COVER SHEET

Title: *Investigation into the impact of integral suppressor configurations on the pressure levels within the suppressor*

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This paper reports on an experimental investigation supported by basic modeling in to the performance of an integral suppressor on a low power firearm. A model was developed to determine the pressure within a suppressor chamber using iterative empirical calculations of the gas properties and flow within the system. The design of a reconfigurable suppressor chamber has been undertaken allowing suppressor chamber volume to be varied through the use of baffles. Pressure transducers were used to determine the pressure within the suppressor chamber for a series of firings. The results of the firings with different configurations within the suppressor are presented allowing trends to be established. The modeling and experimental results show an increase in suppressor chamber volume results in a reduction of recorded pressure within the suppressor chamber.

INTRODUCTION

The use of suppressors with firearms is becoming more commonplace, especially within the UK Armed Forces where there are an increasing number of cases of hearing damage [1]. There are also applications for areas such as animal management where the British Association for Shooting and Conservation state “it may be an act of social responsibility to fit a sound moderator to a rifle” [2]. The use of suppressors reduces the sound signature of the gases from firing by allowing the superheated, high pressure gases escaping from the barrel, to expand, cool and reduce in velocity before being released into the atmosphere. This is achieved by providing a container attached to the muzzle or fitted around the barrel. Within the container baffles are often introduced to provide smaller chambers for the gas to expand into, delaying the exit of the gas.

This paper examines the performance of a suppressor for animal management purposes in particular the configuration of baffles within the suppressor and the modeling that can be conducted to aid design. Many of the early developments of suppressors were made in the 1970s and were mainly empirical in nature [3] . Very little work was done using a computational modeling approach. As the development of models and computing has progressed there have been attempts to model the complex gas flow.

Schmidt [4] investigated many different muzzle devices including suppressors. Several models had been created to predict the gas expansion at the muzzle upon firing developed from contained conventional explosive blast tests. The outputs of the models were not verified against experimental test data from muzzle blasts which differ to conventional blast waves [5]. Schmidt found that the analysis of the effect of muzzle suppressors on the blast was not extensive and had examined only one configuration of baffles within the suppressor.

Bixler et al [6] studied containment devices in more detail both theoretically and experimentally in three approaches:-

• acoustic theory

• blast theory

• quasi-one-dimensional flow theory

Experimental results differed to the theoretical predictions of the models due to many assumptions made. The acoustic theory assumed linear motion which is not applicable to the strong non-linear muzzle blast from a firearm. The blast theory relied on assumptions which are not applicable to the situation by implying that once the blast wave had travelled into the chamber it remains frozen, this does not occur in a suppressor. Bixler's final theory did not account for reflections of the blast wave in the chambers of the suppressor and the movement of the projectile through the suppressor.

However, Bixler et al [6] were unique in conducting a detailed experimental investigation into the attenuation of a weapon by varying the number and spacing of the baffles. Blast attenuation increased rapidly with the number of baffles in a suppressor before maximum attenuation at 12 baffles was achieved and a gradual decline occured (Figure 1). Limited trials at Cranfield University confirmed these results [7] .

Townend and Yendall [8] investigated the calculation of pressure within chambers as used in suppressors. However like Bixler they were unable to account for recoil of the pressure wave from the surface of the baffle and so these equations therefore do not fully represent the situation and the equations cannot be applied to mutli-stage suppressors.

Kirby [9] noted that both Boundary Element Method and Finite Element Analysis have been used as tools to model the gas flows in vehicle exhaust silencers. Kirby also formulated a low frequency algorithm which gave "good correlation between both experimental measurements and also more advanced Finite Element techniques". However when applying to the medium to high frequencies produced during firings there was little correlation to experimental results.

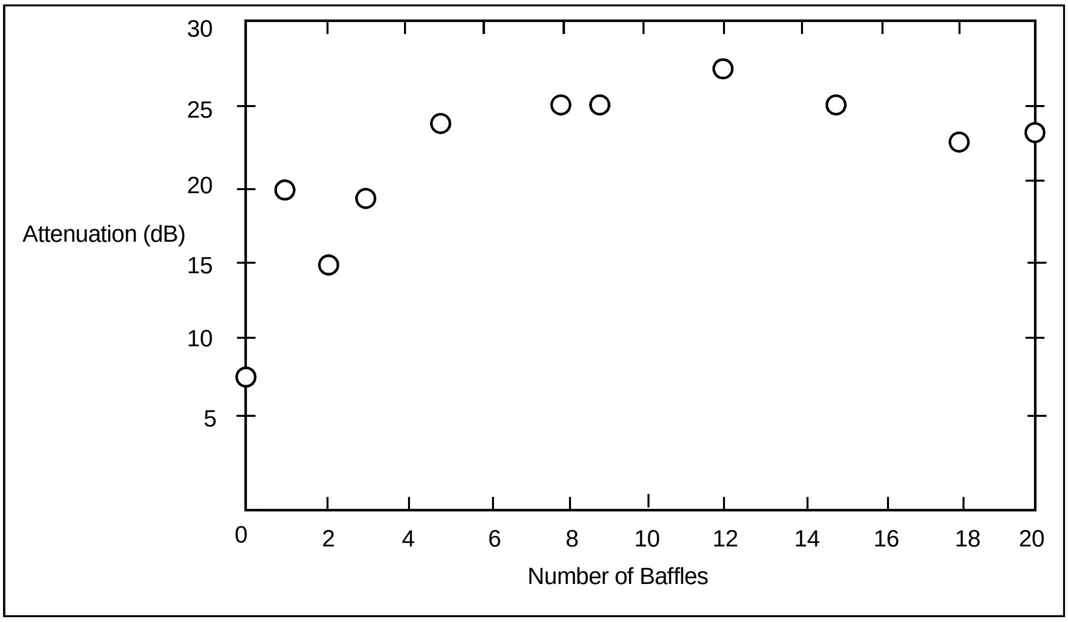

Figure 1 Attenuation with number of baffles [6]

Cummings [10] suggests that computational methods require considerable effort and can be difficult to track and other mathematical models are also reliant on very low Mach number velocities, which limits the application within firearms [11].

With little successfully validated modeling undertaken to establish the factors that affect the attenuation of the suppressor, a study was proposed to establish whether there were other modeling methods which could be experimentally tested. This paper reports on whether trends could be established with a simple model for the design of a suppressor for a low power shotgun system used for animal management.

METHOD

The shotgun system employed a unique method of ignition (Figure 2), using a primed 0.357 magnum cartridge which was shortened, filled with 0.25g of smokeless gun propellant (Alliant Green Dot) topped with cotton wadding and crimped. In order for this to fit in the chamber of a 12 bore shotgun it was fitted within an adaptor. For the purposes of testing a plastic projectile was then inserted into the adaptor and the assembly into a standard 12 bore shotgun chamber. The overall length of the barrel was reduced to 457.2mm (18”).

The weapon used an integral suppressor, where the suppressor is fitted around the barrel with holes in the barrel venting the firing gas into the suppressor. The configuration of baffles was the variable tested, with modeling used to predict the pressures within the baffles.

MODELING

A model was developed to ascertain the impact on the size of a chamber within a suppressor on the pressure within the chamber. The model was a modification of an Cranfield University developed model, originally been developed to determine the

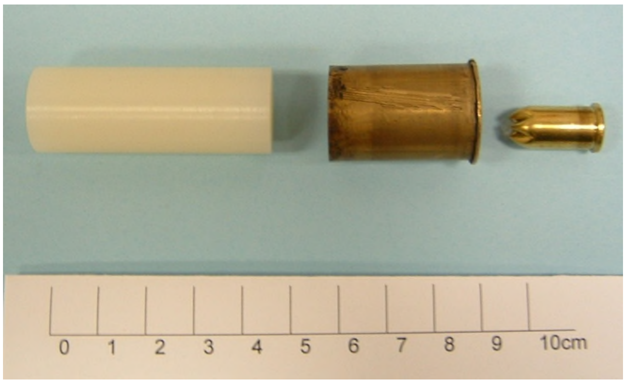

Figure 2 Round Configuration L-R: Dummy round, adaptor, 0.357 Magnum cartridge

flow and heat transfer of gas in a vented vessel [12]. The model detailed the pressure in the gun chamber, barrel and suppressor along with the velocity of the projectile down barrel. The model used an iterative process for the empirical calculations of energy, gas laws, continuity equations, volumes, mass flow rates, equations of motion and heat losses in the system.

With the model correlated with experimental results (see Verification), a series of runs were completed to establish how the volume of the suppressor affected the pressure within the chamber. This simulated the position of baffles along the suppressor. The volume of the suppressor chamber was altered from 4.00x10-5 m^3 – 8.00 $x10^{-4}$ m^3. The diameter of the port from barrel to suppressor chamber was fixed at $2.9x10^{-5}$ m^2.

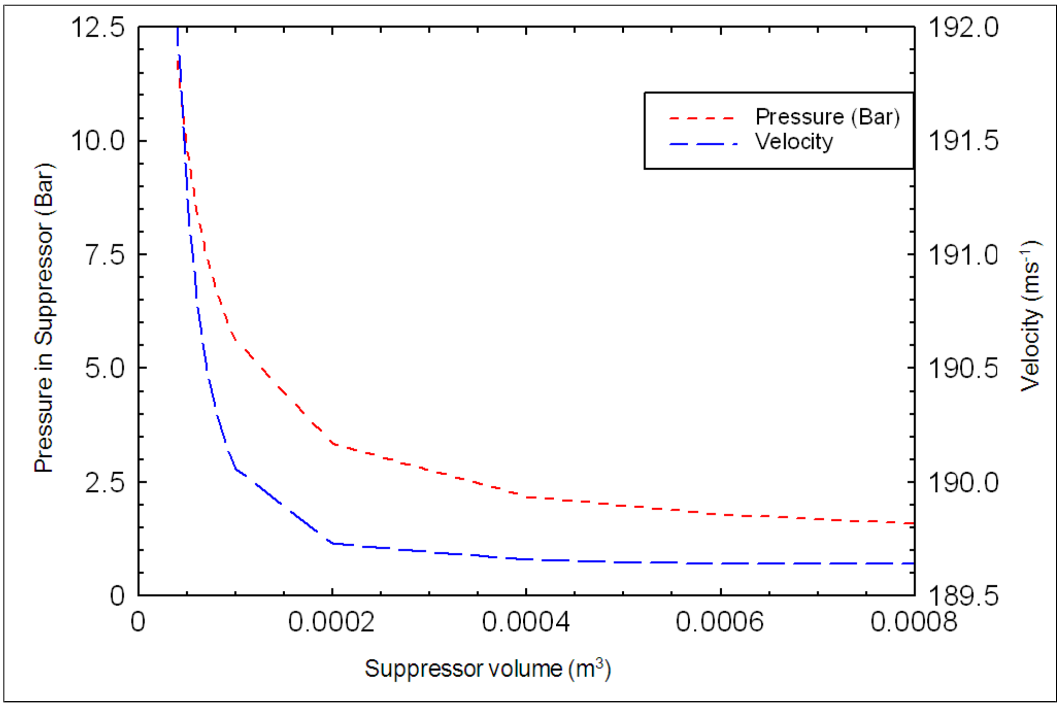

Figure 3 Effect of changing the suppressor chamber volume on the pressure and round velocity

It can be seen from Figure 3 that as the volume of the suppressor chamber increased the pressure within the suppressor chamber and the muzzle velocity dropped. The pressure dropped from a maximum of 12.5 bar with a chamber volume of $4.0x10^{-5}$ m^3 to approximately 1.5 bar with a larger chamber volume of $8.0x10^{-4}$ m^3. The pressure reduction was initially rapid, dropping 10 bar to a chamber size of $2.0x10^{-4}$ m^3 after which there was a gradual decline from 3.5 bar to 1.5 bar. The drop in pressure as the chamber volume increased was to be expected, in line with the ideal gas law. The velocity reduction over the volume range computed was approximately 2.4 ms^{-1}. There was an initial rapid reduction in velocity for the volume range $4.0x10^{-5}$ m^3 to $2.0x10^{-4}$ m^3 from 192 ms^{-1} to 189.7 ms^{-1} after which the muzzle velocity reduced by 0.1 ms^{-1}.

Verification

The model was verified by a series of tests to establish whether the configuration of the cartridge (Figure 2) was correctly modeled. A pressure distance plot for the barrel without any venting into a suppressor was produced. The results from this were then compared against measured pressures at four points along the barrel. A 12 bore shotgun barrel length 457.2 mm was modified to accommodate four Kistler 217C transducers (Figure 4). 10 shots were fired gathering both pressure and muzzle velocity (using Doppler Radar) for the system.

Figure 5 shows the theoretical pressure predicted by the model with the four pressure readings taken along the barrel. A difference of approximately 12 bar can be seen for the first measurement (0.1m shot travel) position. At positions two to four the predicted and measured pressures are comparable within experimental uncertainty.

The mean velocity recorded 182.5 ms^{-1} ± 10.0 ms^{-1}. The variation in this muzzle velocity can be attributed to the hand loading and wadding of the cartridge. The model predicts a peak velocity of 214.0 ms^{-1} by 180 mm of travel along the barrel. A variation in 10 ms^{-1} considering the unusual configuration of the cartridge and projectile (Figure 2) is acceptable for this arrangement.

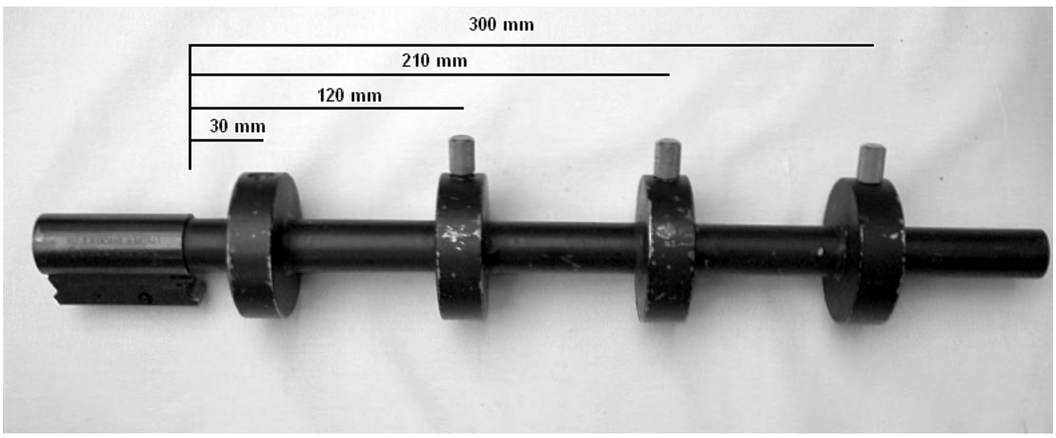

Figure 4 Modified barrel to accommodate Kistler 217C transducers

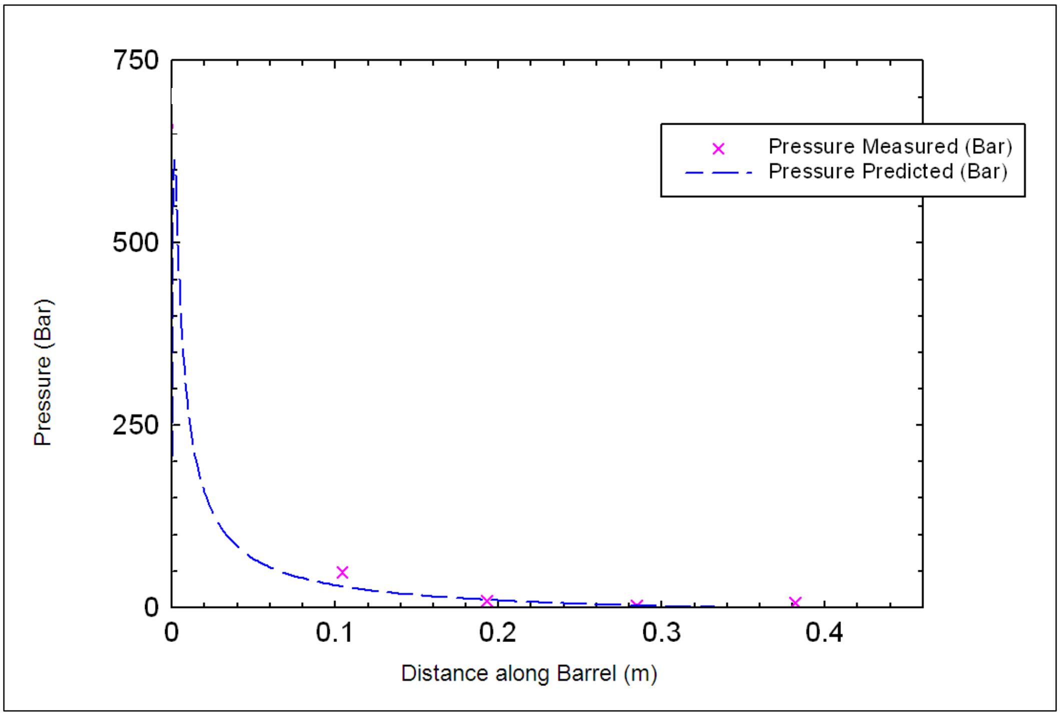

Figure 5 Theoretical vs Measured Pressure along barrel

EXPERIMENTAL

An experimental design was developed for quantifying the pressure within a suppressor with varying chamber sizes. The outer wall of the barrel was machined for a cylindrical profile. Eight 2 mm diameter holes equi-spaced around the circumference with 20mm between centers were machined along the length of the barrel. Baffles with 2mm holes as shown in Figure 6 were manufactured along with spacers of 18mm, 28mm and 58mm length allowing the baffles to be spaced along the suppressor. The suppressor tube to contain the spacers, baffles, barrel and allow pressure measurement was selected for optimum wall thickness as shown in Figure 7.

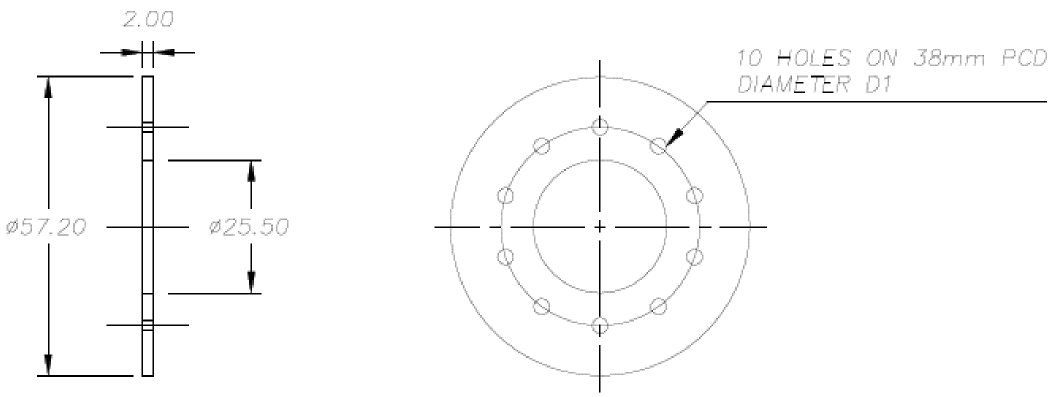

Figure 6 Baffle design

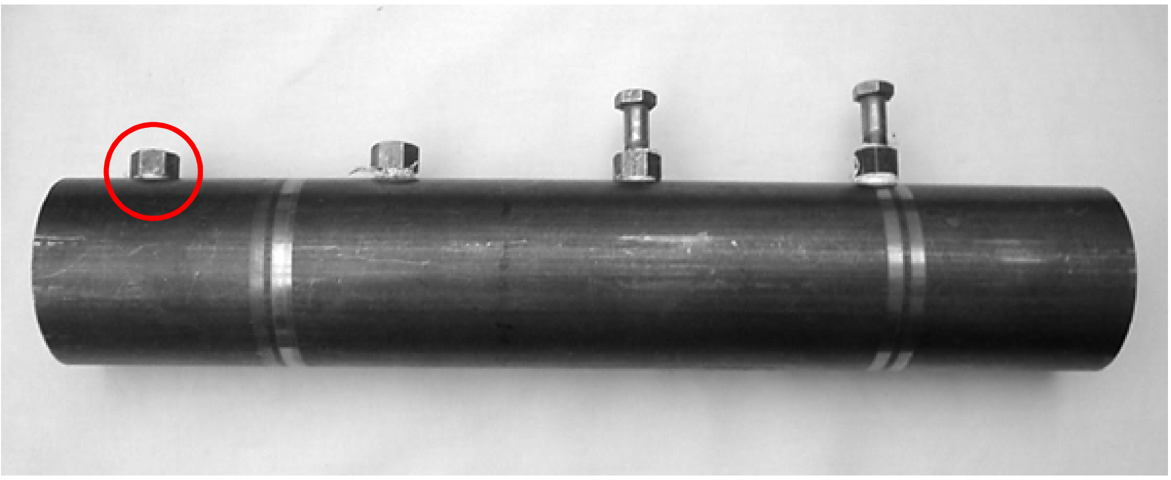

Figure 7 Suppressor tube showing transducer position and blanking caps

Method

The weapon and suppressor was assembled to test four possible configurations as can be seen in Table I. Pressure measurements were taken using a Kistler 217C transducer at first position along the suppressor (Figure 7). Three shots were taken for each configuration. The maximum pressure was recorded for each shot along with muzzle velocity using Doppler Radar.

Results

The results can be seen in Table I. The results show the smaller the volume of the first chamber the greater the pressure recorded within the chamber. This correlates with the predicted pressures from the model where by smaller volume of suppressor chamber results in a greater pressure within the chamber. The experimentally recorded pressures were 2.5 to 3.5 times less than the pressure predicted by the model within the chamber. The lower pressure recorded could be attributed to the fluid dynamics effect of the flow of combustion gases through the barrel hole/s into the suppressor chamber.

Fluid mechanics and Bernoulli's equation when applied to flow through an orifice, in this application the holes through the barrel, results in a lower fluid pressure downstream of the orifice [13]. The model only accounts for one hole through the barrel wall to the chamber, whereas the experimental procedure increased the number of holes through the barrel from eight for 18 baffle configuration through to 24 for six baffle configuration. The increase in the number of holes may have resulted in a reduction on the pressure recorded within the suppressor when compared with the model.

A comparison of velocities between the testing without a suppressor and with the configurations shows that the results fall within the range expected for the velocity.

Table I PRESSURE MEASUREMENT AT POSITION

Volume of first baffle chamber (m^3)	Number of baffles in system	Measured Pressure (Bar) Mean	S.D	Velocity (ms^{-1}) Mean
$1.42x10^{-5}$	18	6.13	0.24	175.1
$3.00x10^{-5}$	9	3.49	0.12	188.2
$4.58x10^{-5}$	6	3.34	0.28	188.9
$1.45x10^{-4}$	1	1.73	0.02	172.5

CONCLUSION

The modeling to determine the pressure within a suppressor chamber using iterative empirical calculations of the gas properties and flow within the system has suggested an increase in suppressor chamber volume results in a decrease in the maximum pressure within the chamber. The experimental results of the firings with different configurations within the suppressor revealed the same trend, as the volume of the suppressor chamber is increased there is a reduction in the peak pressure recorded within the chamber. The difference between the model and experimental results may be attributed to the use of multiple barrel holes in the experimental testing and only one hole from barrel to suppressor chamber modeled.

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