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Preliminary Report on Proposed Baffled Noise Abatement Structure

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ABSTRACT

A preliminary concept for an artillery noise abatement structure is presented. The structure is a sand-covered oval corrugated steel arch structure with transverse baffles and is designed to act like a reactive muffler. The structure can accommodate a battle tank and provides clearance for target practice. The results of an acoustical 1/200 scale model test by the Georgia Institute of Technology are presented and assessed, together with available full scale test data from other types of artillery mufflers. It is concluded that the data from the model test and other available information are encouraging enough to justify the continuation of the study of a baffled tunnel structure.

Key Words: Acoustics; artillery noise abatement; mufflers

CONTENTS

1. INTRODUCTION AND SCOPE

The U.S. Army Construction Engineering Research Laboratory (USACERL) is engaged in developing means for mitigating the noise produced by practice firings from large caliber weapons with emphasis on tank artillery.

Two organizational meetings were held in 1989 at CERL, with the objective of defining the problem and initiating research. Attendees included university faculty members and government researchers from the U.S. Army (Ballistics Research Laboratory at Aberdeen Proving Ground, and Waterways Experiment Station), the U.S. Navy, and the National Institute of Standards and Technology (NIST).

Three research areas were identified: (i) development of energy absorbing materials which can be used in acoustic barriers; (ii) development of shielding structures which could enclose a tank or be mounted in front of the gun; and (iii) quantification of the energy release and pressure fields associated with the firing of large weapons.

This report deals with a proposed shielding structure designed to act as a reactive muffler[1]. Other structural concepts, such as an energy absorbent expanding cavity structure and shielding structures of different geometries were also proposed but are not included in this report.

Section 2 of the report contains a description of the proposed structural concept and configuration. Available performance data are described in Section 3. The data are discussed in Section 4. NIST recommendations are presented in Section 5. References are listed in Section 6. The copy of a research report on model studies performed by G.L. Main at Georgia Tech is appended for reference.

2. PROPOSED NOISE ABATEMENT STRUCTURE

2.1 The Baffled Tunnel Concept

Since the sound pressure signature emitted by tank artillery has typically a dominant frequency in the 20-60 Hz range, adequate noise reduction by sound-absorbing linings is probably not practical with present technology. For this reason, one of the options proposed was to build an enclosing structure which could act like a reactive muffler. Under consideration is a long arched sand-covered tunnel structure with transverse baffles at its end and at intermediate locations.

The objective is to design the geometry of the enclosing structure in a way which will result in noise reduction primarily by the modification of the rate of energy release. The energy responsible for the sound effect is released from the muzzle of the gun in the form of

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[1] The acoustical performance of a **reactive muffler** is determined mainly by its geometrical shape, which is designed to provide an impedance mismatch, whereas the performance of a **dissipative muffler** is achieved by the presence of sound absorbing material.

pressurized propellant gas which expands into the surrounding atmosphere. The baffles intercept the gas flow, causing a pressure increase in the chambers enclosed by successive baffles which in turn forces gas to flow through the opening orifices (Fansler et al., 1989). Similarly, the baffles reflect acoustical energy back toward its source and back and forth among baffles (Embleton, 1989). This process results in a reduction in the rate of energy release into the atmosphere, prolonging the duration of the pressure pulse and, as a consequence, reducing its peak (Fansler et al., 1989). The process described does not require energy dissipation by absorbent surfaces.

The design of a baffled tunnel is governed by several constraints:

1. The terminal opening must be large enough to permit target practice and prevent hazardous buildup of pressure and heat.

2. The size of the enclosing arch structure should be as small as possible to be cost effective.

3 The buildup of pressure, heat, toxic fumes and explosive gases within the structure must be kept within limits, which are compatible with health and safety considerations.

4. The structure must be designed to withstand a large enough number of loading cycles and anticipated adverse atmospheric loads, and must be made of materials that will insure serviceability throughout the anticipated life of the structure.

Constraint 1 imposes a limitation on the noise reduction that can be achieved, even if the design is optimized. Constraint 3 will require careful evaluation by remote firing before personnel are permitted in the structure. Relief can probably be provided by venting, including forced ventilation.

The reactive muffler concept has been successfully applied in the past to the noise attenuation of artillery of similar or larger caliber than that considered in this project (Sneck et al., 1980, Walton, 1990, Salisbury, 1969). However, the proposed structure is larger in size and has a larger terminal opening than structures that were built in the past. For applications other than target practice, the size of the terminal opening, as well as the other baffle openings, could be substantially reduced to improve attenuation.

2.2 Proposed Structural Configuration

The proposed structure described in this Section should be viewed as an initial concept which needs further study. The structure considered is a multi-plate corrugated steel arch covered by sand. This type of structure is very economical and, because of its ductility, can also resist many load cycles. It is also flexible, and its deformation under the anticipated impulsive load will dissipate some of the energy. When subjected to dead load only the structure will support the weight of the sand resting on it. When the pressure of the propellant gas is applied, it will approximately cancel the weight of the supported sand overburden. Thus the propellant gas will effectively unload the structure.

Figure 1 shows inside dimensions of a cross section of the proposed structure. The outline of an M1 tank, and the proposed level of earth fill at the floor are also shown. The arch structure will be surrounded by a mound of dry, clean sand fill, the dimensions of which have not yet been determined (they will be determined when more accurate data on the anticipated internal overpressures become available).

Figure 2 shows the location and dimensions of the proposed baffles. A plan view of the tunnel structure is shown in figure 3. No specific guidance was available with respect to operational requirements governing the baffle openings. In the absence of such guidance, assumptions were made which are considered conservative (the opening size is probably larger than required). It was also assumed that there would be adequate clearance to prevent the fireball which forms in front of the nozzle from impinging on the baffles.

Figure 4 shows some structural details in U.S. customary units. The stability of this type of structure generally depends on the lateral thrust exerted by the surrounding soil. The thrust beams are designed to bridge possible weak points of lateral support. The wide flange ring beams are necessary for this size of arch to provide adequate stiffness. Some secondary support system, such as connecting rods between the thrust beams which pass through the arch, may also be desirable to insure lateral stability.

At this stage, no decision can be made on the baffle construction. At least some of the baffles will probably have to be made of reinforced concrete or some other heat resistant material because of the proximity of the fireball. The panels will also have to be relatively stiff. Since sound transmission through the baffles may be a problem, double walls with a sand core should be considered.

If it is found to be beneficial, sound-absorbing linings for all the structural elements could be provided.

It should be noted that in this preliminary design the baffle openings are large when compared with the tunnel size. This design was chosen for two reasons: The arch structure is the largest structure of this type that can be built with presently available, relatively inexpensive, off-the shelf components. A larger arch may very well be desirable or even necessary. The baffle openings can probably also be reduced. This design permits the tank to drive through the structure. If this is not required, the bottom of the baffle openings could be above the driving surface. Also, for applications other than target practice the baffle openings could be much smaller than those shown in Figures 2 and 3.

In summary, this design was chosen because the structure is the most economical structure judged to be potentially effective.

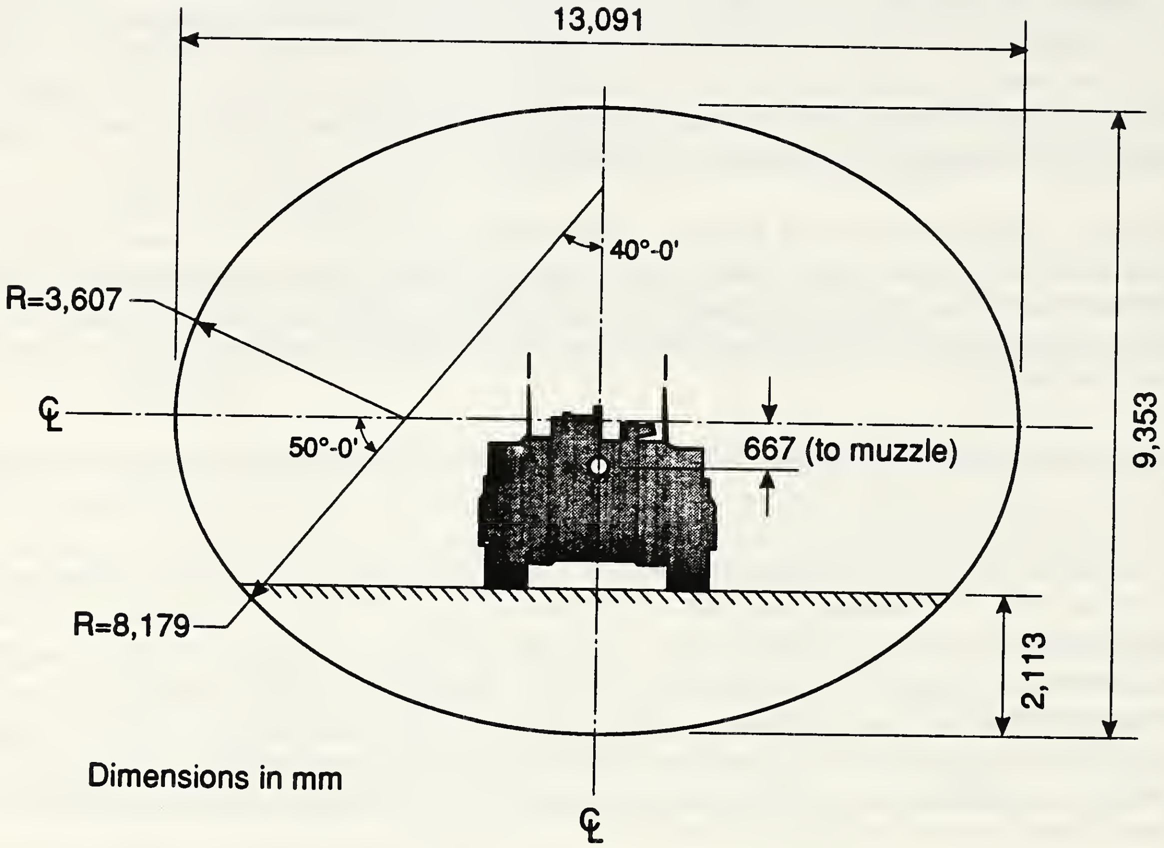


Figure 1. Inside dimensions of Cross Section of Proposed Structure

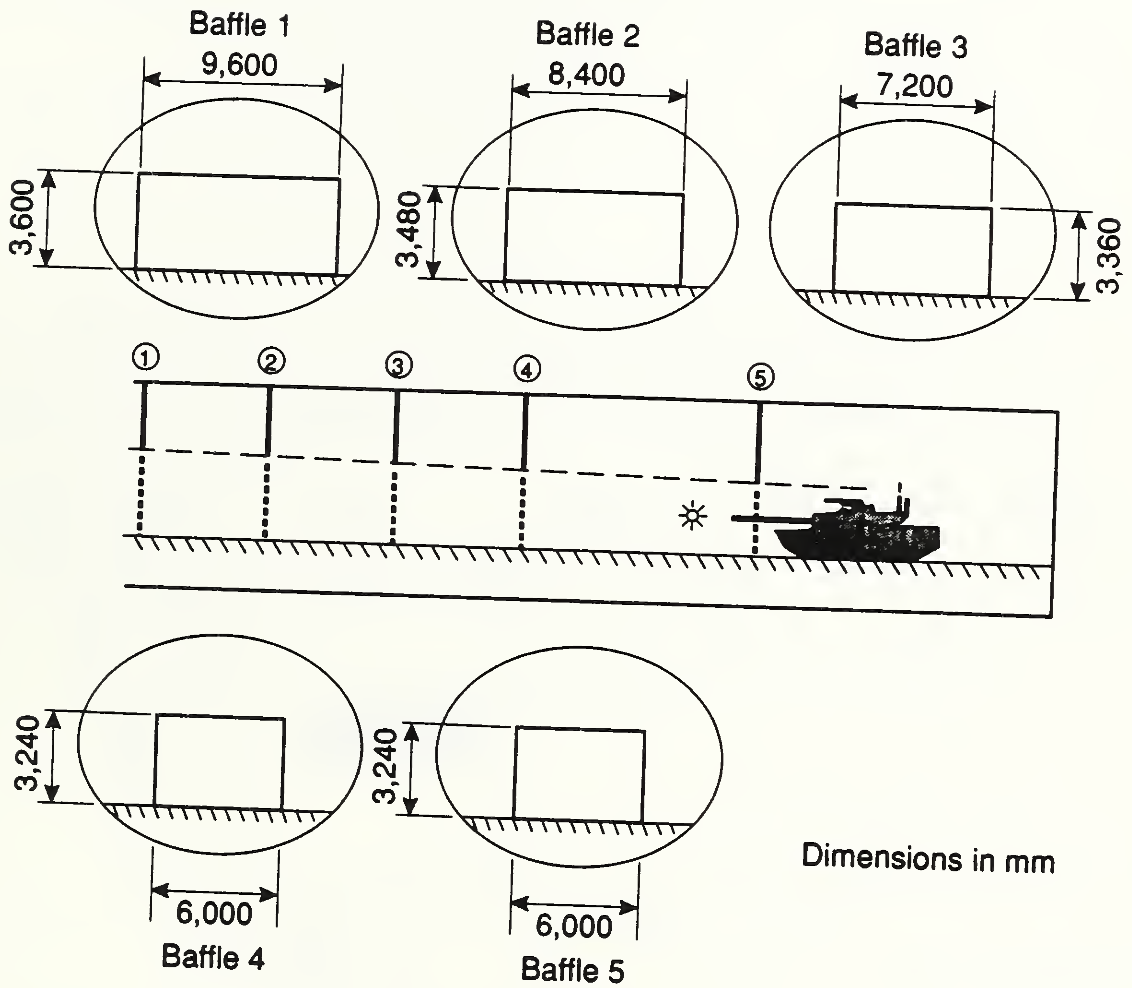


Figure 2. Longitudinal Section of Proposed Structure and Baffle Elevation and Dimensions.

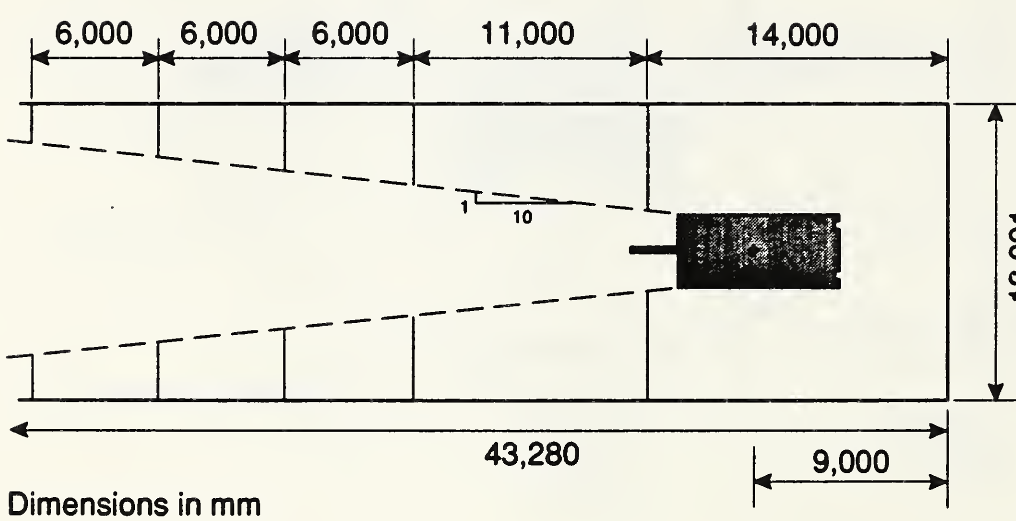


Figure 3. Plan View of Inside Dimensions of Proposed Structure

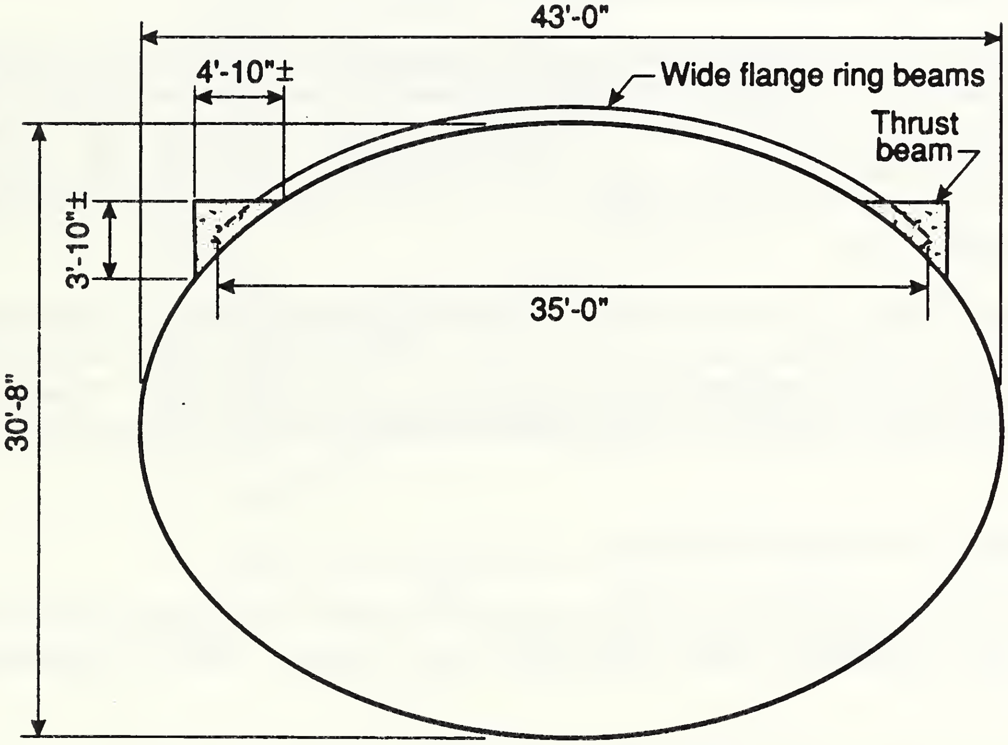


Figure 4. Details of Thrust and Ring Beams

3. AVAILABLE PERFORMANCE DATA

3.1 Results of Model Study of Proposed Structure

An acoustical test on a 1/200 scale model was performed by G.L. Main at the school of Mechanical Engineering of the Georgia Institute of Technology under a CERL contract (Main, 1990). The test report is included as an Appendix. The results are summarized below.

The model used contained no sound absorbing materials so that its efficiency as a reactive muffler could be evaluated. An electrical spark, located approximately at the point in front of the muzzle identified in Figure 2 was used as energy source. The frequencies of interest were assumed to be 20-60 Hz. For the scale model these frequencies were scaled to 4 to 12 kHz.

The result of the experiment are shown in Figure 5 for the tunnel without baffles, the tunnel with the four baffles in front of the muzzle, and the tunnel with all five baffles. The measurements were made along an arc of 700mm radius whose center is at the mouth of the tunnel. The 0°
point is located in the line of fire. The insertion loss[2] shown is relative to a free field measurement with a model of the tank in position but without the tunnel.

The results demonstrate that, for the experimental setup, the baffles are effective in spite of the large opening. For the tunnel without baffles there is a noise increase between 0 and 35° and a gradual noise reduction from 0 dB at 35° to 12 dB at 90°. For the tunnel with all five baffles in place there is a noise reduction ranging from 6 dB at 0° to 22 dB at 90°. Even though there are no measurements, it is reasonable to assume that the insertion loss between 90 and 180° would exceed 22 dB.

The author (Main) notes that in the very far field the directional redistribution of acoustical energy would probably not be as pronounced as in the data. If this were the case, the tunnel without baffles would not be very effective (see corresponding curve in figure 5). However, at least the average attenuation produced by the baffled tunnel would be maintained in the very far field.

3.2 Performance Data for Full Scale Mufflers

Several sets of data for full scale experiments with reactive mufflers are available (Sneck et al., 1980, Walton, 1990, Salisbury, 1969). One set of data (Walton, 1990) is presented hereafter.

Figure 6 shows a schematic drawing of a muffler constructed and tested at the Aberdeen Proving Ground. The muffler consists of a 12'x12'x24' (3.66 m x 3.66 m x 7.32 m) box made of 1" (25.4 mm) steel plates and reinforced by circumferential wide flange beams (not shown). This box is connected to a 9'- 6" (2.90 m) diameter, 32' (9.75 m) long concrete pipe. Four baffles with 2'x4' (.61 m x 1.22 m) openings were inserted as shown in the figure. The

[2] The difference, in decibels, between the sound pressure levels, measured at the same point in space, before, and after a muffler is inserted between the measurement point and the sound source.

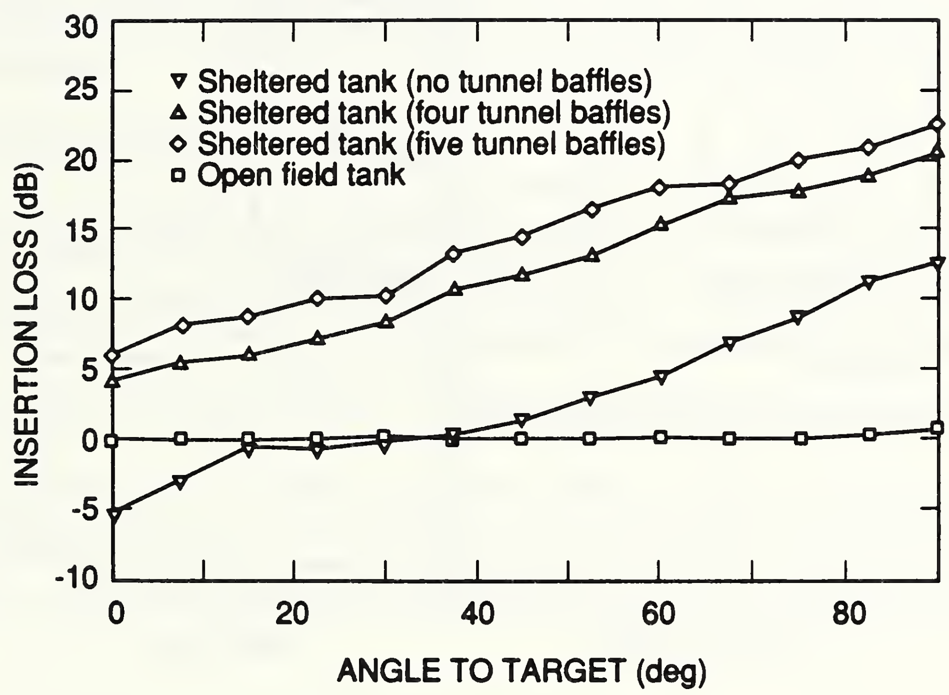
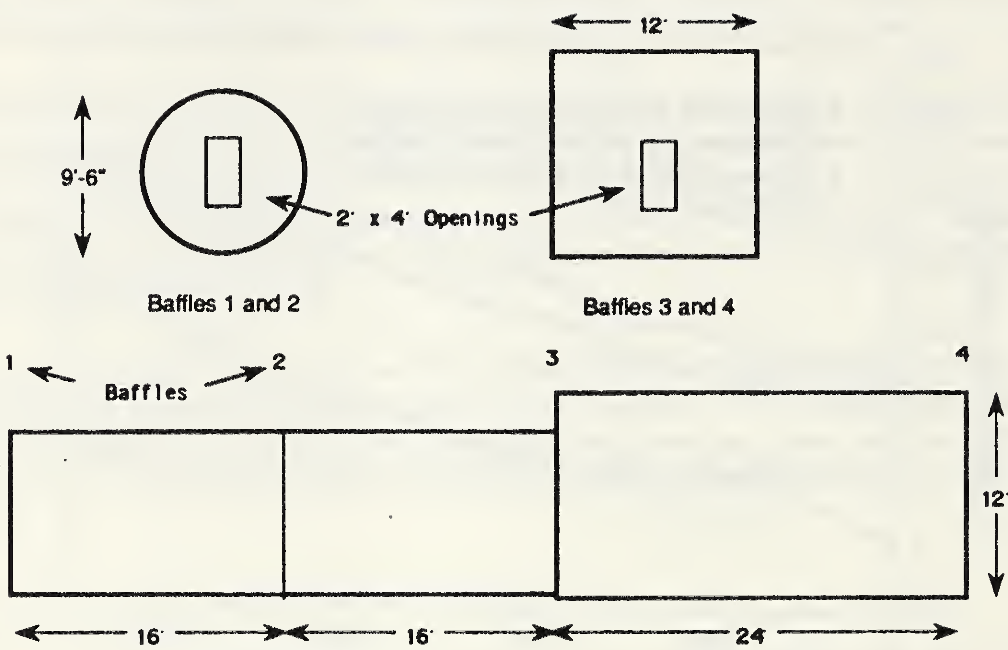


Figure 5. Results of Noise Reduction Study on Scale Model (taken from Main, 1990).



APG #1 MUFFLER

Figure 6. Schematic Drawing of Muffler Constructed at Aberdeen Proving Ground

muffler was tested in the field with the muzzle inside the steel box using 155 mm and 120mm guns. The approximate layout of the test site is shown in Figure 7. Table 1 shows the test results. Note 2 in Table 1 indicates that at some point during the test the steel box ruptured and that this reduced the attenuation. The results do not distinguish between noise levels generated by the gun and those generated by the supersonic boom caused by the projectile. This is noted in footnote 4 for Howell Point, where no attenuation was observed for the 155 mm howitzer. There was also significant transmission through the walls of the steel box and the pipe. Nevertheless, significant noise reduction was achieved, proving that reactive mufflers can be successfully used to reduce artillery noise. Similar conclusions can also be drawn from Fansler, 1989, Sneck et al., 1980, and Walton, 1990.

4. DISCUSSION OF AVAILABLE DATA

The data presented by Main, 1990, show significant noise reduction with a scale model of the proposed baffled tunnel, but no appreciable noise reduction when no baffles are used. Significant noise reduction was also achieved in full scale artillery tests with various types of reactive mufflers.

Before proceeding with this work and moving on to larger scale models, it is necessary to decide on the basis of available data whether this concept is viable. The following issues should be considered:

1. Is this a practical solution to the problem?

At this time no viable alternative to the shelter concept for noise reduction in training was presented. However, before proceeding with this project, it is necessary to carefully examine whether the shelter concept can serve its intended purpose. In particular, careful consideration should be given to the minimum clearances necessary for target practice, safety, and mobility.

2. Is there enough energy dissipation to modify the acoustic signal in the far field?

Even though a reactive muffler does not dissipate energy by the use of absorptive materials, there are other mechanisms of energy dissipation at work (Fansler, 1989, Embleton, 1989). However, not enough energy would be dissipated to modify a steady-state emission. A transient energy pulse, however, can be attenuated by emitting the same amount of energy over a longer time increment.

3. Will the acoustic attenuation observed in the model test be present in the far field, which is of the greatest interest?

The following statement is made in Main's report: "In the very far field, it is doubtful that this effect (redistribution of acoustic energy with target angle) would remain important". However, Main's data for the baffled tunnel show that there is a significant average insertion loss, which would be maintained in the far field even if the re-distribution of acoustic energy observed in the measurements were modified.

In addition to the above, it is also noted that in the model test not much attenuation was achieved by a tunnel without baffles, while the baffled tunnel was highly effective.

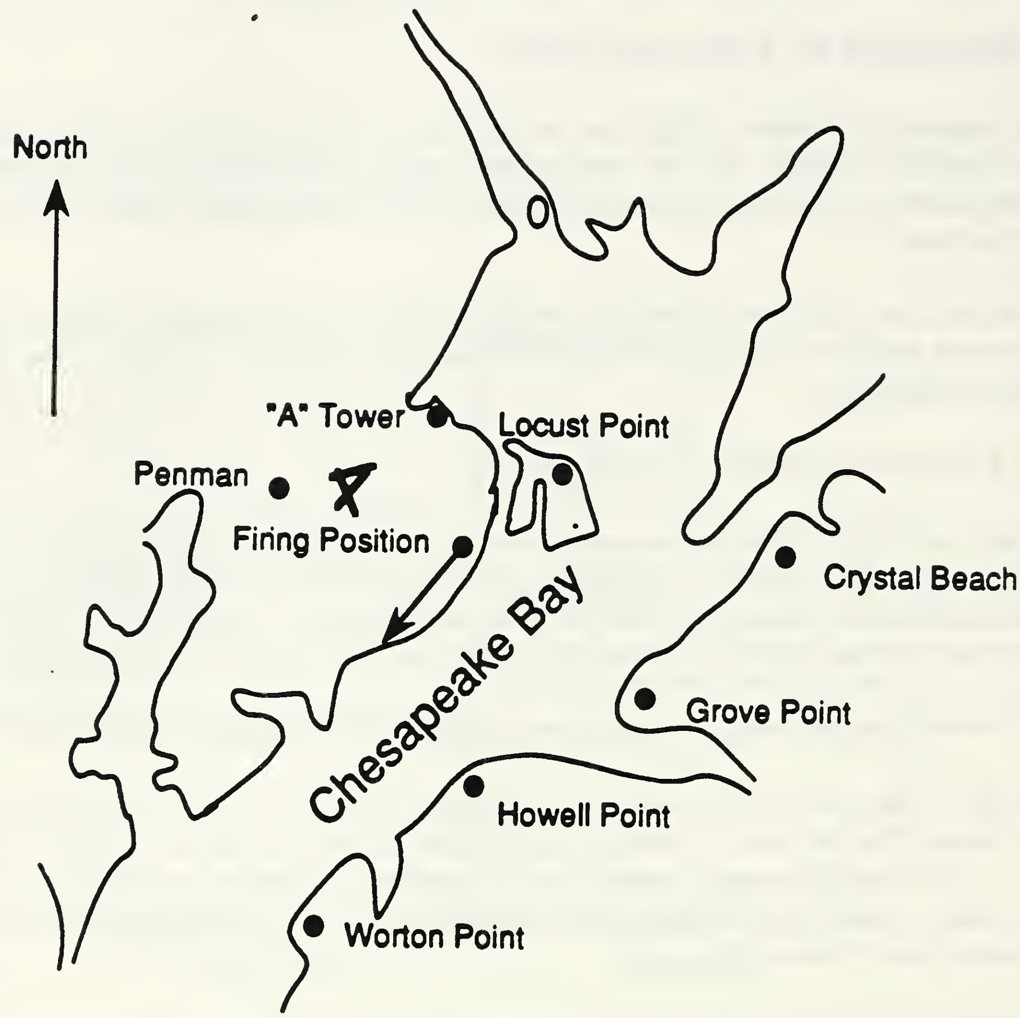


Figure 7. Layout of Test Site for APG #1 Artillery Muffler

TABLE 1: RESULTS OF APRIL '88 TESTS OF APG #1 MUFFLER

(All noise levels in dB)

Location	Distance,km		Amb.Frg	25 lb	155 mm Howitzer,M4A2 Chrg.			155 mm Howitzer,M203 Chrg.			120 mm Super Slug		
	Gun	Impact	Noise	Chrg.	Outside	Muffler	Atten.	Outside	Muffler	Atten.	Outside	Muffler	Atten.
Worton Pt.	15.9			115.8	104.0	95.4	- 8.6	111.3	114.1	+ 2.8	112.2	100.4	-11.8
Howell Pt.	8.7	6.2	118	120.6	116.7	119.9	+ 3.2	122.2	122.2	0	116.8	110.1	- 6.7
Grove Pt.	7.9		110	108.6	104.8	93.9	-10.9	108.5	95.6	-12.9	84.1	82.4	- 1.7
Crystal B.	11.0		100-110	106.4	94.8	92.4	- 2.4	97.6	87.8	- 9.8	Below amb.level (93-100dB)		
Perryman	7.5		110	110.4	106.4	97.6	- 8.8	100.7	100.7	0	102.1	97.0	- 5.1
Locust Pt.	4.6		110	108.4	90.6	86.5	- 4.1	96.5	90.8	- 5.7	100.4	91.1	- 9.3
Ballistic R.	1.1		121	130.2	124.0	111.8	-12.2	130.1	115.9	-14.2	123.5	109.5	-14.0
"A" Tower	2.5			104.8	92.5	91.5	- 1.0	100.1	97.3	- 2.8	113.2	108.8	- 4.4

Abbreviations: amb. = ambient; frg = firing; chrg. = charge; atten. = attenuation, dB.

Notes

1. "A" Tower data contaminated by ambient noise
2. Ballistic Range shows 12 - 14 dB attenuation; showed 20 dB atten. before rupture of steel tank
3. Significant attenuation at Ballistic R., Grove Pt., Worton Pt?
4. Howell Pt. loudest except for Ballistic R.; must be picking up projectile supersonic boom.
5. 155 mm noise level comparable to 120 mm except at Grove Pt. and Crystal beach, where noise was below ambient level.
6. Note that measurements 1100 m from gun in muffler are lower than measurements from unmuffled gun fired 3000 m away.

5. CONCLUSIONS AND RECOMMENDATIONS

The practicality of the use of a shelter enclosure for training has so far not been studied. However, a shelter of this type would also be practical for other purposes, such as test firings, and could be made more effective for such purposes by reducing the size of the baffle orifices. The study of functionality, safety, and geometric constraints should therefore be given priority.

Even though the acoustic wave propagation from a signal generated by an electric spark is not the same as that from the shockwave generated by the discharge of a gun, the data from the model test and available information on full scale tests are encouraging enough to justify continuation of the study of a baffled tunnel structure. It is recommended that the next stage of the study concentrate on two areas: (1) laboratory studies (similar to those reported by Sneck et al., 1980) and mathematical modeling; and (2) use of a larger-scale model (a 1/4 scale corrugated steel or aluminum structure) and appropriate (smaller than 120 mm) caliber weapons. The objective of this effort would be to determine feasibility and optimize geometric design before a full-scale test structure is built. The Aberdeen Ballistic Research Laboratory team should participate in this study.

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APPENDIX

FINAL RESEARCH REPORT

Acoustic Model Testing of Noise Reduction
Enclosures for Large Caliber Guns

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Technical Monitor:
Mr. Rich Lampo

February 9, 1990

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SUMMARY

Acoustical model tests have been carried out on a noise reduction enclosure for the M1 Abrams tank proposed by Felix Yokel of NIST. The model is of 1:200 scale and therefore the frequencies of interest, 20 to 60 Hz are scaled to 4000 to 12000 Hz. The model experiments show a noise reduction in this frequency band ranging from 6dB in front of the enclosure to 22 dB at the sides to even less behind the enclosure. This is a promising result because it indicates that significant noise reduction (10 dB or more) is feasible with a practical enclosure.

The model contains no sound absorbing materials and in that sense is a worst case estimate of the noise reduction. It accomplishes the noise reduction via baffles which do not obstruct the shell's trajectory or the gunner's view. One model was tested without baffles and shows a 4 dB increase in front of the enclosure and a 12 dB reduction at the sides, in effect, acting like a megaphone. Thus the baffles work.

Finding the optimum configuration of baffles and other arrangements of the enclosure would be difficult by experiment. Therefore, at this stage, some numerical modelling should be done to find an arrangement of the enclosure with the best predicted noise reduction in the frequency range of interest.

Figures 1,2 and 3 show the Yokel enclosure design of which the model experiments were a 1:200 scale model.

EXPERIMENTAL FACILITY

This section contalns a description of the laboratory and the experimental method used in the study. The laboratory contained a large table, a electric spark Sound source, a scale model tunnel and tank, microphones, and other data collection and processing equipment. The actual spark gap was located just above and near the center of the table top. One microphone was given a fixed position relative to the spark gap, and was termed the *reference* microphone. Another microphone was used to make *field* measurements at various angular distances around the spark gap. Both microphones were connected via a preamplifier, power supply, and amplifier to an A/D data collection board and associated personal computer. Data reduction was performed by software stored in the personal computer. The end result of the measurements was an evaluation of the attenuation at the various field locations due to the presence of the tunnel enclosing the spark gap and tank. The details of the experimental procedure and the laboratory follow.

LABORATORY DESIGN

The laboratory was housed within a standard university small laboratory room of dimensions 8.2 m by 6.1 m by 4.3 m and located on the campus of the Georgia Institute of Technology. The walls of the room were cinderblock, the floor was tiled, and some of the walls were lined with shelves. In no sense did this room approximate the ideal of an anechoic chamber.

Four tables were made to be used for the scale model experiments. Each table was 1.2 m wide by 2.4 m long and 0.9 m high with a table top made of 3/4 in (~2 cm) CDX plywood. Each small table frame was constructed of two-by-six (5 cm by 15 cm) yellow pine grade #1 planks; the table legs were constructed of four-by-four (10 cm by 10 cm) yellow pine grade #2 beams. The fasteners holding the table together were machine bolts and wood screws. The four small tables were bolted together, forming one large table 4.9 m long by 2.4 m wide.

The sound source was an electric spark generator. The design of the spark generator was inspired by a photo of an apparatus designed by Dr. Mendel Kleiner at the Chalmers Institute of Technology. The important features of the spark generator were as follows. A gap of approximately 1 mm separated two stainless steel rods or electrodes. (Originally, copper electrodes were used; however, problems were encountered with the tips either exploding or ablating away.) The electrodes were pointed at each other forming a spark axis. Each electrode was approximately 1.5 mm in diameter. A third electrode was positioned midway through the gap and pointed perpendicular to the other two electrodes. All three electrodes were held in place by a narrow wedge-shaped plexiglass block. Each of the first two electrodes was connected by an insulated copper cable to one point of a 1 μF, 10 kV (nominal) capacitor. One point of the capacitor was grounded while the other was connected to a 10 DCkV variable power supply through a 10 W resistor, nominally rated at 10 MΩ. The third electrode was connected to a standard automobile ignition coil by way of a 10 kΩ resistor.

The spark source was oriented such that its axis was perpendicular to the centerline of the tunnel. Under free field conditions (e.g. the spark gap suspended far above the flat table top), a typical waveform had a peak acoustic pressure on the order of 130 Pa at 1 m from the source, a pulse duration of approximately 40 μs, and a broadband frequency spectrum from 5 kHz to at least 50 kHz.

The spark discharge was initiated by a manual trigger attached to the ignition coil. The coil delivered a low current, high voltage ($\approx$ 10-15 kV) electrical discharge through the tip of the third electrode. This discharge ionized the gap separating the first two electrodes, which were the power electrodes. Once the gap was ionized, its electrical resistance plummeted, and the main body of charge stored in the capacitor was discharged to ground. This discharge produced the transient acoustic waveform. An antenna situated near the spark source transmitted the spark's electromagnetic pulse to an external TTL port associated with the A/D board. Data collection was triggered by the reception of this pulse.

A hole was cut near the center of the table top and filled with a slotted plexiglass disc. The spark source was located under the table top such that the spark electrodes protruded through the slots of the plexiglass disc. In this way, the spark gap was located roughly 1 cm above the center of the table top.

Two Brüel & Kjær 4136 quarter-inch condenser microphone cartridges were used for making the sound pressure measurements. Each microphone cartridge was attached to a Brüel & Kjær 2615 cathode follower (pre-amplifier) via a Brüel & Kjær UA0035 adaptor. The cathode follower and the microphone cartridge were powered by a Brüel & Kjær 2801 microphone power supply. Each microphone cartridge had a dynamic range rating of up to 180 dB, ad a rated sensitivity of $\approx$ 1 mV/Pa. More details about these microphones can be found in the manuals available from Brüel & Kjær.

Each microphone was connected in line with its own low current amplifier. Each amplifier consisted of a Motorola LF351N FET operational amplifier microchip, which had a high voltage slew rate of 13V/μs and a flat response up to 100 kHz.

The amplified analog signal of each microphone was converted to digital form by an integrated hardware and software system produced by RC Electronics Inc. and called "Computerscope ISC-16". This system consisted of a 16 channel A/D board, which was inserted in the IBM PC, an external instrument interface, and the scope driver software. The system was capable of recording an input voltage signal with a peak to peak range of 20 volts centered at zero and of resolving it to 12 bit accuracy, or equivalently to approximately 1 part in 4000.

The data acquisition system was composed of two microphones, two amplifiers, an analog-to-digital converter, and an IBM personal computer (figure 4). The system was capable of gathering data at a aggregate rate of 500 kHz ad possessed an aggregate memory buffer of 64 kilobytes. Software purchased from RC Electronics, Inc. enabled the digitized data to be downloaded into standard ASCII coded files which were subsequently processed by the PC. A triggering device activated the data capturing system simultaneous to the firing of the spark source. The analog signals of the two microphones were sampled at rate of 250 kHz, digitized to 12 bit precision, stored in a 64 kilobyte memory buffer, and bandpass filtered. Interesting portions of the total data field were then selected.

GENERAL PROCEDURE

The general experimental procedure was as follows. Every time the spark source was fired, the resulting pressure transient was measured by two microphones, one of which was located at a reference point approximately 6 mm above the table surface, 70 cm from the spark gap, and 5° off of the tunnel centerline. The other microphone, referred to as the *field* microphone, was located at the same height above the table surface and at the same distance from the spark source but at various angles from the tunnel centerline. At all times, both microphones were oriented such that the normal of each microphone diaphragm pointed to the mouth of the tunnel (or the spark source, in those cases when no tunnel was used.) The two corresponding analog voltage signals, which were output from the microphones, were amplified, sampled at intervals of 4.0 μs, and digitized to 12 bit precision. A constant was automatically added to each data sample such that the mean of the data sample was approximately zero. Since the voltage increment registered by a microphone was opposite in sign to that of the corresponding pressure increment, the sign of the shifted digitized data was reversed. Then the data sets were filtered by a bandpass digital filter which eliminated those portions of the transient pressure waveform below 4 kHz and above 12 kHz. (The exact formula for the digital waveform was not known, but a plot of the filter response versus frequency indicated that the majority of the transient waveform's energy between 4 and 12 kHz was retained.) After the filter was applied to the data, a waveform portion of interest and representative of what would be received if there were no undesired reflections contaminating the data was selected. The waveform portion was then squared; that is, the numerical value of the pressure at each point of the waveform portion was squared. The integral of the squared waveform portion was then computed using Simpson's rule, thus yielding a quantity related to the energy of the waveform portion.

These results of such integration were used as a measure of the total effectiveness of a tunnel. Specifically, the transmission loss at a field point due to the presence of the tunnel surrounding the tank was calculated from

$$\Delta_{dB} = 10\log_{10}\left[\frac{I w/tunnel}{I_{ref} w/tunnel}\right] + 10\log_{10}\left[\frac{I_{ref} w/tunnel}{I_{ref} w/o\, tunnel}\right]$$

where

$$I \equiv \int_{t_1}^{t_2} P^2(t)\, dt$$

The first of the two above ratios describes the angular variation of the transmitted energy, while the second ratio describes the transmission loss at a reference point associated with a tunnel. Together, the two ratios describe the total transmission loss at a field point due to the tunnel.

Due to symmetry about the tunnel centerline, field measurements were made every 7.5° over a total angular distance of 90° from the tunnel centerline. The distance between the field microphone and the spark gap was kept fixed at 70 cm, or roughly 20λ at 10 kHz.

RESULTS

A preliminary set of measurements were made with both the scale tunnel and tank absent. Measurements were made every 7.5° over the 90° perimeter. Transient pressure data were collected at both the reference and field microphones. However, the bandpass filter was not applied to the data. (Rather, a lowpass filter with a cutoff frequency of 75 kHz was applied to the data.) The data was input to a discrete Fourier transform program with the resulting transformed data sets interpreted as the discrete frequency components of the original transients. At the given frequencies of 4, 8, and 12 Hz, the ratio of the field component to reference component was calculated, in dB, for each field location. Figure 5 shows the results of these calculations. The figure indicates that the unobstructed spark source was within $\pm$ 1 dB of being omnidirectional over the 90° range.

Next, the scale model tank was placed directly behind the spark gap such that the spark gap was located roughly where the end of a tank's cannon would be located. Again, pressure transients were measured every 7.5° just as when the tank was absent. However, the bandpass filter was applied to this data set, and the square integral of each filtered transient was calculated, as described above. This data is referred to as the open field tank data in

Figure 6. The figure indicates that the presence of the scale tank did not substantially affect the distribution of energy to the perimeter.

Following the open field tank measurements, a hollow scale tunnel (i.e. a tunnel with no baffles) was placed around the tank and spark gap. An approximately 1 in thick layer of fine sand was then poured atop and around the tunnel, leaving only the tunnel entrance uncovered. Measurements at the reference and various field locations were made with this new set up. As before, the pressure transients were bandpass filtered, squared, and integrated. The results of these measurements are also shown in Figure 6, and referred to as the sheltered tank with no tunnel baffles data. Interestingly, at target angles of less than 30°, the energy transported to the perimeter was greater than that at the same locations when no tunnel was present (i.e. the open field data). However, for target angles greater than 40°, the energy transported to the perimeter fell off exponentially with target angle. This result is not surprising in that the interior walls of the tunnel were acoustically hard such that little energy absorption occurred within the tunnel. Rather, the energy was apparently concentrated by the tunnel within target angles near zero, that is, dead ahead of the tunnel. One would guess that this concentrated effect would diminish in the very far field, and that the mouth of the tunnel would appear as a point source at such distant locations.

The next set of measurements were identical to those just discussed except that baffles were inserted in the tunnel (see diagrams). In one set of measurements, four equally spaced baffles were present within the tunnel. All four baffles were located to the front of the scale tank and the spark gap. In the other set of measurements, a fifth baffle was inserted between the spark gap and the scale tank. The results for both cases are shown in Figure 6 as well. It is clear from the figure that the total energy transported to the perimeter relative to that for the open field case was decreased by the presence of the baffles. In fact, at the target angle of 0° (front dead center), the four and five baffle tunnels had losses of roughly 5 and 7dB greater than that for the open field case. At all target angles, the five baffle case showed a 2-3 dB loss greater than that found in the four baffle case. The rate of loss with increased target angle was found to be roughly the same for all three types of tunnel, and was roughly 1 dB per every 6°.

In sum, the presence of the tunnel shell itself brought about a redistribution with target angle of the acoustic energy transported to the perimeter. In the very far field, it is doubtful that this effect would remain important. On the other band, the presence of the baffles brought about an attenuation of the total energy transported to the perimeter. The larger number of baffles was shown to produce the greater attenuation. This attenuation would, of course, be seen in the very far field as well.

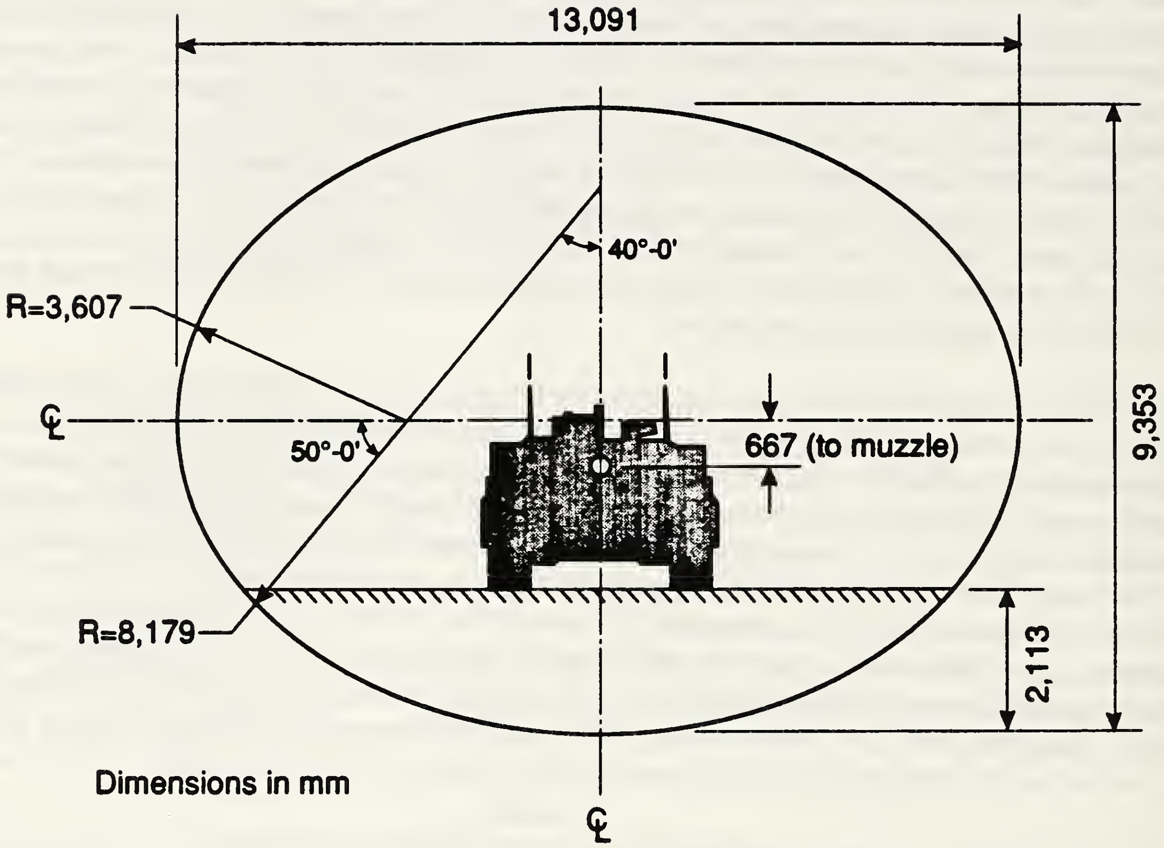
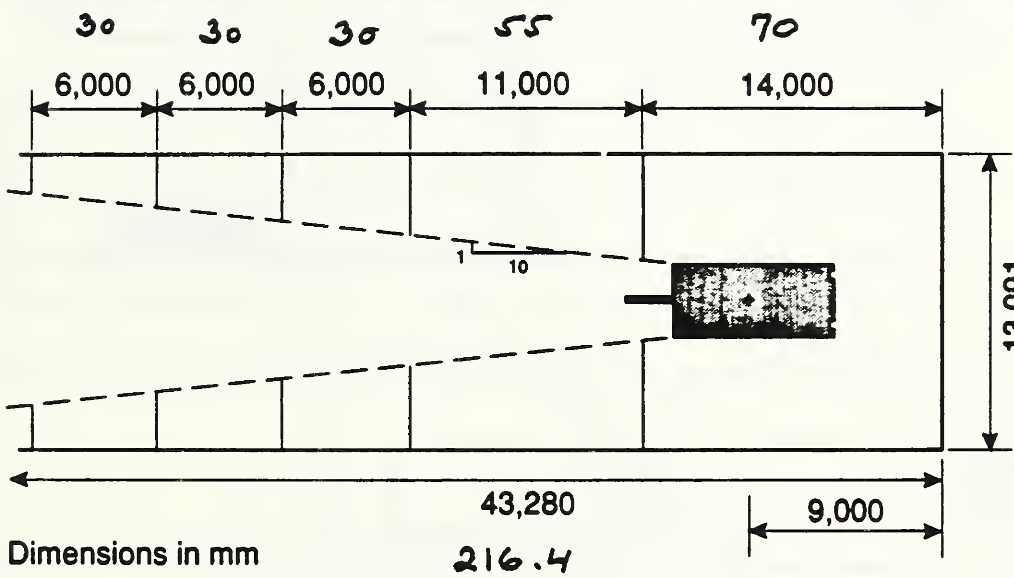

13,091
40°-0'
R=3,607
℄
50°-0'
667 (to muzzle)
9,353
R=8,179
2,113
Dimensions in mm
℄

Figure 1



Dimensions in mm

Figure 2

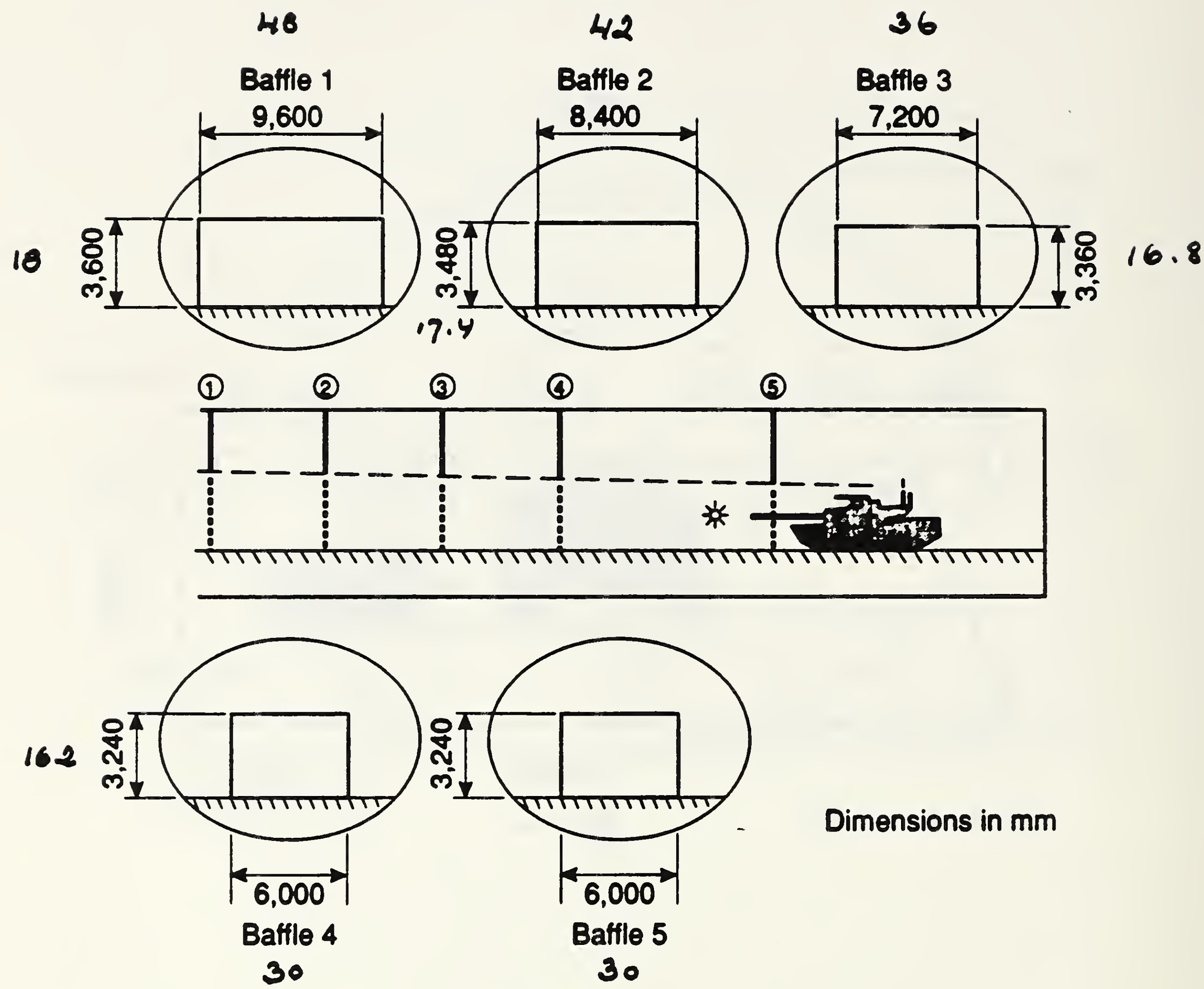

46
Baffle 1
9,600
3,600
18
42
Baffle 2
8,400
3,480
17.4
36
Baffle 3
7,200
3,360
16.8
1
2
3
4
5
3,240
16.2
6,000
Baffle 4
30
3,240
6,000
Baffle 5
30
Dimensions in mm

Figure 3

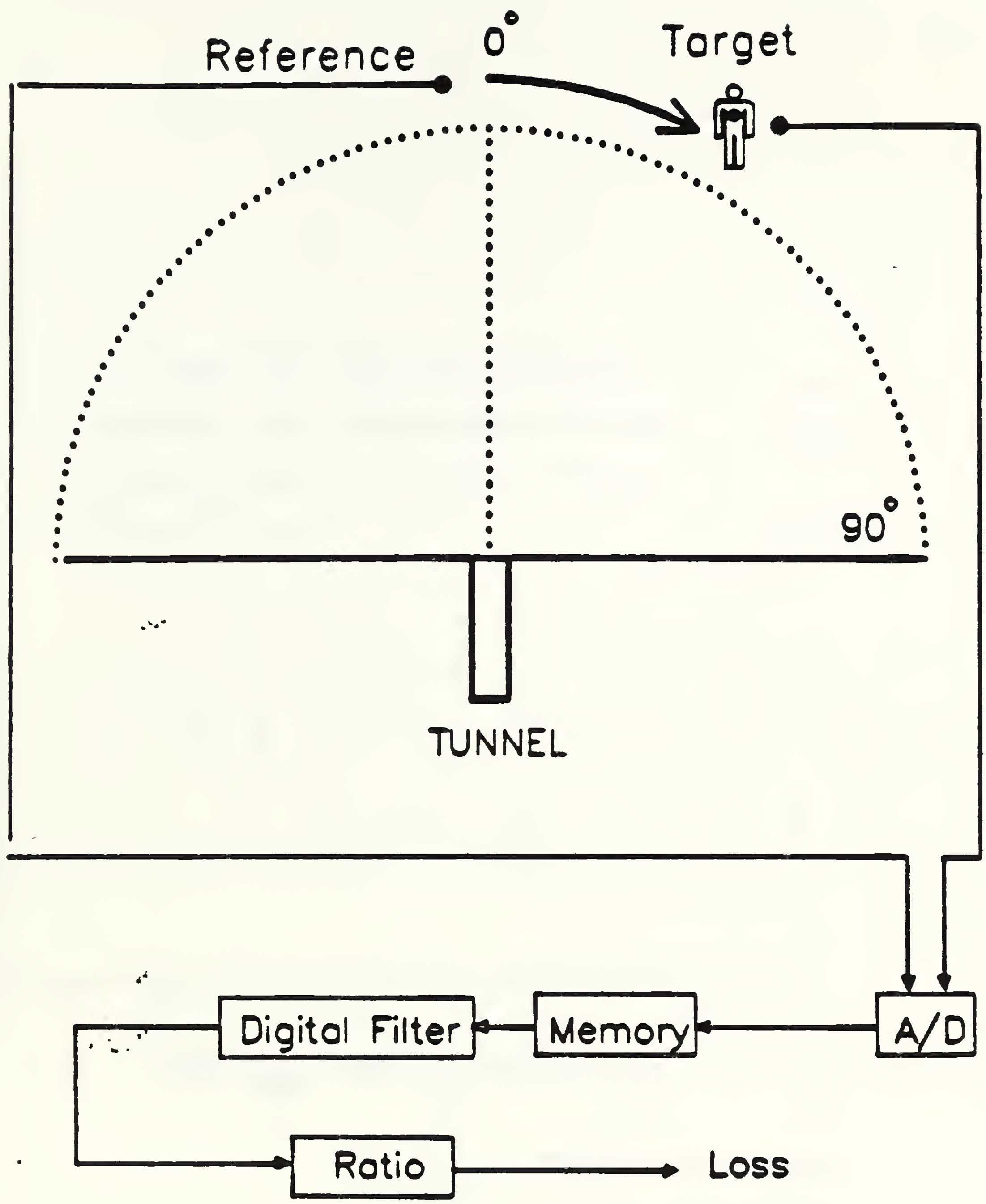


Figure 4: Schematic of the interior of the laboratory room used in the study. Shown is the sequence of data processing associated with a single firing of the spark source. Reference and field microphones were stationed along a circular perimeter located 70cm from the spark gap.

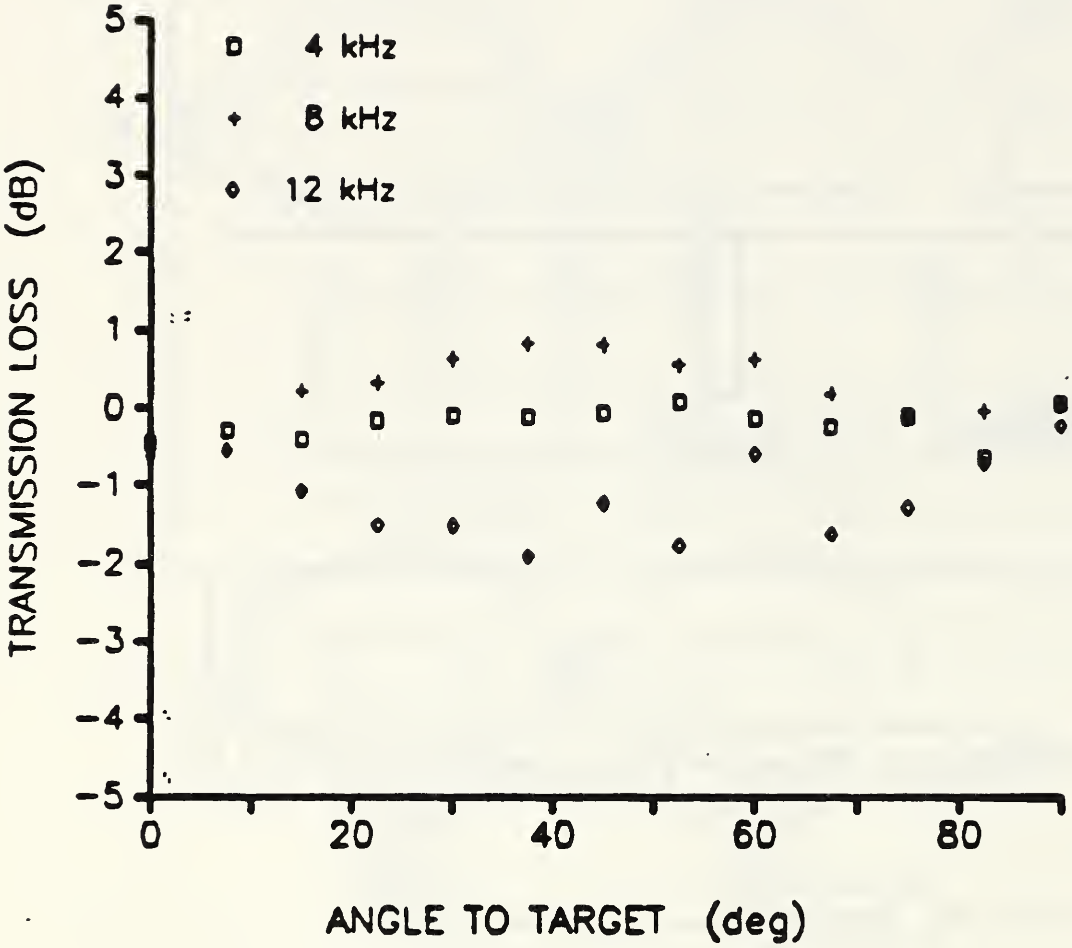


Figure 5: The Directionality of the Spark Gap at 4, 8, and 12 kHz.

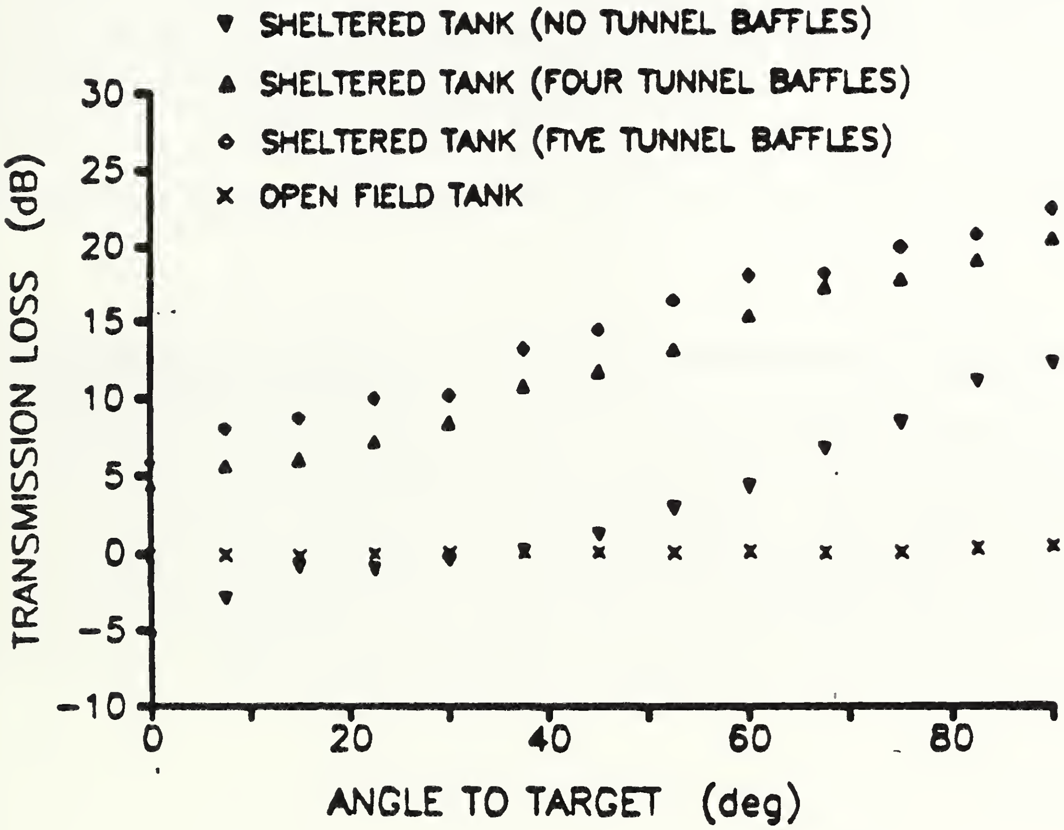


Figure 6: Noise Reduction with the Enclosure

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

A preliminary concept for an artillery noise abatement structure is presented. The structure is a sand-covered oval corrugated steel arch structure with transverse baffles and is designed to act like a reactive muffler. The structure can accommodate a battle tank and provides clearance for target practice. The results of an acoustical 1/200 scale model test by the Georgia Institute of Technology are presented and assessed, together with available full scale test data from other types of artillery mufflers. It is concluded that the data from the model test and other available information are encouraging enough to justify the continuation of the study of a baffled tunnel structure.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)
Acoustics; artillery noise abatement; mufflers.

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