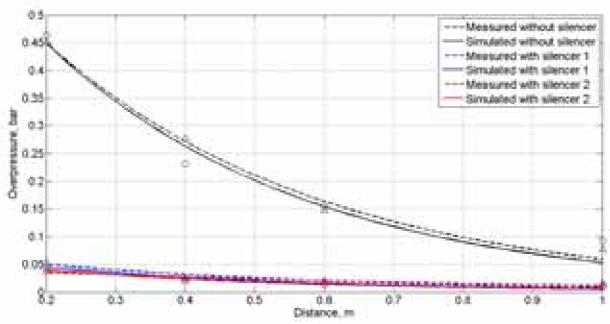

Figure 12: Diagrams of measurement and simulation results for angle -45°

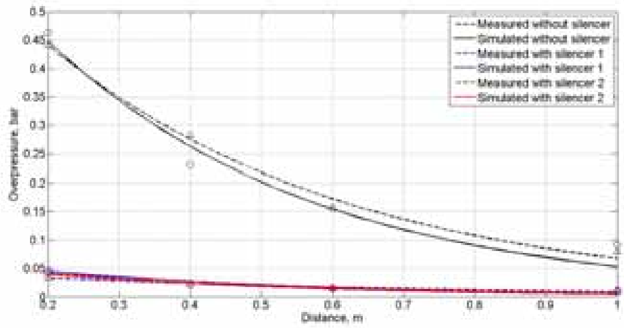

Figure 13: Diagrams of measurement and simulation results for angle 45°

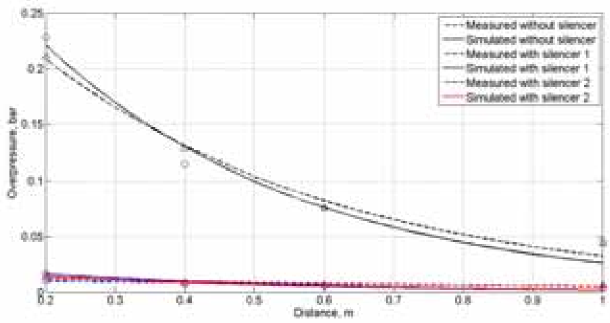

Figure 14: Diagrams of measurement and simulation results for angle -90°

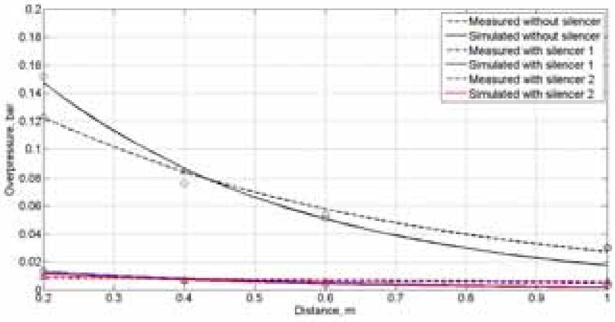

Figure 15: Diagrams of measurement and simulation results for angle 135°

Based on the shown diagrams it can be concluded that a silencer as an acoustic device reduces the peak overpressure ten times. The simulation results obtained by application of the decomposition approach are in good agreement with the experimental results. The simulation results for the angles of -45° and -90° show the least error, which is important for the silencer use.

The noticed error for the angles of 45° and 135° is the result of not taking into account, in simulations, the projectile rotation and air whirling, which are negligible.

8. CONCLUSION

This paper gives a comparative analysis of the obtained results for the muzzle blast overpressure peak under given conditions and at given distances without the use of a silencer and with the use of two types of silencers.

The silencer with an extended (spiral) powder gas flow has been noticed to exhibit better performance in reducing the muzzle blast overpressure at longer distances.

Decomposition approach and electroacoustic analogies were used to simulate the silencer performance.

The simulation results are in a good agreement with the experimental results, which together with other advantages of simulation (cheap, fast, no need for experiments) justify its use.

The simulation method offers many possibilities like a simple way to change distances and referential point angles, which practically means that the whole area around the silencer can be simulated. It is also very easy to generate the input signal for any kind of weapon, while the desired type of a silencer can be modeled using the right combination of its constituent elements. Time needed for preparation of a new simulation model is very short, and the simulation results are obtained quickly.

The simulation model is open to further improvement until it becomes fully automatized by relating construction data from the 3D silencer model and final output parameters, by expanding the range of the output parameters, as well as by taking the parameters from the environment into account.

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