ARMY RESEARCH LABORATORY

A General Purpose Prototype Muffler for the Bradley Fighting Vehicle 25-mm Automatic Cannon

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13. ABSTRACT *(Maximum 200 words)*

In response to noise problems in Germany incurred by the Bradley Fighting Vehicle (BFV) 25-mm M242 Chain Gun, two prototype mufflers for use with all types of ammunition were designed, fabricated, and performance-tested against requirements given by an Operational Needs Statement. One muffler is used with a standard barrel while the other muffler requires a unique perforated barrel. Tests included noise attenuation, toxic fume concentrations within the BFV, and projectile dispersion. Noise requirements were met and even exceeded by the muffler that requires perforated barrel. Subsequent testing was performed with the perforated barrel/muffler system. With a modified ventilation scheme, the most severe training scenario could be run three times in succession without exceeding the maximum permissible toxic levels of the relevant MIL standard. Moreover, the visible smoke was removed from the BFV interior and there was no eye irritation. It is recommended that this ventilating scheme could be used with the muffler. Dispersion testing of M793, M791, and M910 ammunition, when firing both stationary and on the move, resulted in the barrel/muffler system performing as well as or better than the standard barrel/brake system in five of the six events. However, more testing is needed to draw statistically firm conclusions. For this particular muffler, noticeable erosion occurred in the material around the exit hole. For future mufflers, implementation of a small design change should eliminate any erosion problems.

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PREFACE

The U.S. Army Ballistic Research Laboratory was deactivated on 30 September 1992 and subsequently became a part of the U.S. Army Research Laboratory (ARL) on 1 October 1992.

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I. Introduction

Residents of villages bordering on US Army training areas in the Federal Republic of Germany have long complained of excessive noise from gun firings. Residents of Dalherda, which adjoins the Wildflecken Training Area (WTA) on the northwest side, have even used noise measuring instruments to document their complaints. The German guidance levels for maximum noise vary with the designation of the area.[1] These noise levels are given in terms of A-weighted decibels. The lower frequencies of noise are heavily filtered to yield the A-weighted values. The human ear also filters the lower frequencies and has a greater sensitivity to the higher frequencies. The A-weighted values of noise are commonly used for lower amplitude noise. Commercial plants are permitted to produce up to 70 decibel (dB) while for hospitals the level is 45 dB by day and 35 dB at night. Dalherda, with its mix of residential and commercial structures, would be designated as 60 dB in the daytime and 45 dB for the night hours, unless there were mitigating circumstances. During the day, short noise peaks that exceed the daytime designated level by less than 30 dB are permitted. The night value is 20 dB. However, these levels may be exceeded when the implementation of noise prevention measures conflicts with military requirements or when the expenditures necessary for noise prevention measures relative to the attainable noise reduction are not justifiable.[2]

Noise measurements[3] at Dalherda in 1986 showed that the A-weighted impulse noise level for the standard Bradley Fighting Vehicle (BFV) firing at Range 10 of the WTA was 65.5 dB. Of course, the measured noise can vary widely with the weather conditions. Measurements obtained at another time yielded more than 70 dB.[4] Thus, if gun blast noise is classified as a short noise pulse, the noise levels for night training at Range 10 may be above the German guidance values. The 20 mm German Marder automatic cannon has been fired at Range 10 but its noise output was 6 dB lower than the 25 mm cannon firing the M793 training ammunition.

Recently, a group from Dalherda obtained an injunction preventing urgently needed construction and conversion of Range 10 to a BFV training range. The gun blast noise needs to be reduced to help lift this injunction. The U. S. Army in Europe (USAREUR) has investigated many alternatives for reducing impulse noise, including earthen berms, autobahn noise barriers, and even a carport-like structure. These options, however, allow only stationary firing positions and are relatively ineffective and expensive. In 1987 the Deputy Chief of Staff of Engineers (DCSENG), 7th Army, issued a requirement that the impulse noise should be reduced 10 dB for all training at Wildflecken. From the discussion above, this amount of attenuation should be sufficient to meet the German noise guidelines at Dalherda.

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[1] Committee for the Application of Measurement Techniques, "VDI-Guideline Society of German Engineers Assessment of Working Noise in the Vicinity VDI 2058, No. 1," English translation,US Army Foreign Service and Technology Center, FSTC-HT-208-87, June 1987.

[2] Committee for the Application of Measurement Techniques, "Specialties and Special Areas - Noise Prevention in the German Federal Armed Forces - Revision," English translation, US Army Foreign Service and Technology Center, FSTC-HT-207-87, June 1987.

[3] Schomer, P., "Private Communication," U. S. Army Construction Engineering Research Laboratory, Champaign, IL, September 1986.

[4] Chapman, COL, "Private Communication," Office of Deputy Chief of Staff, Engineers, USAREUR, June 1986.

In October 1989, an Operational Needs Statement (ONS) for a general purpose muffler was signed by the Commander in Chief (CINC), USAREUR. The general purpose muffler should be capable of being used both with TP-T and saboted rounds. The need for this noise attenuation device has been extended to other German Training Areas in Bergen, Grafenwoehr, and Baumholder. The device is required by the ONS to reduce the noise by at least 10 dB to the sides and rear of the firing vehicle. Furthermore, it should be durable, reliable, safe, and have the same training performance as the barrel-brake combination. The Ballistic Research Laboratory (BRL) has already fabricated a fieldable prototype muffler that reduces the noise more than the required amount, does not degrade capacity for training, and does not harm any components of the Bradley system.[5] However, the muffler is designed to be used only with TP-T ammunition. With the M910 saboted training round arriving soon in Germany, the need is apparent for a general purpose muffler.

In response, BRL has designed and fabricated two prototype mufflers capable of being used with all types of ammunition. These prototypes can be used to establish the feasibility of reducing the 25 mm gun-induced noise from the German Training Areas (GTA). Hopefully, a production muffler could be built that differed only minimally from the prototype.

The muffler design was influenced by assumptions about its projected role. The developed version of the prototype would be used at selected training sites and would not be used tactically or in training that involves travelling over rough terrain at high speeds. The mufflers would be attached to a barrel and kept close to the range. Troops would remove their barrel/brake system and replace it with the barrel/muffler system. Removal and replacement is facilitated by a twist-lock installation of the barrel.

This report describes the experiments, design efforts, and tests performed. The tests were performed primarily to affirm that the requirements of the ONS had been met.

II. Muffler Optimization Experiments and Analysis

The early design phase was guided primarily by experiment, but computer models were also used. The configurable muffler, also used in the design of the TP-T muffler[6] and shown in Figure 1, is not designed to be used with saboted projectiles. Nevertheless, components were used that would function like those used with a sabot-capable muffler. Pressure histories in each chamber and in the free field to the side and rear of the configurable muffler were obtained. Numerical studies[7,8] of selected muffler configurations also helped optimize the design of these mufflers. From these tests and studies, approximate optimum parameters were obtained for two fundamentally different configurable muffler designs. These optimized parameters were then used to design a muffler that would attach to a special perforated

[5] Lewis, H. N., "TECOM Project No. 1-WE-100-BUS-004, Research Test, Noise Suppressor Study for Gun, Automatic, 25-MM, M242," U. S. Army Combat Systems Test Activity, Firing Record No. S-51048, March 1988.

[6] Fansler, K. S., and D. H. Lyon, "Attenuation of Muzzle Blast Using Configurable Muffler," ARBRL-TR-2979, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, January 1989. (AD A206565)

[7] Cooke, C. H. and K. S. Fansler, "Numerical Simulation and Modeling of Silencers," BRL-MR-3735, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, January 1989. (AD A206746)

[8] Fansler, K. S., C. H. Cooke, W. G. Thompson, and D. H. Lyon, "Numerical Simulation of a Multi-Compartmented Gun Muffler and Comparison with Experiment," *Proceedings of the 60th Shock and Vibration Symposium*, held at Virginia Beach, VA on November 14 - 16, 1989. Hosted by the David Taylor Research Center, Portsmouth, VA.

barrel; the other muffler was designed to attach to the standard barrel.

The conventional muffler cannot be used with saboted rounds because the sabot components immediately separate outward away from the subprojectile and impinge upon the first baffle. A design that could be used with saboted rounds is shown in Figure 2. This design is mounted on the standard M242 barrel. Ideally, the exit hole is placed far away from the muzzle to allow the flow to expand and thus lower the peak energy efflux. The energy efflux determines the gun muzzle blast noise level, according to a computer-implemented predictive method.[9,10,11,12] But the hole must also be placed near the muzzle to minimize the diameter of the exit hole, since the envelope encompassing the sabot component boundaries expands rapidly with distance from the muzzle. An optimum distance exists for minimizing the noise production.

The envelope of the sabot outer boundary can be ascertained by both theory and experiment. Figure 3 gives the calculated envelope diameters of the sabot components and also of a particle located on the circumference of the bore. The envelope diameter is given for a sabot that breaks into four components. For this calculation, the aerodynamic forces on the sabot components and particles were neglected. For a particle, the radial distance increases only slowly at first and then asymptotically approaches a constant radial velocity. The diameter of the center of mass for the sabot components also asymptotically approaches a constant radial velocity but the rotation of the sabot components will cause the envelope diameter to undulate. This behavior is seen for larger distances than are depicted here. X-rays of the M-910 sabot components are in agreement with the calculations. M910 subprojectile/sabot systems were also fired through an aluminum ring placed on the bore axis and the predictions were further confirmed. However, the expanding propellant gas pushed propellant particles out and against the front surface of the ring even though the ring was located to allow unimpeded sabot passage.

Exploratory experiments with the configurable muffler[6] shown in Figure 1 were conducted using the component set-up shown in Figure 4. The gage numbering convention was the same as shown in Figure 4. The exit hole was located four calibers from the muzzle with an exit hole diameter of 1.1 caliber. Far-field tests yielded 10.1 dB A-SEL to the side and 19.2 dB A-SEL to the rear. A muffler designed to be used with saboted ammunition and with an exit hole that was located four calibers from the muzzle would require a large exit hole to pass the expanding sabot components. The noise attenuation for sabot-capable mufflers might be much reduced from the configurable muffler values. Further experiments were performed to establish optimum exit hole distances from the muzzle. These experiments and results are discussed in the Appendix.

Prediction methods adapted for the computer indicated that for the exit hole diameters

[9] Fansler, K. S., and E. M. Schmidt, "The Relationship Between Interior Ballistics, Gun Exhaust Parameters and the Muzzle Blast Overpressure," AIAA Paper 82-0856, *Proceedings of the AIAA/ASME 3rd Joint Thermophysics, Fluids, Plasma and Heat Transfer Conference*, St. Louis, Missouri, 7-11 June 1982.

[10] Heaps, C. W., K. S. Fansler, and E. M. Schmidt, "Computer Implementation of a Muzzle Blast Prediction Technique," *The Shock and Vibration Bulletin*, Part 1, published by The Shock and Vibration Center, Naval Research Laboratory, 22-24 October, 1985, pp. 213-230.

[11] Fansler, K. S., "Dependence of Free Field Impulse on the Decay Time of Energy Efflux for a Jet Flow," *The Shock and Vibration Bulletin*, Part 1, published by The Shock and Vibration Center, Naval Research Laboratory, 22-24 October, 1985, pp. 203-212.

[12] Smith, F., "A Theoretical Model of the Blast from Stationary and Moving Guns," *First International Symposium on Ballistics*, Orlando, Florida, 13-15 November 1974.

required to pass the sabots, the resulting noise attenuation might be inadequate to meet the requirement of 10 dB attenuation. The noise performance cannot be increased by increasing the chamber volume after a minimum value is attained. The limited attenuation possible contrasts with the noise attenuation attained by conventional mufflers that depend on volume, number of chambers, spacing of baffles, etc., to achieve a required performance. An alternative design was explored that used a nonstandard barrel with perforations bored into the barrel near the muzzle. The muffler would slip over the perforated portion of the barrel and attach to a threaded area on the barrel located behind the perforated area. The noise attenuation performance of this design can be increased by chamber volume and other parameters. The configurable muffler discussed earlier was also used to find optimized geometries for this design concept. Components, such as simulated perforated gun tubes and perforated baffles, were designed and fabricated to be used with the configurable muffler. Figure 5 shows two of the perforated baffles used in testing these configurations. Some of the simulated slotted gun tube sections are shown in Figure 6. Slots three-eighths of an inch wide were milled into the tube 90 degrees apart. The exit tubes used in these experiments are shown in Figure 7. The Appendix describes most of the configurations tested and subsequent results.

III. Design and Stress Analysis of Mufflers

With the optimized geometrical parameters obtained from the configurable muffler experiments, mufflers for a perforated and a standard barrel were designed. The perforated barrel muffler, shown in Figure 8, is derived from the S1L3E2R configuration (discussed in the Appendix). The standard barrel muffler is shown in Figure 9. Drawings of the two muffler designs were used by the BRL model shop to fabricate the prototypes. They were machined from eight-inch round bar stock of 17-4 PH stainless steel. This type of stainless steel was used in an earlier successful TP-T muffler design. The weight of the mufflers was minimized in order to avoid both degradation of projectile dispersion and interference with execution of training. Each muffler weighed approximately 6 kg.

To minimize weight and design for maximum structural integrity, extensive stress analysis was performed on the perforated barrel muffler. Figure 10 shows one of many Finite-Element (FE) meshes created for analysis. The muffler was modeled with 2-Dimensional axisymmetric elements. Based on the results from the S1L3E2R configuration, a pressure of 40 MPa was placed on the interior of the muffler. This pressure is represented by the arrows in Figure 10. The shape of the aft section came directly from the proven TP-T muffler. The center baffle went through numerous iterations in order to minimize its weight and stress. Overpressure was assumed on only one side of the center baffle as a worst case loading condition. Figure 10 shows the Von Mises stress contours in the final baffle design under that loading. The front baffle was perforated to allow the propellant gas to pass through and fill the chamber volume. This baffle acts to reduce peak reflected pressures in the muffler and thus reduce maximum material strains. Because the perforated baffle is not axisymmetric, it also was modeled with 3-dimensional solid elements. No stress analysis was performed for the standard barrel muffler. Much of the perforated barrel muffler's geometry could be incorporated into the standard muffler design with minor changes.

A special perforated barrel was designed concurrently. This design was preferred to a perforated barrel extension that would be integral with the muffler and would fit onto the standard barrel. Possible problems with the barrel-extension axis moving relative to the bore axis of the standard barrel are avoided. With a perforated barrel, the perforations, and thus the muffler, can be located nearer the breech. This design will minimize the moments transmitted to the cannon mounting and stabilization system.

An experimental long barrel was modified to have the M242 standard barrel contour except near the muzzle, where adaptation was made to fasten the muffler to the barrel and add perforations. Figure 11 shows the final design for the perforated barrel. The holes were spaced at the interval shown to insure that the sabot remained tightly bound to the subprojectile to prevent slippage while transiting the perforated area. The holes were originally uniform in size through the thickness of the barrel with their axes at a 60 degree angle from the gun barrel axis. The angled holes were used to facilitate flow into the closed chamber and thereby reduce the initial flow rate at the exit hole. Except for the first column of holes, the holes were opened up on the outer dimension of the barrel to improve safety and performance after the results of some toxic fumes tests were obtained. The toxic fumes tests are discussed in the next section. The first run of perforations begin approximately ten cm behind the muzzle of a standard barrel. Velocity tests performed with the perforated barrel and a standard barrel, using M793 ammunition, showed no significant differences. Calculations show that the barrel could be made shorter with the run of perforations placed 8 cm nearer the breech without appreciably changing the ballistic trajectory. The muffler, located nearer the breech, would further reduce the moments of force around the trunnion of the cannon.

IV. Test Plans and Results

The two models were tested for conformance to some of the ONS requirements. In addition to the noise requirement discussed in the Introduction, the firing dispersion must not be degraded by the use of the muffler. The toxic fume levels must meet the Surgeon General's standards for armored vehicles.[13] Troops need to be able to perform the Table VIII day scenario [14] plus the required tasks from the corresponding night scenario without reaching specified toxic levels.[15] In conjunction with the Combat Systems Test Activity (CSTA), tests were performed to obtain noise attenuation, dispersion, and toxic fume concentration levels.

1. Noise Attenuation Test and Results

The first test determined if the muffler could reduce the noise by ten decibels to the sides and rear of the gun. To avoid spurious reflections from woods and hills, a large open field was used. CSTA's Range AA-3 at Aberdeen Proving Ground fulfilled these requirements.

[13] MIL-STD-1472C, "Human Engineering Design Criterion for Military Systems, Equipment and Facilities," 2 May, 1981.

[14] Woods, SSG J., "Private Communications," Bradley Instructor Detachment, Fort Benning, Georgia, 1989.

[15] Beavers, H. L., and C. Herud, "Toxic Fumes Test of 25-mm Muffler," Report No. 90-CC-033, U. S. Army Combat Combat Systems Test Activity, Aberdeen Proving Ground, MD, performed under TECOM Project No. 1-WE-100-BUS-048, January 1990.

Dr. Nelson Lewis and his group from the Army Environmental Hygiene Activity (AEHA), Aberdeen Proving Ground, recorded the sound levels. The noise levels measured were dB A-weighted - Sound Exposure Level with the RMS single event threshold level set at 85 dB. The C-weighted - Sound Exposure Level was also measured with the RMS single event threshold level set at 95 dB. The lower frequency components of C-weighted noise are only lightly filtered electronically but are heavily filtered for A-weighted noise. If the muffler acts as a high-pass filter, the C-weighted attenuation values would be higher than the A-weighted values at closer distances.

The microphones for recording sound level were placed 75 meters to the rear and to the left of the M242 automatic cannon. Longer measurement distances would require an even larger field and increase the difficulty of obtaining accurate measurements. Firings were conducted from a hard-stand using M793 and M910 ammunition. Ten M793 rounds were fired with the brake at 10 second intervals. The brake is the standard muzzle device for the barrel. The barrel was then removed and replaced with the perforated barrel/muffler system. Ten M793 rounds were again fired. The standard muffler model was then tested the same way. The procedure was then repeated for the M910 ammunition. Tests were conducted on 26 October 1989 and again on 22 November 1989. The averaged results for the A-weighted sound exposure level (SEL) measurements are given in Table 1.

Table 1. Noise Attenuation Referenced to Standard Barrel with Brake – dB A - SEL

Position	Perforated-Barrel Muffler		Standard-Barrel Muffler	
	M793	M910	M793	M910
Side	11.1	11.4	9.0	8.4
Rear	17.6	19.7	10.2	11.7

The perforated barrel muffler attenuates more than the required amount to the side while the standard barrel muffler does not attenuate enough to meet the requirements of the ONS. The noise level to the side with the brake was 4.5 dB higher for the M910 ammunition than for the M793 ammunition. It was earlier noted that the 20 mm German Marder, which is allowed unrestrictive firing at Range 10, was 6 dB quieter than the 25 mm M793 firings at Dalherda. Thus, if these ammunition-induced differences do not change at 1500 meters, the muffled M910 should be at least 1 dB quieter than the 20 mm German Marder gun.

The averaged results for the C-weighted SEL measurements are given in Table 2. Because of the high threshold value for initiation of recording, measurements could not be made to the rear for the perforated muffler. From comparison with the results for the standard barrel muffler, the attenuation values must exceed 20 dB. The C-weighted attenuation values are higher than the corresponding A-weighted attenuation values. These results show that both the perforated-barrel and standard-barrel muffler acts as a high pass filter. Such a filter reduces the low-frequency wave components that cause windows and structures to shake and rattle. The high-frequency components are also more rapidly absorbed by ground effects and the atmosphere.

Table 2. Noise Attenuation Referenced to Standard Barrel with Brake – dB C - SEL

Position	Perforated-Barrel Muffler		Standard-Barrel Muffler	
	M793	M910	M793	M910
Side	14.2	13.8	10.0	10.2
Rear	****	****	19.0	20.1

Because the standard barrel muffler did not meet the noise ONS requirement, no other tests were run with it. All further development efforts were channelled to the perforated barrel muffler.

2. Toxic Fumes Test and Results

For the majority of the toxic fume tests, a Bradley M2A2 vehicle identified as serial No. P008 was used. All hatches were closed and the engine was running at an idle pace. The toxic fume levels are lower with the hatches open and the engine not running. The toxic fume levels were monitored at the commander's position, the gunner's position, the driver's position, and a position in the crew compartment. These toxic fumes are commonly occurring components of burnt propellant gas. After a round is fired, the burnt propellant gas enters the crew compartment and turret from the gun breech and other openings. The expected firing schedule for a Table VIII training scenario was used with some night tasks brought forward to the day. The training scenario is meant to simulate possible tactical target encounters. Each task consists of a target to be destroyed and usually requires a certain amount of ammunition to be expended. The scenario involves completing tasks that expends 101 rounds of 25 mm ammunition and 150 rounds of 7.62 ammunition in approximately 20 minutes. No other training scenario is expected to result in a higher percentage carboxyhemoglobin level in the blood (COHB). The COHB value is a measure of the toxic levels in the body and training is permitted until the COHB reaches 10%. If this level is reached, training is suspended for at least eight hours.

Separate test runs were accomplished for the brake alone, with the muffler attached, and finally for the brake with a special machine gun door seal installed and the rear hull fan programmed to come on at trigger pull and then go off when the gun rotor fan stops running. The original rubber stripping (not a seal) around the coaxial-machine-gun doors was removed and replaced with a closed cell weatherstripping foam seal. Functional seals have reduced the toxic fume levels somewhat[16] by limiting entrance of toxic-laden gases from the plenum chamber. Table 3 gives the test results in terms of the Maximum Allowable Consecutive Exposures (MACE) and the COHB. MACE is the number of successive replications of a scenario that may be performed before the COHB (toxic level) reaches the Surgeon-General imposed limit of 10%. As indicated by the Table, the ammunition mix for this scenario is 83 M910 saboted training rounds and 18 M793 full bore training rounds.

[16] Lyon, D. H., and D. C. Kelham, "Bradley Improved Gun Gas Removal System," ARBRL-TR-3035, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, September 1989

Table 3. Table VIII Scenario (83 - M910, 18 - M793)

Description	MACE	Max COHB	Remarks
Brake	3	4.2	
Muffler	8	2.8	Eye Irritation
Brake/Seal/Fan	∞	1.5	

The presence of the muffler decreases the COHB from the brake case. This lowered COHB may be due to additional burning of the propellant gases while in the first muffler chamber. Because the holes are slanted 30° forward for gas entering the chamber, when the pressure in the barrel becomes lower than the chamber pressure, the gas exiting the chamber tends to travel back toward the breech. Some of this expelled burnt gas may exit the breech, with the balance of the gas exiting the muffler projectile hole. The burnt gas would have a lower carbon monoxide content than the unburnt gas. Much of the propellant gas entering the BFV via either the breech or the muffler projectile hole would have been subjected to this burning process, thus lowering the CO concentration of the propellant gas.

Two flashbacks from the breech also occurred and were attributed to the hole perforation design of the modified barrel. When the muffler was first tested, the holes of the barrel were of uniform area and slanted forward, as discussed previously. This could increase the propellant gas flow out the breech and also increase the concentration of propellant gases in the zippered bag that surrounds the breech area of the cannon. Possibly, the concentration and temperature of the propellant gas was high enough to permit flashback. The bag protects the crew from the flashback and also restricts the flow of propellant gases from the breech to the turret and crew area. After the first series of toxic fume tests, the perforating holes in the barrel were opened up to reduce their average angle and thus reduce the propellant gas flow back toward the breech. The perforated barrel showing these redesigned holes is shown in Figure 11.

Erosion of the exit hole by burnt and unburnt propellant particles also occurred during this phase of the test. Minor design changes will reduce the erosion rate or eliminate the problem. By bringing the exit hole nearer to the muzzle with an unchanged diameter, collision of the larger particulates with the lip of the exit hole is avoided. The larger particulates, which do the most damage, have too much inertia to make the velocity change necessary to impinge on the edges of the exit hole. Also, the cone at the exit hole may be given more mass to reduce the temperatures. The erosion is accelerated at higher temperatures. Yet another approach would be to use a replacable screw-in cone.

To assure that eye irritation no longer occurred when smoke was removed with a fan modification and that the toxic fume levels were acceptable after the perforating holes had been modified, a second trial series was run with the same M910/M793 combination. Further modification of the fan system operation was performed for this test, based on other toxic fumes tests.[17] For this configuration, both fans come on when the trigger is pulled but the

[17]Beavers, H. L., and C. Herud, "Private Communication," U. S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD, April 1990.

front hull fan's flow direction is reversed. The tests that used these modifications were run with the BFV identified as PQT-G 600 HP Vehicle M2A2-20443. Table 4 gives a summary of the results.

Table 4. Table VIII Scenario (83 - M910, 18 - M793)
Front Hull Fan Reversed - Trigger Actuates All Fans

Description	MACE	Max COHB	Remarks
Brake	No Restrict.	2.20	Negligible Smoke
Muffler	3	4.12	Negligible Smoke No Eye Irritation

When the trial was performed with the regular issue brake, only 76 M910 rounds were fired instead of the standard 83 rounds. A miscount of the rounds had occurred. From the data, the maximum COHB value would have approximated 2.30 if the standard number of rounds were fired. For the test with the muffler, the COHB values allow three repetitions. No breech flashbacks occurred. The muffler with the two-fan modification has the same MACE as for the BFV that was tested earlier with no modifications and with the brake attached. A BFV crew usually fires one Table VIII scenario during the day and completes the rest of the Table VIII tasks at night. The limit of 10% COHB would only be exceeded if the crew had to perform the enhanced day scenario more than three times because of weak performances.

3. Dispersion Test and Results

The dispersion tests were conducted primarily to determine if the dispersion would not be significantly degraded by the use of a muffler. These tests were designed to simulate as well as possible the actual training conditions. Tests were conducted both statically and on the move. Tests were performed on the move because, even though the muffler might perform satisfactorily while firing in a static position, there was a possibility that the presence of the muffler might interfere with the proper operation of the stabilization system and thereby degrade the dispersion. The 9.1 meter square target cloth, placed 1000 meters downrange, was fired upon with the BFV both stationary and moving forward at 20 km/hr. One of the firing sequences found in the Table VIII scenario was used. Two spotting or single shots were fired, followed by two three-round fast rate bursts. This sequence was repeated, thus firing 16 shots into the target except as noted. The lateral, vertical, and radial dispersion are all given in Table 5.

Much more data have been obtained for the M910 saboted training round. The first row shows the first data obtained. To determine if the first results for the M910 round might be a fluke, it was selected for more extensive testing. This testing is not yet complete as two more firing events with the muffler are planned and five more firing events are to be performed with the brake. The results, although incomplete, indicate no significant degradation of dispersion due to use of the muffler.

Table 5. Dispersion for Static Firings

	$\sigma_x(mil)$		$\sigma_y(mil)$		$\sigma_r(mil)$	
	MUFF	STD	MUFF	STD	MUFF	STD
M793	0.43	0.53	0.57	0.50	0.74	0.75
M791	0.57	0.46	0.55	0.39	0.82	0.62
	0.50		0.39		0.68	
M910	1.06	0.56	0.61	0.61	1.25	0.85
	0.43		0.46		0.65	
	0.47		0.52		0.72	
	0.45		0.56		0.75	

For the fire-on-the-move trials, the BFV fired as it moved frontally toward the target on a paved road. Most of the training roads used by the BFV in the German Training Areas are gravelled. Nevertheless, the paved road should provide a more severe test since a paved road would provide less vibration damping. As the speed of the BFV is increased, the vibrations propagated to the gun system make the target viewed through the BFV sight appear to also be vibrating. As the speed is further increased, the vibrations decrease and firing on the target can commence. The gunner noted no degradation of the sighting view from the presence of the muffler. Table 6 gives the dispersion values when firing on the move.

Table 6. Dispersion for Fire on the Move

	$\sigma_x(mil)$		$\sigma_y(mil)$		$\sigma_r(mil)$	
	MUFF	STD	MUFF	STD	MUFF	STD
M793	0.79	0.81	0.54	0.74	0.98	1.13
M791	0.53	0.96	0.63	0.41	0.88	1.08
M910	0.82	0.75	0.77	0.86	1.17	1.17

Of the six combinations of the ammunition type with the state of motion, the dispersion pattern for the muffler was equal to or smaller than for the brake in five combinations. With the small sample data, no definite trend favoring either configuration can be seen. Further muffler development should include more exhaustive dispersion tests.

V. Summary, Conclusions, and Future Directions

In response to the need to reduce BFV firing noise emanating from German Training Areas, a prototype fieldable muffler has been designed, fabricated, and tested. First, experiments were conducted with a configurable muffler to optimize geometries for sabot-capable mufflers. A configuration utilizing a simulated perforated gun tube and one that could be used with the standard gun tube was selected. Mufflers utilizing the selected optimized parameters were designed with the aid of stress analysis to minimize weights. These designs were fabricated and tested against performance requirements.

Noise attenuation tests of the two mufflers were first performed. The noise was measured in terms of A-weighted SEL and C-weighted SEL. The perforated barrel muffler more than met the noise requirements but the standard barrel muffler could not attenuate enough to the side. Therefore, further testing was performed only with the perforated barrel muffler. The standard barrel muffler development was abandoned because of the limited potential for improving its noise attenuation performance.

Toxic fume concentrations were measured for both the perforated barrel muffler and the brake. These concentrations were measured while performing a Table VIII scenario that combined some night events into the day events. With only the muffler installed, the toxic fume concentrations were low but excessive smoke was generated in the BFV. The resulting irritation to the eyes was attributed to the smoke generated by firing the M910 round. The scenario was also performed with modifications for reducing toxic fume levels and smoke in the BFV. One modification involved reversing the front hull fan and switching on all fans when the trigger was pulled. This modification kept the toxic fume levels low while removing almost all the smoke from the BFV interior. No eye irritation was noted. It is recommended that this modification be adopted for use with the general-purpose muffler.

Dispersion comparisons between the perforated barrel muffler and the standard brake were made with 16-shot groupings on a 1,000 meter target. Firing was performed with both the BFV stationary and on the move. Although the dispersion for the muffler was smaller or the same for five of the six firing combinations, the small amount of data precluded definitive conclusions.

A small design change to combat erosion by particulates is necessary to meet the requirement that the muffler should last as long as the barrel. Such a small design change will not significantly degrade muffler performance.

To reduce loads on the stabilization system and trunnions, the muffler weight has been minimized while retaining sufficient muffler durability to match or exceed the barrel life. The resulting structure is geometrically complex and not easily machined. Another method of fabricating the muffler is needed to reduce production costs. The U. S. Army Armament Research, Development and Engineering Center (ARDEC) has explored the producibility of the muffler. Investment casting may be a good approach.[18] A muffler made from composite materials might also be a low-cost approach. The use of composites could significantly lower the muffler weight and improve performance.

There are other possible design improvements that could be implemented if the time and resources were available. Propellant gases presently must pass from the bore through numerous elongated holes into the entrance chamber. These holes are placed over most of the length of the chamber to obtain the necessary flow rate of propellant gas into the chamber. Instead of these elongated holes, slots could be placed at the beginning of the chamber (breech side of the chamber) to obtain the required flow rate. Experiment shows (see Appendix) that this placement improves attenuation performance. Because the length required for slots is less than for holes, the potential exists for also reducing the chamber

[18] Seeling, E. R., "Private Communication," U. S. Army Armament Research, Development, and Engineering Center, Picatinny Arsenal, NJ, January 1990.

length and perhaps the muffler length. The moment of force about the trunnions could then be reduced. However, the use of slots might degrade dispersion. Experiment could ascertain whether a good dispersion pattern could be maintained. The performance might also be improved if the perforated gun tube protruded through the second muffler chamber. The use of a perforated or slotted tube in the second chamber would remove the necessity of designing to reduce erosion. As for the first chamber, the use of slots would facilitate rapid emptying into the second chamber. With an exit hole the size of the projectile system instead of an exit hole that had to be larger than the expanding sabot components, the mass flow rate from the exit hole would be reduced. The resulting reduced peak energy efflux would enhance noise attenuation performance.

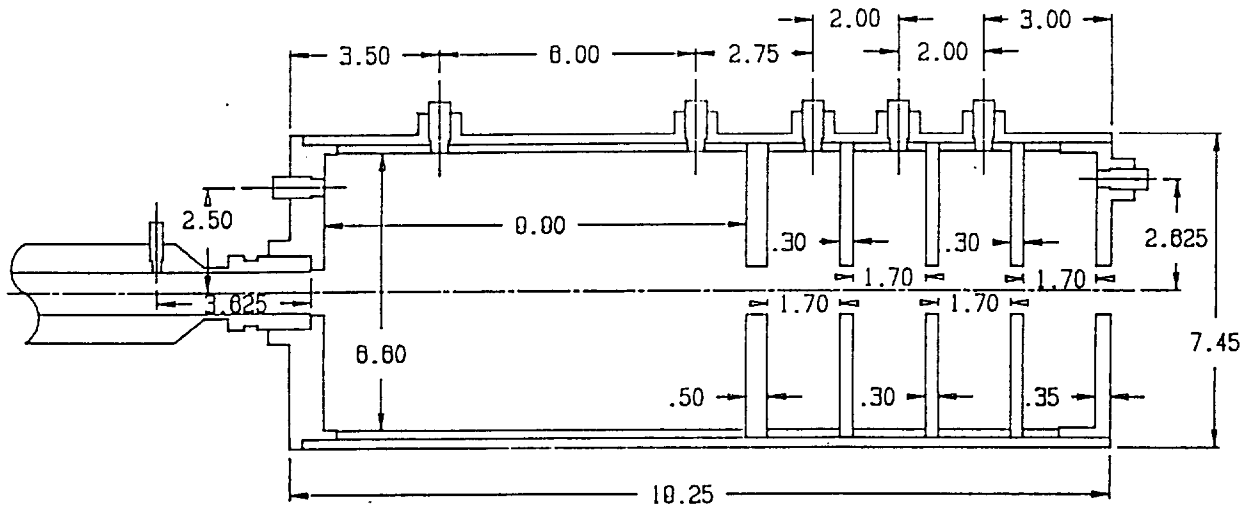


Figure 1. Configurable Muffler Shown with Pressure Gages

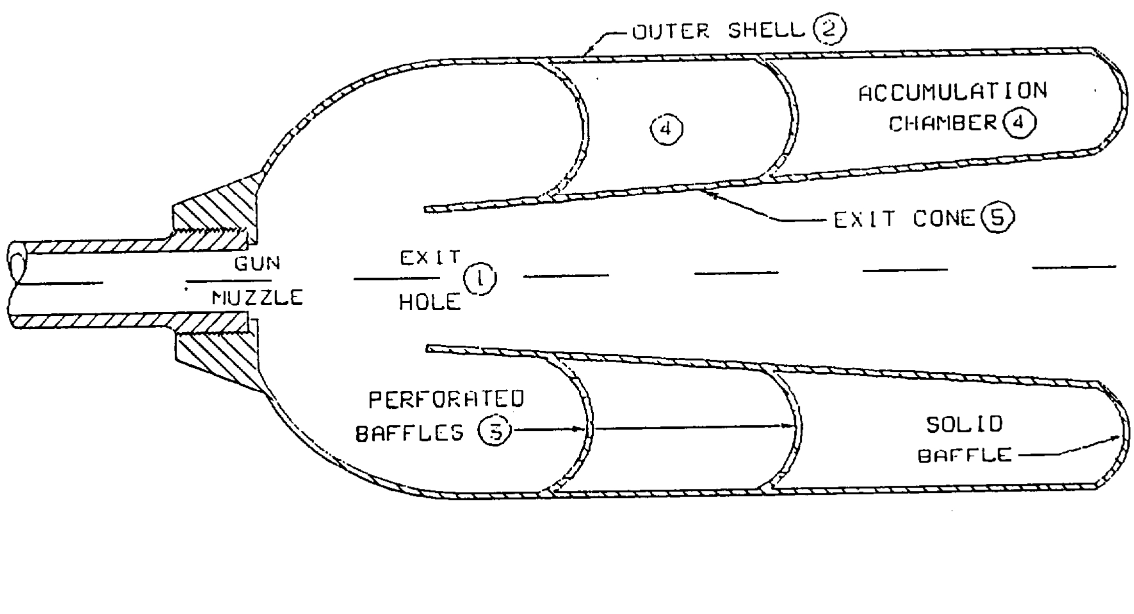


Figure 2. Design for a Sabot-Capable Muffler

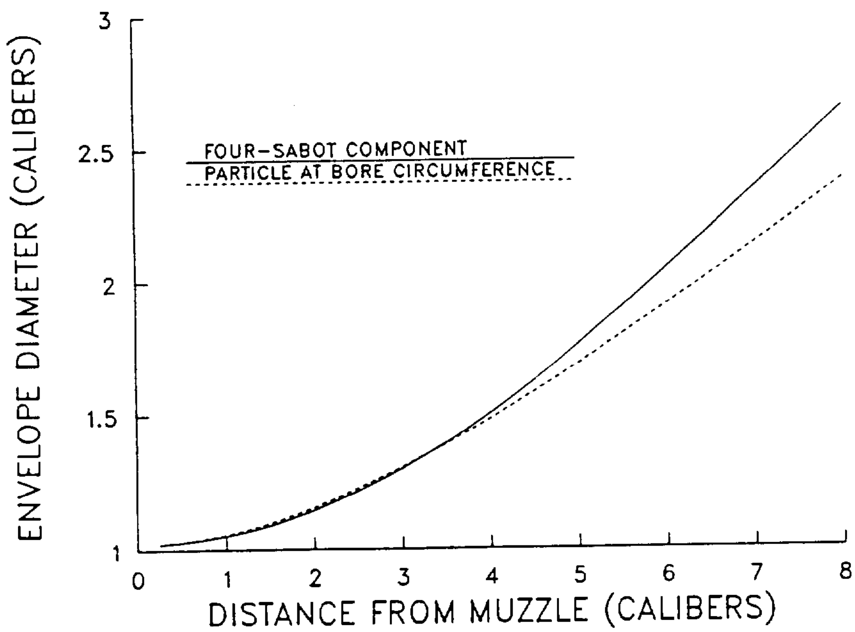


Figure 3. Outer Boundary Trajectories for Sabot Components and Particle on Circumference of Bore

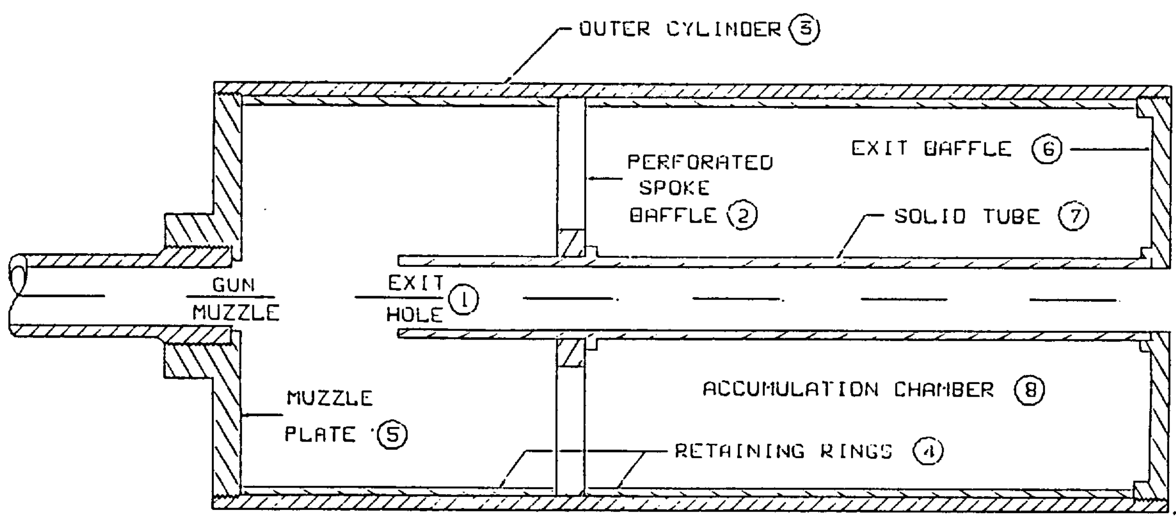


Figure 4. Muffler Configured to Test Attenuation Capability for a Sabot-Capable Muffler

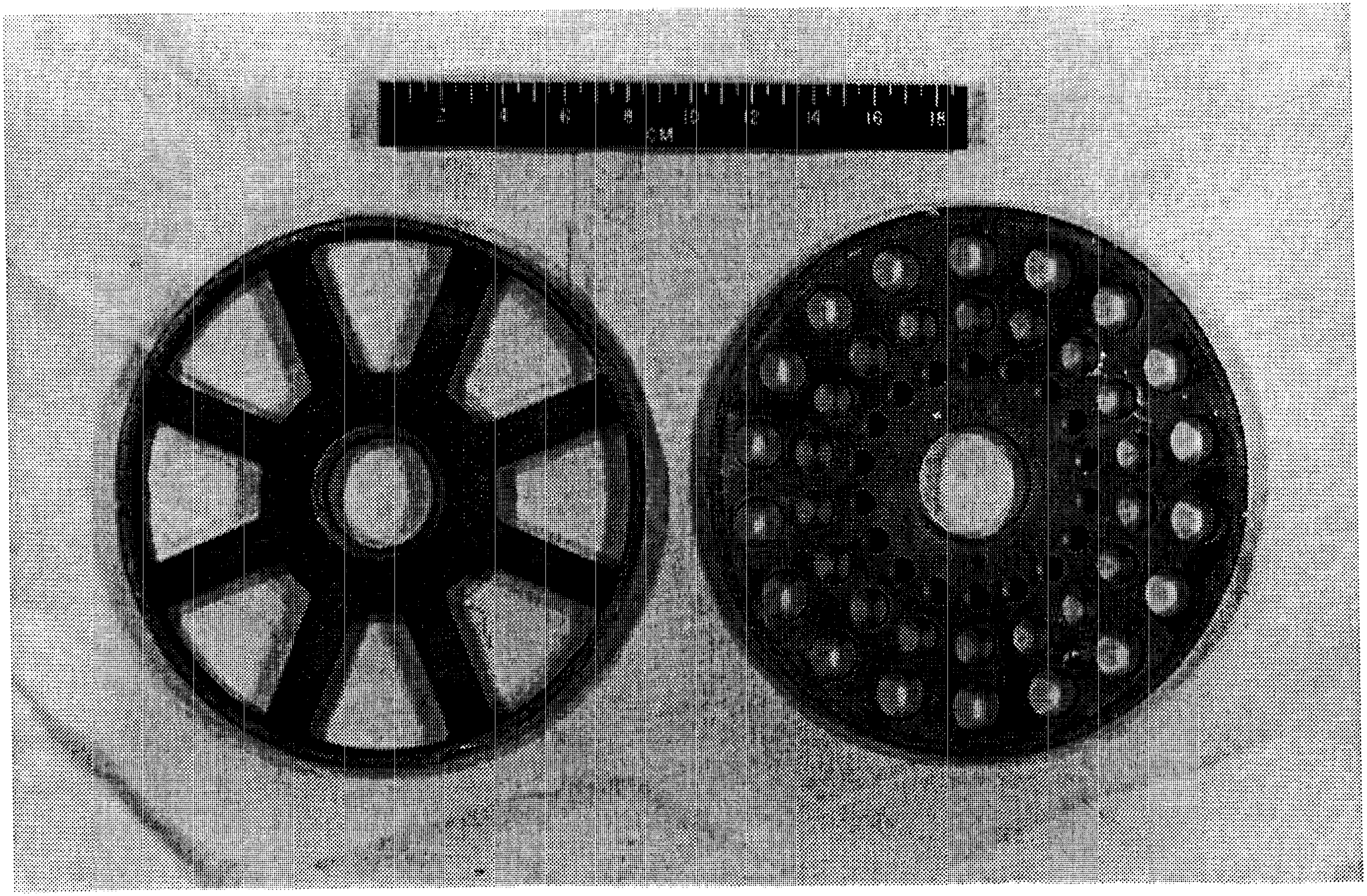


Figure 5. Two of the Perforated Baffles Used with the Configurable Muffler

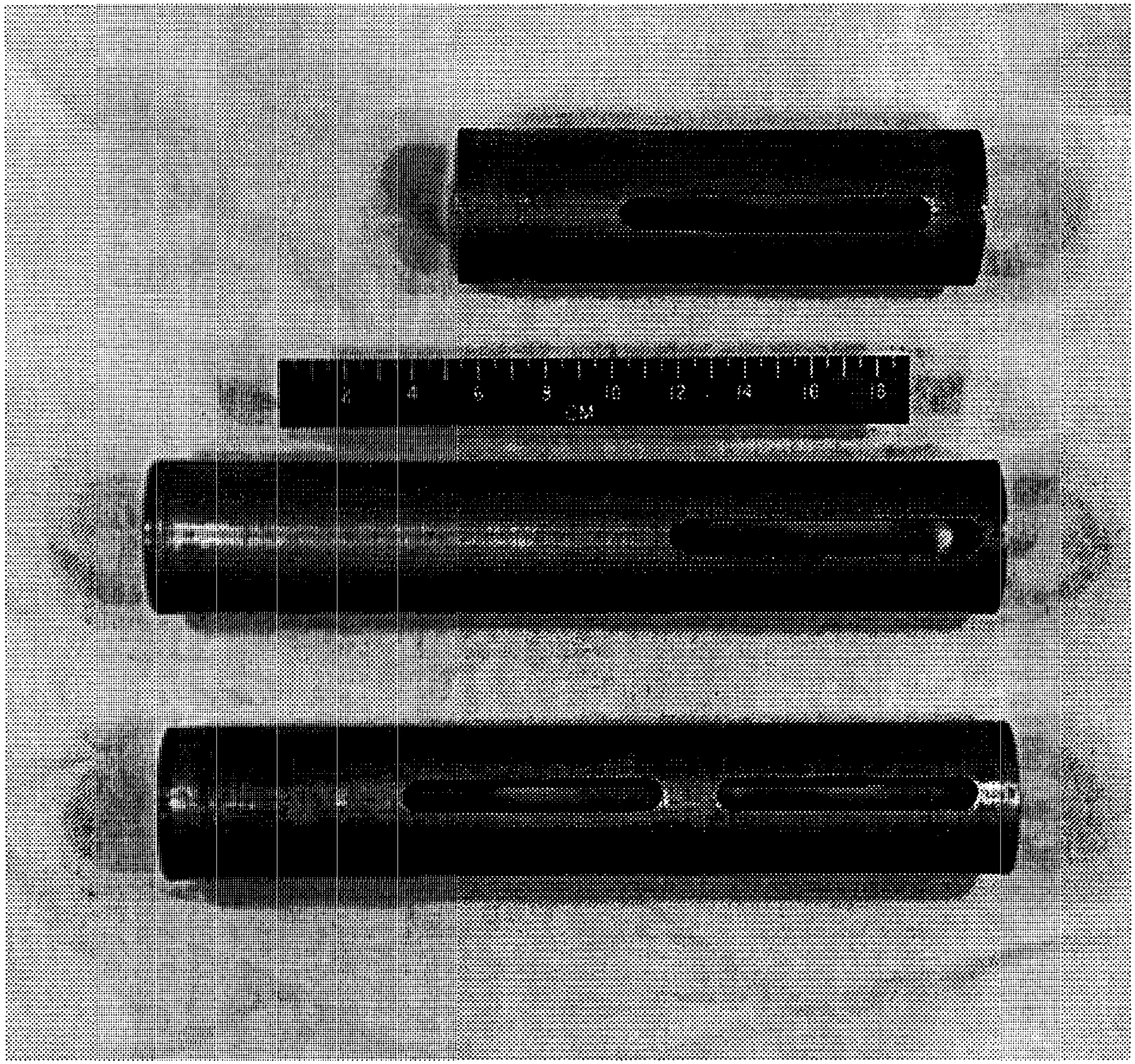


Figure 6. Simulated Slotted Gun Tubes Used with the Configurable Muffler

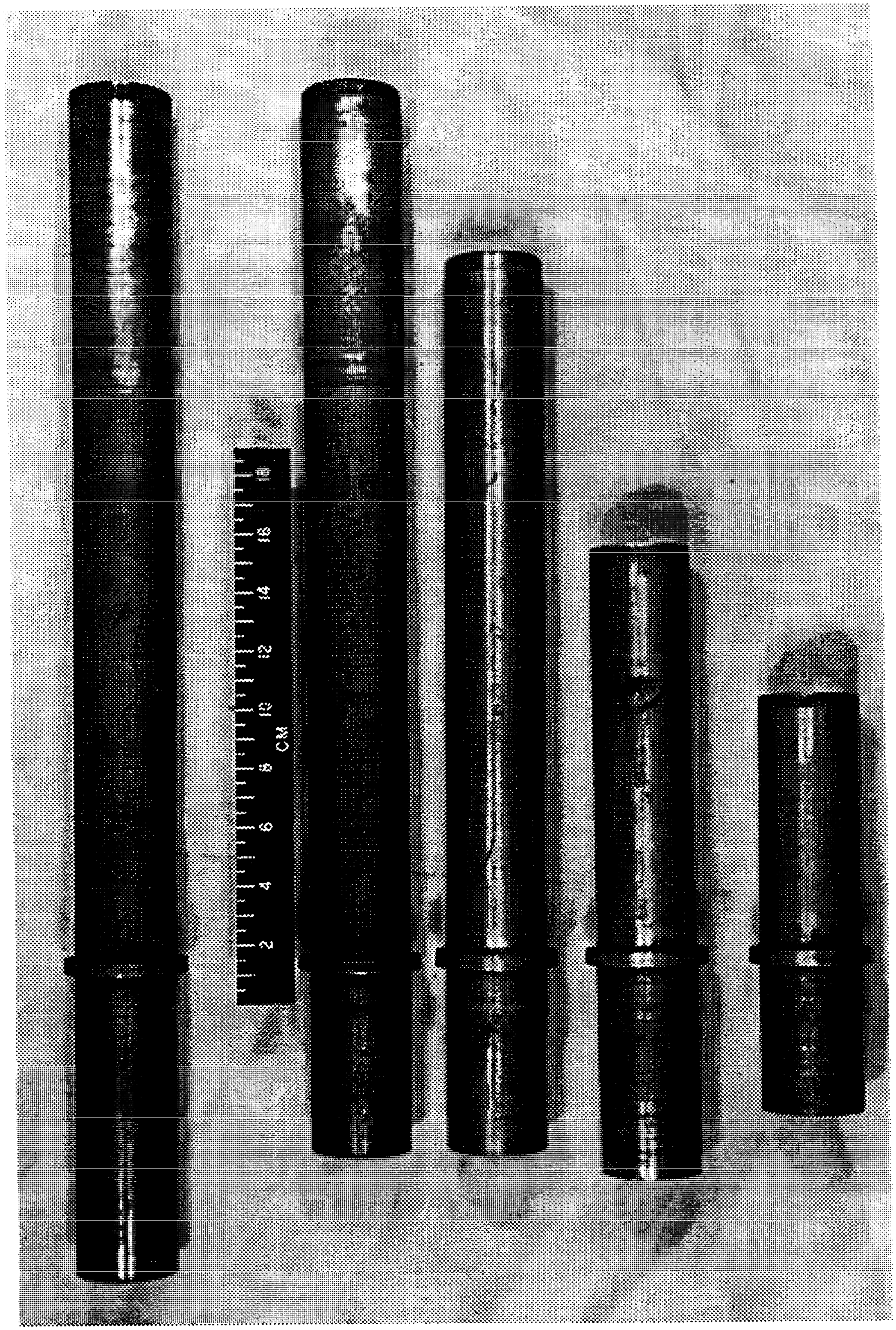


Figure 7. Exit Tubes Used with the Configurable Muffler

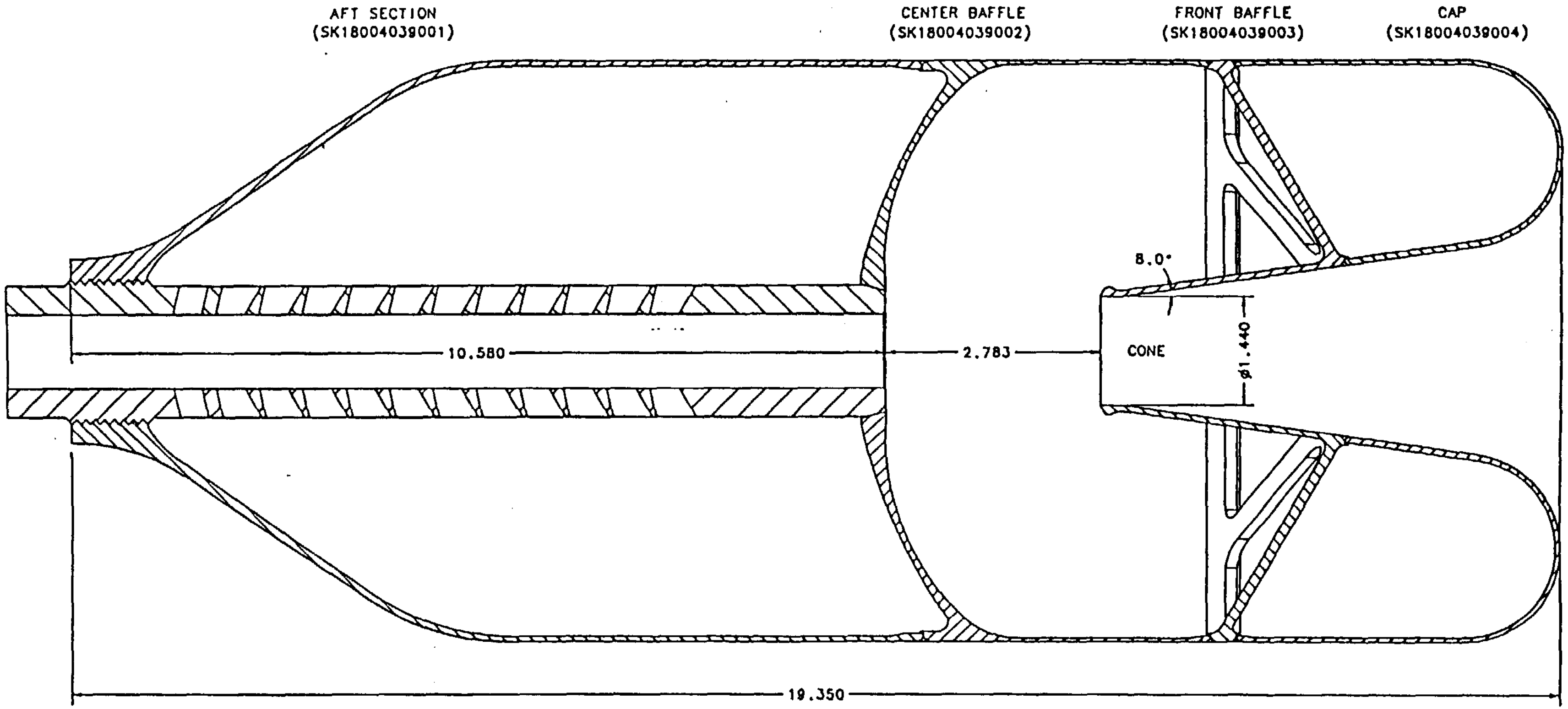


Figure 8. Schematic of Perforated-Barrel Muffler

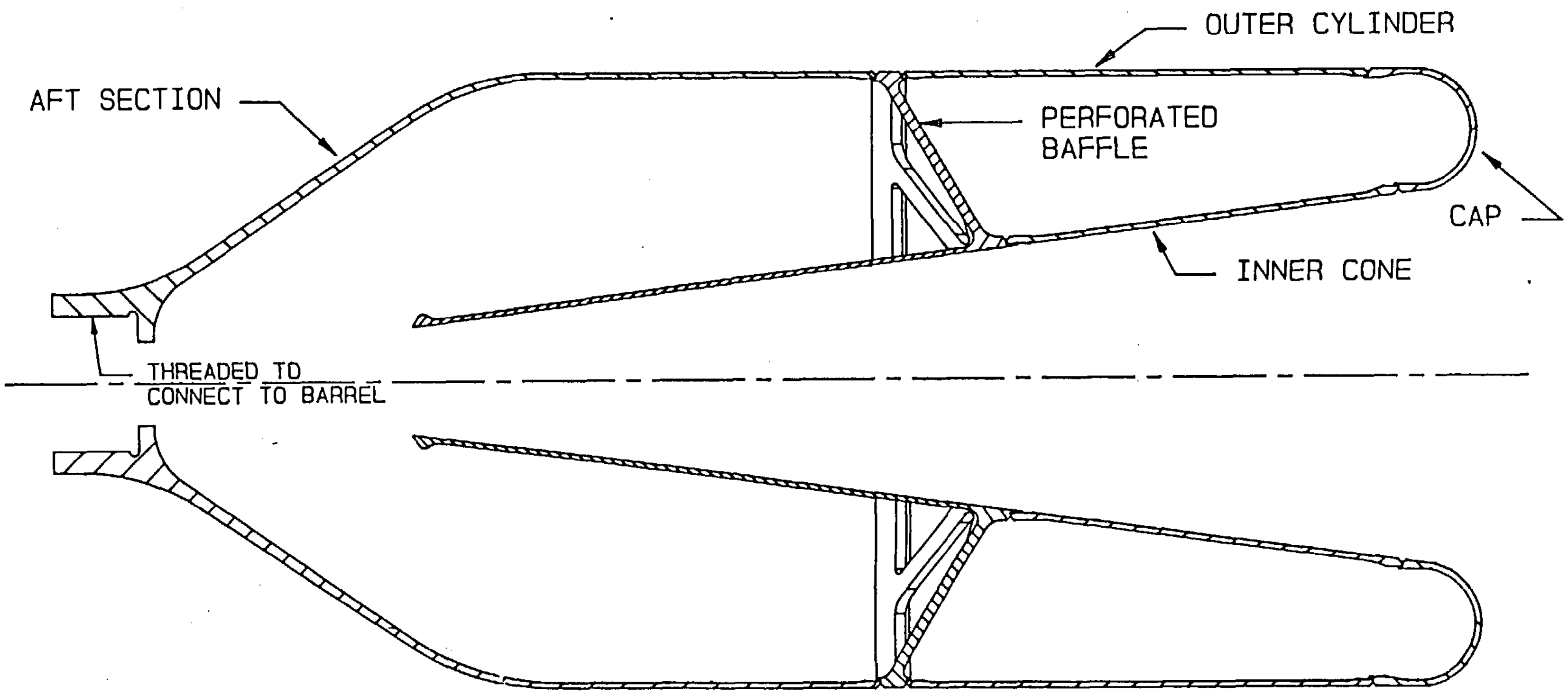
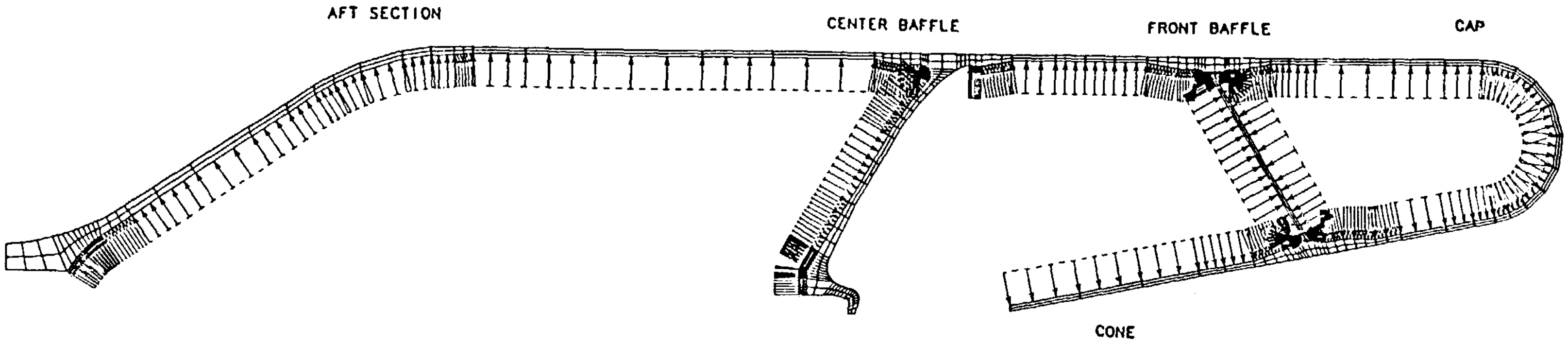
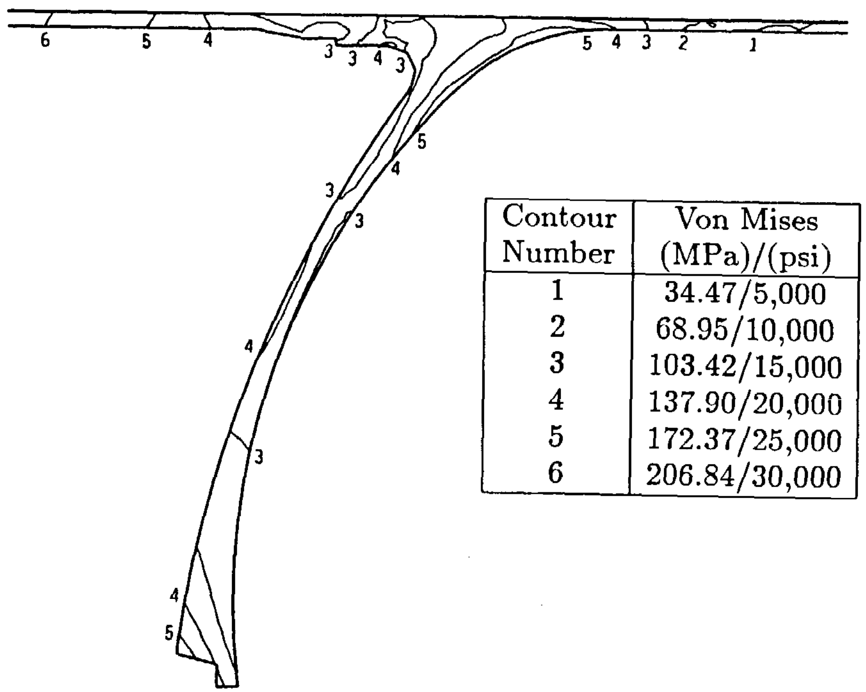


Figure 9. Schematic of Muffler to be used with the Standard Barrel





Contour Number	Von Mises (MPa)/(psi)
1	34.47/5,000
2	68.95/10,000
3	103.42/15,000
4	137.90/20,000
5	172.37/25,000
6	206.84/30,000

Figure 10. A Muffler Design with Loadings Shown for Subsequent Stress Analysis

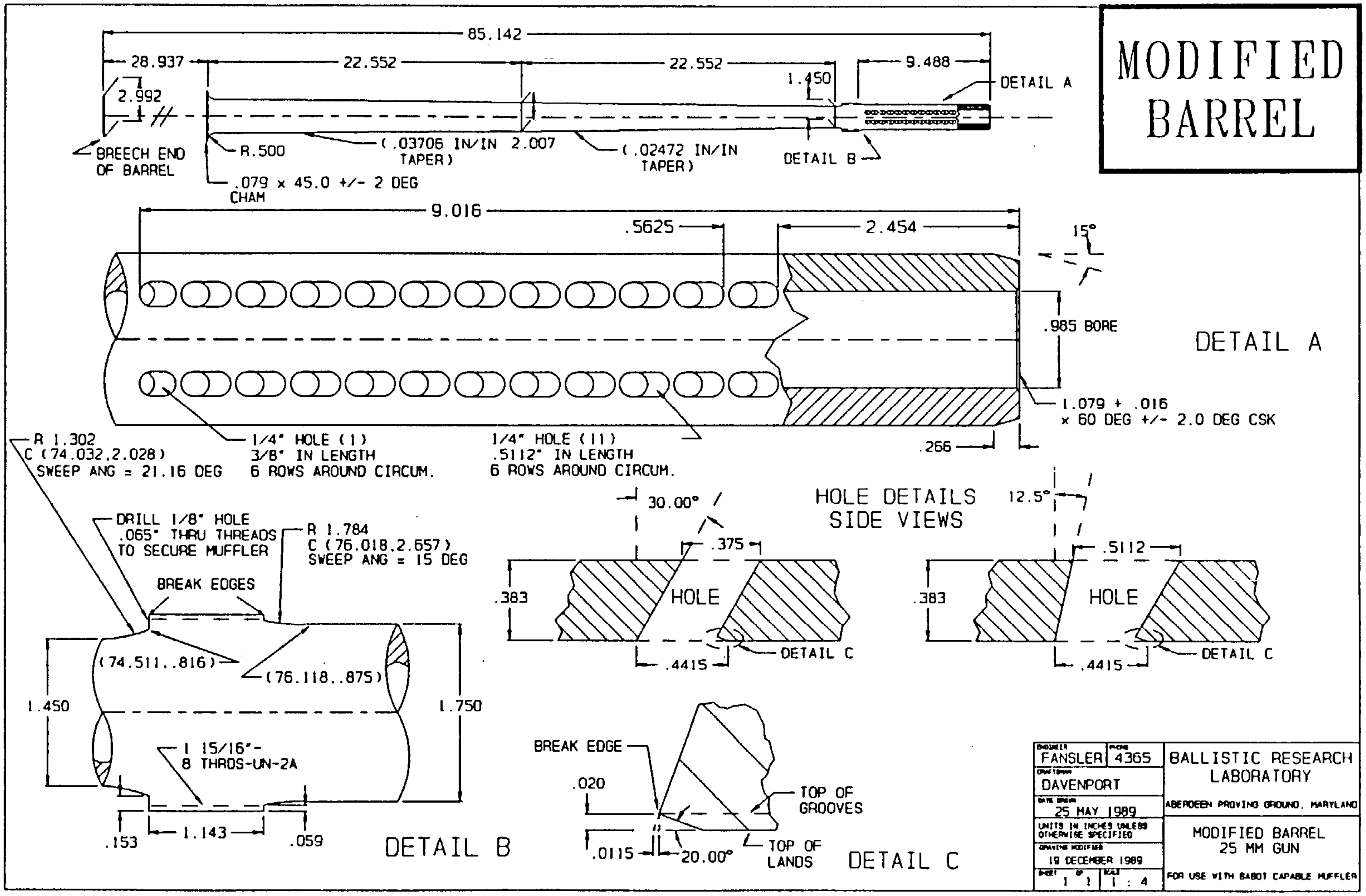


Figure 11. Perforated Gun Tube

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VI. Appendix. Configurations and Results Obtained for Optimization Study

Table 7 describes the various configurations. The first series of configurations starting with the letters "SEM" are variations on the original configuration shown in Figure 4. The other configurations have two chambers with a slotted tube secured between the backplate and the first baffle. This slotted tube, shown in Figure 6, has an inner diameter of approximately 1.1 caliber and is used to simulate a gun tube with slots near the muzzle. The slot location value given in the Table is the distance from the beginning of the slot to the cannon muzzle. The baffle position is the distance from the exit baffle to the back of the given baffle. For the row designated by the dagger, the long simulated slotted gun tube was turned around and both the front and back of the slot was milled at a 50 degree angle from the vertical such that the propellant gas when entering the chamber would tend to flow forward. The baffles used are designated in parenthesis and are shown in Figure 5. The baffle designated as B2 was perforated with more than 60% of its area removed to facilitate flow forward to the exit baffle. It also acted to hold the exit tube in place and centered. These exit tubes are shown in Figure 7. The baffle designated as B7 had considerably less clear area and functioned as a partial reflector to lower peak pressures in the front part of the chamber.

The peak pressures obtained are shown for some of the configurations in Table 8. Gages 3, 4, 6, and 8, which are shown in Figure 1, were used for measuring the internal pressures in the muffler. Gages placed 50 calibers from the muzzle at polar angles of 90^o and 135^o were used to obtain free-field pressure traces.

For the constant area exit tubes, the performance of the mufflers without the perforated barrels is improved when the distance of the exit hole from the muzzle increased. However, for the spinning saboted projectiles, the hole diameter must increase with exit hole distance from the muzzle. The hole must be kept as small as possible to limit the maximum energy efflux but the larger the exit-hole-to-muzzle distance, the smaller the flux density at the exit hole. The short slotted tube mufflers perform better when the exit tube is placed further away from the exit of the slotted tube. However, little difference in performance is noted between the short slotted version and the long slotted version. For the slotted long tube mufflers, again there seems to be little difference in performance between the tubes with one 1.5 caliber slot, two 1.5 caliber slots, and one 3 caliber slot as long as the slots are oriented away from the gun muzzle. However, for the configuration S1L3E2R, where the slots are oriented toward the muzzle, the performance is much improved. Perhaps when the slots are located near the front of the chamber and away from the muzzle, the pressures immediately become higher in the forward part of the chamber and the propellant gas starts emptying back into the barrel well before the pressure in the back part of the chamber equilibrates with the forward part of the chamber. These higher pressures that push the propellant gas out of the chamber would result in higher energy deposition rates from the muffler exit.

Table 7. Configurations Tested for Optimization Study

Config. Name	Length Simul. Barrel (cal)	Slot Size (cal)	Slot Locat. (cal)	Slotted Baffle Position (cal)	Distance Exit Hole (cal)
SBM22	–	–		12.45(B2)	2.1
SBM23	–	–		12.45(B2) 4.05(B7)	2.1
SBM24	–	–		11.95(B2)	4.1
SBM25	–	–		11.95(B2) 4.05(B7)	4.1
S1L1.5E2	10.1	1.5	7.65	4.15(B2)	2.0
S2L1.5E2NB	10.1	1.5	7.15	4.15(B2)	2.0
S1L3E2	10.1	3.0	7.00	4.15(B2)	2.0
S1L1.5E2B2ST	6.2	1.5	3.05	6.15(B2)	2.0
S1L1.5E2B3ST	6.2	1.5	3.05	6.15(B2) 1.95(B7)	2.0
S1L1.5E3B3ST	6.2	1.5	3.05	6.15(B2) 1.95(B7)	3.0
S1L3E2B2ST	6.2	3.0	2.75	6.15(B7)	2.0
S1L3E2B3ST	6.2	3.0	2.75	6.15(B7) 1.95(B2)	2.0 2.0
S1L3E3B3ST	6.2	3.0	2.75	6.15(B7) 1.95(B2)	3.0 3.0
S1L3E2R†	10.1	3.5	0.85	4.15(B2)	2.0

Table 8. Peak Overpressures Obtained for Some Configurations

Configuration Designation	Gage No. 3 (MPa)	Gage No. 4 (MPa)	Gage No. 6 (MPa)	Gage No. 8 (MPa)	Free Field 90° (kPa)	Free Field 135° (kPa)
SBM22	2.9	3.4	3.6	4.7	4.9	2.3
SBM23	3.0	2.5	3.5	4.0	4.6	2.5
SBM24	2.7	3.5	4.6	6.2	3.0	1.6
SBM25	2.8	3.3	5.4	3.7	2.7	1.5
S1L1.5E2	2.9	3.0	3.5	3.4	4.6	2.5
S2L1.5E2NB	2.8	3.3	2.4	2.5	5.2	2.0
S1L3E2	4.0	6.5	1.8	1.6	5.2	2.5
S1L1.5E2B2ST	4.7	2.9	2.5	3.0	5.2	2.1
S1L1.5E2B3ST	4.4	2.1	2.5	2.2	5.2	2.3
S1L1.5E3B3ST	2.1	3.9	3.6	2.5	2.9	1.6
S1L3E2B2ST	5.9	2.1	2.2	2.6	4.7	2.2
S1L3E2B3ST	6.6	1.9	2.2	2.4	5.3	2.3
S1L3E3B3ST	5.2	2.1	2.3	2.2	2.5	1.6
S1L3E2R †	4.3	4.1	2.1	2.3	1.9	1.6

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