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BRL

A MUFFLER DESIGN FOR TANK CANNON ACCEPTANCE TESTING

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13. ABSTRACT *(Maximum 200 words)*

To reduce the transmission of gun-generated noise from Aberdeen Proving Ground to the surrounding community, we have designed a noise attenuator to be used with the tank cannon (120 mm and 105 mm) proofing work performed by Combat Systems Testing Activity (CSTA). The dimensions of the muffler were determined and loadings on the interior surfaces were estimated by utilizing the results from the 25-mm muffler experiments. The results from CSTA tests with a full-scale muffler also influenced the final configuration. Finite-element stress analysis was used to determine the thickness and detailed geometry of the muffler. Costs can be reduced by using commercially available heads and pipe sections, which can be fabricated from HSLA-80 steel. The resulting muffler is light enough to be lifted into position and used when firing the cannon at 30° elevation.

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I. Introduction

Noise from gun and ammunition tests on proving grounds often reach surrounding communities. Muzzle blast, sabot discard, projectile flight, and terminal events can all contribute to noise signature. Wind, thermal gradients, and other atmospheric conditions can locally enhance the noise. Developing communities surrounding proving grounds have become more concerned with maintaining a pleasant environment and are pressuring test activities to reduce noise levels. Noise control techniques[1,2,3] are successfully applied to many of the critical proving ground activities. One such technique is to reduce or stop gun firings when weather conditions result in adverse noise propagation. However, a reduction of activities can interfere with carrying out the overall objectives of the mission. Tank gun acceptance testing is an example of an activity that must sometimes be stopped because of unfavorable conditions that enhance noise propagation.

Before they are fielded, new tank cannons must meet maximum chamber pressure and maximum recoil requirements. A given percentage of the cannon tubes are tested or proofed to verify that they meet these requirements. To proof a gun tube, the tester fires three projectile slugs at successively higher chamber pressures that correspond to first 80%, then 100%, and finally 120% normal chamber pressure. For the recoil test, a steel slug is fired with the cannon elevated 30° to increase the load transmitted to the recoil system. To avoid undue wear or even damage to a new cannon tube, the testers use an old worn tube with the new recoil mount.

There are two sources of impulsive noise from the proofing work: gun blast noise and projectile bow shock noise. The gun blast is highly directional. Locations directly in front of the gun are about 15 decibels (dB) higher than for equidistant locations directly to the rear of the gun.[2] The projectile bow shock noise only occurs forward of the gun, in a region determined by the supersonic velocity of the projectile. This noise is localized nearer to the gun if the slug is unstable in flight and thus decelerates quickly to subsonic speeds.

The Combat Systems Test Activity (CSTA), Aberdeen Proving Ground (APG), has proofed tank guns for many years and has built extensive facilities to support this testing. CSTA's proofing facilities are located at Mulberry Point, which is adjacent to the Chesapeake Bay. The cannons to be proofed are pointed toward the bay in a southeastern direction and fired. The noise from the cannons is directed predominantly to the front and is attenuated much less over water than over vegetated land. The noise levels are much higher for residents who live across the Chesapeake Bay on the Eastern Shore than for residents located at equal distances to the rear of the cannon. Although some of the Eastern Shore residents may hear the projectile-induced noise, most of the residents are located far enough away from the projectile line-of-fire that the launch blast noise is the major contributor to the noise signature.

[1] Schomer, P., "The Statistics of Amplitude and Spectrum of Blasts Propagated in the Atmosphere," Technical Report N-13, U. S. Army Construction Engineering Research Laboratory, Champaign, IL, November 1976.

[2] Schomer, P. D., Little, L. M., and Hunt, A. D., "Acoustic Directivity Patterns for Army Weapons," Interim Report N-60, U. S. Army Construction Engineering Research Laboratory, Champaign, IL, January 1979.

[3] Lehto, D. L. and Larson, R. A., "Long Range Propagation of Spherical Shockwaves from Explosions in Air," Technical Report NOL-TR- 69-88, Naval Ordnance Laboratory, White Oak, MD, July 1969.

Mufflers are commonly used to reduce launch blast noise. Investigations[4] and development of mufflers have been primarily centered on small firearms. Mufflers are designed to allow gun gases to expand into chamber volumes so the maximum pressure at the muffler exit hole is reduced. The diameter of the baffle holes is kept as small as possible. These design strategies effectively reduce the energy efflux from the muffler exit hole. The maximum energy efflux determines the blast magnitude.[5,6]

Guns larger than 30 *mm* can also be muffled effectively with large, possibly unwieldy, devices. For a small-caliber to medium-caliber gun, a muffler is attached directly to the muzzle of the gun. A muffler of the required size attached to a large-caliber cannon would excessively load the barrel and interfere with the recoil test phase of the tank gun proofing. Instead, the gun is inserted into a hole on the back plate or baffle of the muffler. CSTA has performed tests with such large mufflers, but they are heavy and hard to move in and out of position.[7] Using its expertise from prior muffler development programs,[8,9,10] the Ballistic Research Laboratory (BRL) has designed a muffler to reduce the noise associated with proofing. This muffler is smaller and lighter than the mufflers tested by CSTA. Figure 1 shows the muffler. It consists of a series of elliptical-dished tank heads (commonly used in boiler fabrication) and cylindrical sections welded together to form several chambers. This report details the design of that muffler.

II. Related Muffler Work

Because of excessive costs, a full-scale configurable muffler could not be fabricated to develop an optimum design. Development work for a 25 *mm* cannon muffler[8,9,10] is applicable to the tank cannon muffler design and has saved much time and expense. Test results for a large-caliber muffler built by Textron Corporation, Mass. (formerly AVCO) were also used to improve the design and avoid potential problems.[7]

1. Medium Caliber Configurable Muffler

Results from tests that used a configurable research muffler were utilized to develop fieldable mufflers for a 25 *mm* cannon. The muffler could be rapidly assembled to test different volumes, baffle placements, and other parameters. Pressure gages were placed both

[4] Bixler, O. C., Dahlke, H. E., Kaplan, R. E., and Van Houten, J. J., "Analytical and Experimental Studies of Weapon Muffling," LTV Research Center Report 0-71200/7TR 123, August 1967.

[5] Heaps, C. W., Fansler, K. S., and Schmidt, E. M., "Computer Implementation of a Muzzle Blast Prediction Technique," ARBRL-MR-3443, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, May 1985. (AD A158344)

[6] Fansler, K. S., "Dependence of Free Field Impulse on the Decay Time of Energy Efflux for a Jet Flow," ARBRL-MR-3516, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, May 1986. (AD A168365)

[7] Walton, S., "Private Communications," U. S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD, 1988-1990.

[8] Fansler, K. S., Thompson, W. G., Carnahan, J. S., and McClellan, D. F., "Attenuation of Muzzle Blast from the 25 mm M242 Automatic Canon," BRL-MR-3557, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, December 1986. (AD B109970)

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

[10] Fansler, K. S., Cooke, C. H., Thompson, W. G., and Lyon, D. H., "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.

inside the muffler and in the free field. After BRL performed experiments with different muffler configurations, a configuration was selected to maximize the attenuation of the blast. The same configurable muffler served as a guide to designing the proofing muffler because the results should be roughly comparable if the key dimensions are nondimensionalized by muffler exit-hole diameter. A model of the maximum pressure on the baffle of the entrance chamber was also developed to compare with the experiments.

2. Large-Caliber Textron Corporation Muffler

A muffler that was originally owned by Textron Corporation has been assessed at APG for possible use with the gun proofing work (Figure 2). This muffler, designed to be used with saboted rounds, had baffle holes whose diameters increased with distance from the muzzle. CSTA fired slugs from a 120 *mm* tank gun through the muffler with the original baffle holes. The muffler attenuated the noise by 10 dB behind the gun, but reduced noise only negligibly to the sides and front.

To achieve better attenuation, CSTA reduced all the baffle exit holes to 30.5 cm (12 in) with supplemental baffle plates. Testing of this configuration yielded an overall mean attenuation of 12.5 dB. A measuring point on the Eastern Shore recorded 20.8 dB attenuation. A low value of 5.3 dB was recorded at an APG position located close to the cannon and the line of fire. The projectile bow shock may have made a major contribution for this location, but APG is only concerned with the noise received off of its premises.

The modified Textron Corporation muffler attenuated satisfactorily, but as configured, it could not be used for tank cannon proofing. Video coverage showed that a large fireball exited the rear of the muffler and enveloped the cannon. Probably the gun gas flow was excessively hindered by the four forward baffles. As a result, the muzzle flash, which is normally directed down range, was directed back toward the weapon from the one rear baffle hole. Further testing might have damaged the weapon. This unbalanced flow also caused the Textron Corporation muffler to move forward as each shot was fired. After the third shot, CSTA personnel observed that the first two supplemental baffle plates had failed. To continue testing, CSTA would need to design and fabricate new supplemental baffle plates. Even if the muffler were modified to fix the above problems, it is far too heavy (26 metric tons) to be positioned for firing with the cannon elevated 30°.

III. Preliminary Design Work

We needed to obtain at least a 10 dB peak level attenuation from the designed muffler. Specifically, the amount of attenuation depends on the chamber volume, the baffle hole size, the number of baffles, and the placement of the baffles. These parameters are obtained by using a blend of predictive models and experimental observations. The baffle location and muffler sizing was determined by analysis of the 25 *mm* configurable experiments and the results of the Textron Corporation muffler tests. The loading on the muffler interior was estimated from the results obtained with pressure gages installed in the 25 *mm* configurable muffler. Computational and modeling techniques also influenced the design.

1. Baffle Location and Muffler Sizing

The Textron Corporation muffler experimental results were used to make some fundamental design decisions. In order to minimize the impulse differences on the front and rear baffles, and thus prevent forward movement. CSTA modified the original proofing muffler design by reducing the number of forward baffles from four to three and increasing their hole diameters. Two baffles to the rear of the muzzle instead of one will further restrict the rearward-directed flow.

The rear holes allow propellant gas to exit, which adds to the total energy efflux from the muffler and thereby decreases the attenuation capability. For the proofing muffler, the rear baffle hole sizes were selected to be 25.4 cm (10 in) in diameter, only large enough to insert the barrel through the two rear baffles and to fire without the recoiling barrel striking the muffler. The total propellant gas that exits the rear holes should be significantly less than the gas that exits front holes, and the loss in attenuation should be minimal. In contrast, the large-caliber Textron Corporation muffler's cannon entrance hole is 30.5 cm (12 in) in diameter.

A configurable muffler with approximately the same scaled length (scaled by muffler exit-hole diameter) and 85% of the scaled diameter of the proofing muffler attained approximately 12 dB Sound Exposure Level (SEL) to the side.[9] The baffle separation distance chosen for the BRL muffler scales approximately with that for the 25 *mm* muffler. The dimensions of the tank cannon muffler should be sufficient to achieve the attenuation goal.

2. Load Estimates

A one-dimensional blast model,[9] which assumes steady propellant flow from the entrance tube, predicted a pressure of 10 MPa on the baffle. The estimate is too high because the propellant flow rate, which determines the magnitude of the blast wave, is not steady in the chamber. The first baffle is placed far enough from the muzzle that when the blast wave front arrives, the flow rate and hence the strength of the shock are significantly reduced. Also, the space behind the muzzle allows the gases to expand to the rear, which further lowers the pressure from that predicted by the one-dimensional blast model. As an added benefit, the large distance from the muzzle to the first forward baffle will reduce the amount of erosion caused by impinging propellant particles.

A maximum entrance chamber pressure of approximately 5 MPa was measured in the configurable 25 *mm* muffler.[10] Earlier designs of the proofing muffler had ratios of propellant mass to entrance chamber volumes approaching the ratio observed for the 25 *mm* configurable muffler. The load on the entrance chamber walls of the proofing muffler were also assumed to be 5 MPa. Although the entrance chamber volume for the final design is significantly larger than for the earlier designs, a pressure of 5 MPa was retained to give an extra measure of safety.

The pressure on the baffle surfaces facing away from the gun muzzle was assumed to be zero to impose worst case conditions. Again, guided by test results of the 25 *mm* muffler, we set the pressures on the first and second chambers in front of the entrance chamber at 4 MPa and 3 MPa, respectively. Because the flow from the entrance chamber to the rear chamber is more restricted, the pressure on the rear chamber was set at 3 MPa.

The propellant gas inside the muffler may react with air and combust. This process can significantly increase the pressures inside the muffler.[10] Some mixing could occur at the air-propellant interface as the shockwave front travels toward the baffle. However, most of the burning occurs after the blast wave front is reflected at the baffle. The increase in pressure is hard to estimate and numerical techniques cannot presently treat this problem adequately. Nevertheless, an idea of the pressures inside the first chamber at later times can be obtained by an extreme simplification. The flow from the gun was approximated as a Joule expansion into a closed container. This closed container had a volume equal to the volume of the muffler's entrance chamber. The overpressure value found from the Joule expansion model is approximately one MPa. Even if the rise in pressure is a factor of two larger, the result would still be a peak overpressure smaller than the maximum pressure already assumed (5 MPa).

3. Material Selection

The muffler's operating conditions must be well known in order to make a good choice of the fabricating material. The muffler will be used when the cannon is fired at 30° elevation and must be raised in place by a light lifting mechanism. The weight of the muffler can be minimized by designing thin walls, which requires the use of a high-strength steel. The muffler will have thousands of rounds fired through it so the material must also be fatigue-resistant. The muffler will be used with corrosive gun propellant gases and be subject to weather extremes. The material must be able to stand up to such use or else be painted or coated with a protective material. The muffler must be fabricated using standard production techniques and must be low cost. Thus, the material must be easily worked, in common use, and commercially available.

A steel material with special properties should fulfill the above requirements. Stainless steel 17-4 PH was successfully used for a 25 mm gun muffler. The PH steels offer an alternative means of obtaining high yield strength (> 930 MPa) in a stainless material by a relatively low-temperature heat treatment that can be applied after fabrication. However, the proofing muffler would be a large structure, which would require a large furnace to elevate the temperature and maintain it for the proper length of time. To maintain a uniform temperature throughout the muffler, and thus guarantee homogeneous properties, would be difficult. Stainless steel 17-4 PH is also expensive. Therefore, it was desirable to find an alternative to 17-4 PH.

Several high-strength steels, developed for the US Navy, were considered. They are the High Yield (HY) series, such as HY-80 and HY-100, and the High Strength Low Alloy (HSLA) series, such as HSLA-80 and HSLA-100. The number in the name refers to the steel's yield strength (kpsi). These steels are used in the structural designs of new ships and submarines. The HY steels require preheating in areas that are to be welded. The preheating process increases the probability of making mistakes and increases fabrication cost. The HSLA steels were developed to avoid the preheat requirement. HSLA-100 has only recently been developed and certified.[11] HSLA-80 has been used much more extensively, has a greater database,[12] and is more readily available. Because of the aforementioned qualities, HSLA-80 steel (MIL-S-24645) was selected. It is an optimized version of ASTM A710, Grade A steel, which is a low-carbon, copper-precipitation-strengthened steel.

IV. Detailed Muffler Design

The detailed muffler design is concerned with parameters such as wall thickness, baffle shaping, and reinforcements. These design details were determined largely by the use of finite-element modeling and stress analysis.

1. Wall Thickness

The wall thicknesses needed can be approximated without the detailed use of finite-element modeling. The thin-wall pressure vessel equation has the form:

$$S_h = \frac{PR}{t} \tag{1}$$

where S_h is the maximum hoop stress, P is the estimated internal pressure, t is the thickness, and R is the mean radius.

A wall thickness of 19.05 mm(0.75 in) provides a safety margin of 2.75 when a pressure of 5 MPa is assumed. This wall thickness is used for the smaller chambers. The main chamber wall was chosen to be 25.4 mm(1.0 in) thick in order to provide a greater safety margin and to compensate for any thinning of the walls that may be caused by gun-gas erosion.

2. Baffle Shape

Commercially available tank heads, used in the manufacture of boilers and other pressure vessels, were explored for use as baffles. Some typical head shapes include hemispherical, radius-dished, and elliptical-dished. Hemispherical heads offered the strongest shape, but they were disqualified as a baffle choice because the required welding would be difficult, and this head type is more expensive than others considered for selection. Radius-dished heads are the cheapest, but had high stresses in the region where the dish and the cylindrical flange blend together. Elliptical-dished heads, with a 2:1 ratio for the ellipse's axes, offered the best compromise. Although not as strong as the hemispherical shape, they possess adequate strength, are relatively inexpensive, and the pipe section can be butted against the outside of the head to provide a good weld joint.

[11] Czyryca, E. J., Link, R. E., Wong, R. J., Aylor, D. A., Montemarano, T. W., and Gudas, J. P., "Development and Certification of HSLA-100 Steel for Naval Ship Construction,"Naval Engineers Journal, May 1990.

[12] McCaw, R. L., Wong, R. J., "Certification of HSLA-80 Steel for Naval Ship Construction ," David W. Taylor Naval Ship Research and Development Center, Annapolis, MD, June 1985.

3. Reinforcement Around Hole

The results of finite-element analysis calculations show that when the muffler is under internal load, high stress occurs around the exit hole cut into the heads. In order to strengthen the area around the hole, we tried various stiffeners. These stiffeners are shown in Figure 3. A ring placed inside the hole reduced the stress somewhat, but more improvement was noted with placement on the outside. However, even with a ring on the inside and outside, there remained an area of high stress around the hole. Although that stress was below the yield strength of the steel, it was still of concern. Stress cycling on the first fabricated 25 *mm* muffler resulted in fatigue cracking around the entrance chamber's exit hole. So further means of stiffening the areas around the holes were explored.

Bar stock bent to conform to the shape of the head and then welded to the heads along radii to form stiffening ribs was tried. The stress in the material located close to the ribs is reduced, but the material away from the ribs possessed the same stress as before. A long, thin pipe welded in the hole still left a high stress area in the center of the pipe. The vicinity of the hole became one of the lowest stressed regions in the structure when the pipe was shortened and thickened.

4. Final Finite-Element Model for the Complete Muffler

A finite-element model of the muffler is shown in Figure 4. The structure was modeled with 2-D axisymmetric elements, using a static linear analysis. By assuming that the internal pressures act only on the inside surfaces of the heads, we overestimated the loading on the structure. Figures 5a-5c show the Von Mises stress contours in the structure. Von Mises stress is an accepted failure criterion and is akin to a resultant of the principal stresses. This analysis shows that the stress is always less than 172.4 MPa (25kpsi), which is well below the yield strength of HSLA-80 (80 kpsi). The design provides a safety margin of at least three and, since the loading conditions were overestimated, the safety factor is probably closer to four. With the number of firing cycles anticipated, such a conservative design is necessary to forestall fatigue cracking.

V. Experiments with a Scaled Configurable Muffler

Based on 25 *mm* configurable muffler test results, estimates of pressure inside and outside the muffler were made in designing the 120 *mm* muffler. To obtain better estimates of the pressures outside the muffler and the momentum given the muffler during firing, we designed and fabricated a scaled configurable proofing muffler. With the ability to configure the muffler, we could explore the possibility that a modest variation from the present design might yield markedly superior results. The experimental results could point the way to further design improvements of the proofing muffler.

1. Scaled Configurable Muffler

Figure 6 shows the scaled configurable proofing muffler with an additional front baffle (AFBM). The scaled version of the proofing muffler has three front baffles (SM). The muffler was also configured with an additional back baffle (ABBM). A 300 Magnum gun was used to fire through the muffler and simulate the tank cannon. Of course, this muffler does not strictly represent a scaling down of the proofing muffler. In order to make the muffler configurable, the baffles could not be elliptically shaped but had to be flat. Also the 300 Magnum gun does not strictly represent a scaling down of the barrels being proofed. No small-bore weapon can be adapted easily to scale to a tank cannon. Nevertheless, the information obtained here can be used to assess the adequacy of the current proofing-muffler design and to estimate the impulse given the proofing muffler by the tank cannon.

2. Recoil Experiment

To measure the recoil velocity, we mounted the muffler on a recoil-measuring apparatus. The position of the muffler as a function of time was recorded as a voltage on an oscilloscope. Three shots were fired through each configuration. The results are summarized in Table 1. The trends agree with previous work.[9] The magnitude of the impulse given the muffler increases with the number of baffles in front of the muzzle. However, the net impulse given to the muffler decreases with the number of baffles placed to the rear of the muzzle.

Table 1. Impulse Imparted to Scaled Configurable Muffler

Configuration	Impulse kg-m/sec
AFBM	20.3
SM	20.1
ABBM	18.2

The impulse given the proofing muffler can be roughly estimated from the scale model results and a knowledge of the weights of the proofing muffler and the carraige. From Corner,[13] the estimated impulse given to the gun by the propellant gas after the projectile leaves the muzzle is

$$I = 1.35C\sqrt{RT_e} \tag{2}$$

Here, C is the charge mass of the propellant in kg, R is the gas constant for the propellant in $(m/s)^2/^\circ K$, and T_e is the temperature of the exiting propellant gas in $^\circ K$.

The impulse given to a muzzle brake is roughly proportional to I or equivalently the charge weight since the exit temperature will be a weak function of the charge weight.

[13] Corner, J., "*Theory of the Interior Ballistics of Guns*," John Wiley and Sons, Inc., New York, 1950.

Assume then that the muffler approximates the usual proportional relationship between the gas-propellant impulse and the impulse given a muzzle brake,

$$\frac{L_p}{I_p} = \frac{L_s}{I_s}, \tag{3}$$

where L is the momentum given the muffler, the subscript p denotes the proofing muffler, and the subscript s denotes the scaled muffler. The values of the quantities are given below:

$$\begin{aligned} C_p &= 8.16\, kg, \\ \left(\sqrt{RT_e}\right)_p &= 900\, m/s, \\ C_s &= 5.06 \cdot 10^{-3}\, kg, \\ \left(\sqrt{RT_e}\right)_s &= 800\, m/s, \\ L_s &= 20.1\, kg\ m/s. \end{aligned}$$

Using these values, one obtains that $L_p = 3.64 \cdot 10^4\ kg\ m/s$. The mass of the proofing muffler is 5320 kg and the mass of the carriage is 2500 kg. The resultant velocity given to the muffler-carriage assembly would be 4.65 m/s.

3. Peak Overpressure Experiment

The overpressure data were obtained from gages that were located 200 bore diameters away from the front exit of the muffler or, for the bare muzzle case, from the gun muzzle. Figure 7 shows the scaled muffler comparisons in relationship to the bare muzzle data. The data obtained for a polar angle equal to or greater than 60° were taken with Bruel and Kjaer (B&K) quarter-inch diameter microphone probes with their protective grids attached. Although these microphones are responsive to frequencies as high as 70 kHz, comparison of the microphones with and without the protective grids show that the protective grids function as a lowpass filter. The data obtained at 30° were obtained with a PCB gage, which has a better high-frequency response than the B&K microphones with their protective grids removed. The values measured at 30° were somewhat lower because of the lower frequency response of the B&K microphone systems. The peak overpressure differences between the different configurations are small. From these results, it is seen that there is no need to change the basic muffler design. Relative to the bare muzzle results, the peak overpressure is attenuated more to the sides than to the front or back. It is difficult to estimate far-field attenuation of the actual muffler from this relatively near-field data. Different absorptivities at different frequencies make prediction difficult. Moreover, the tank cannon and the 300 Magnum gun have different muffler-volume to bore-and-chamber volume ratios.

VI. Discussion and Summary

To reduce noise received by surrounding communities from APG, we have designed a muffler for use in proofing tank cannons. The location of the muffler baffles and the overall sizing were determined by utilizing configurable muffler experiments, CSTA testing results, and computer modeling. A configurable scaled muffler was used to further explore design options and estimate the recoil impulse. By the use of finite-element modeling, the final design was shaped to minimize stress and weight. The muffler design is conservative and provides a comfortable safety margin. Commercially available heads and pipe sections made from the high-strength steel, HSLA-80, can be utilized. This steel requires no expensive heat treatment and is readily weldable.

We propose a simple cradle mount, as shown (Figure 8), to provide limited proofing operations. The impulse given the proofing muffler plus cradle was estimated by using a scaling approximation and the results of experiments with a scaled configurable muffler. Unfortunately, it may not be possible to use the cradle to conduct elevated gun-recoil proofing. The estimated cost to construct the muffler and simple mount is under $100,000.

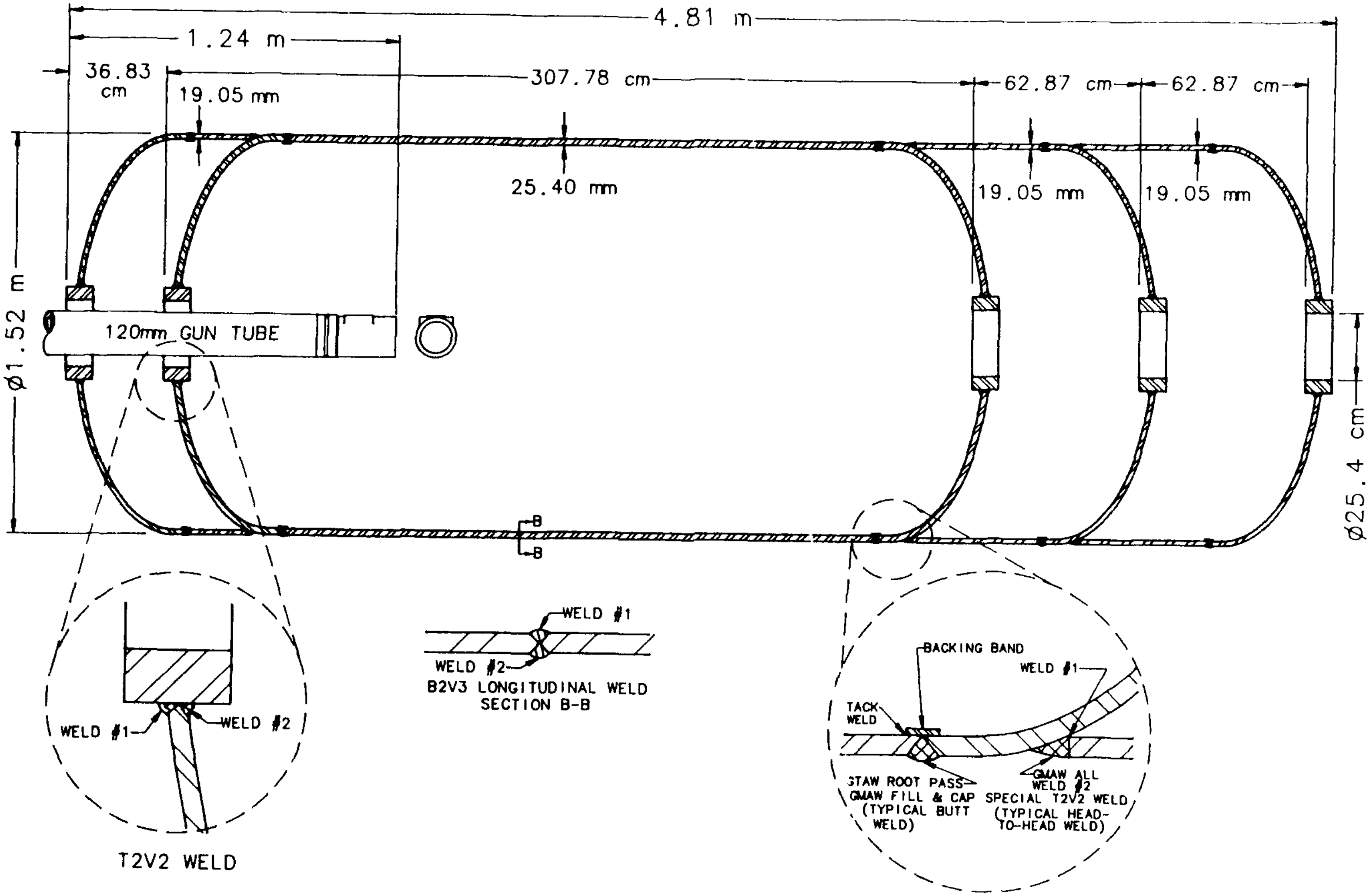


Figure 1. Proof-Testing Muffler.

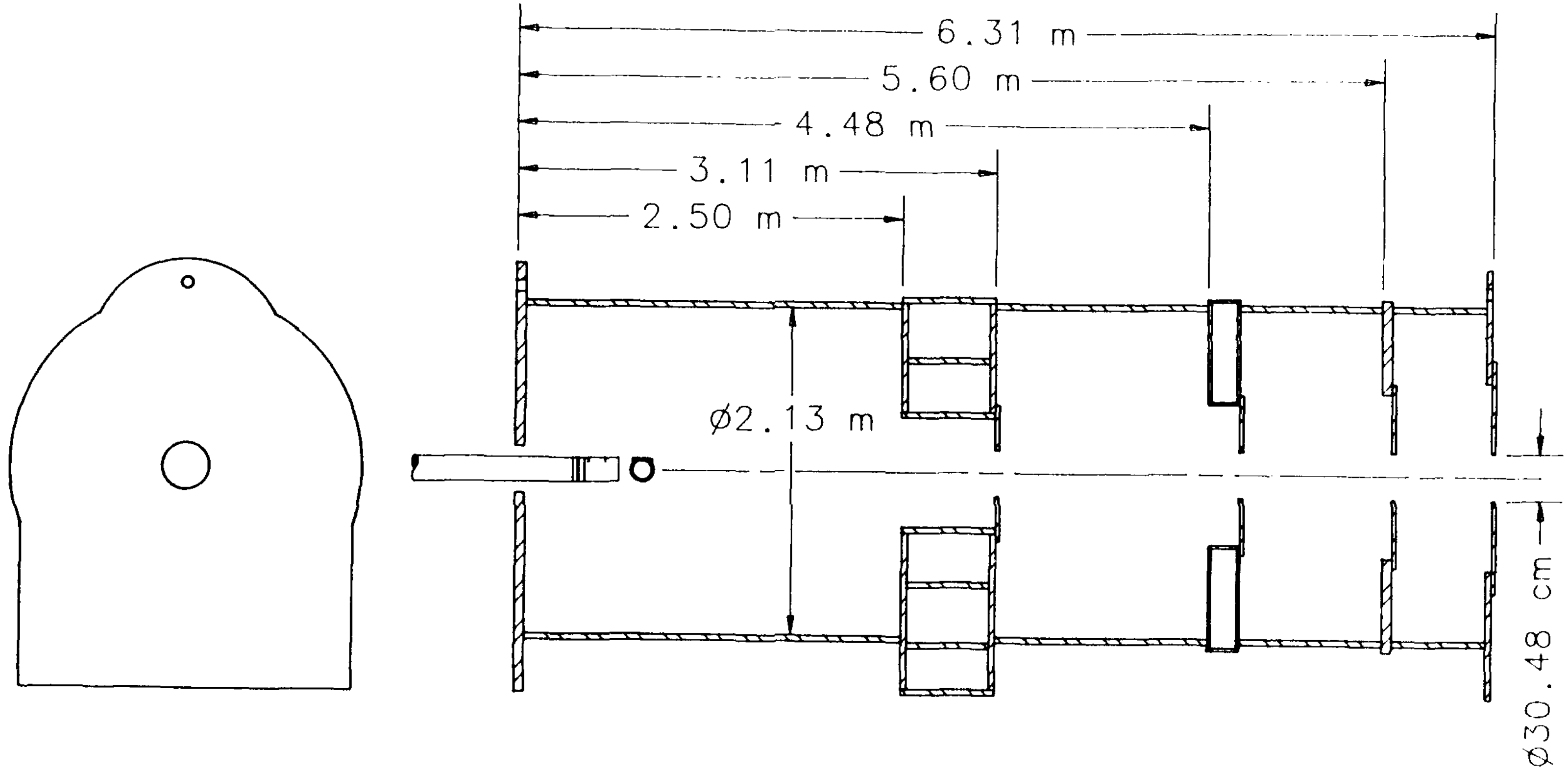


Figure 2. Textron Corporation Muffler.

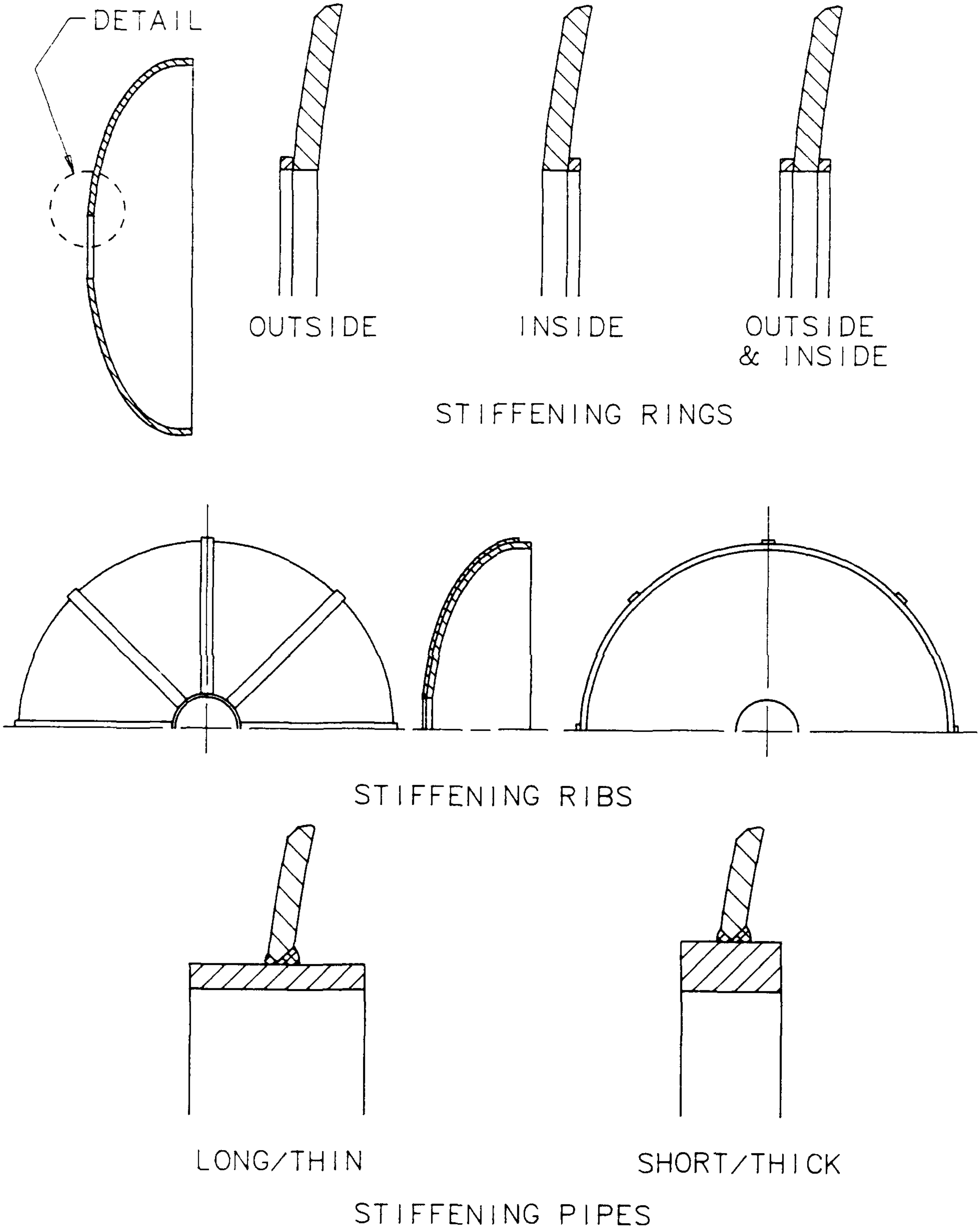


Figure 3. Hole Stiffeners.

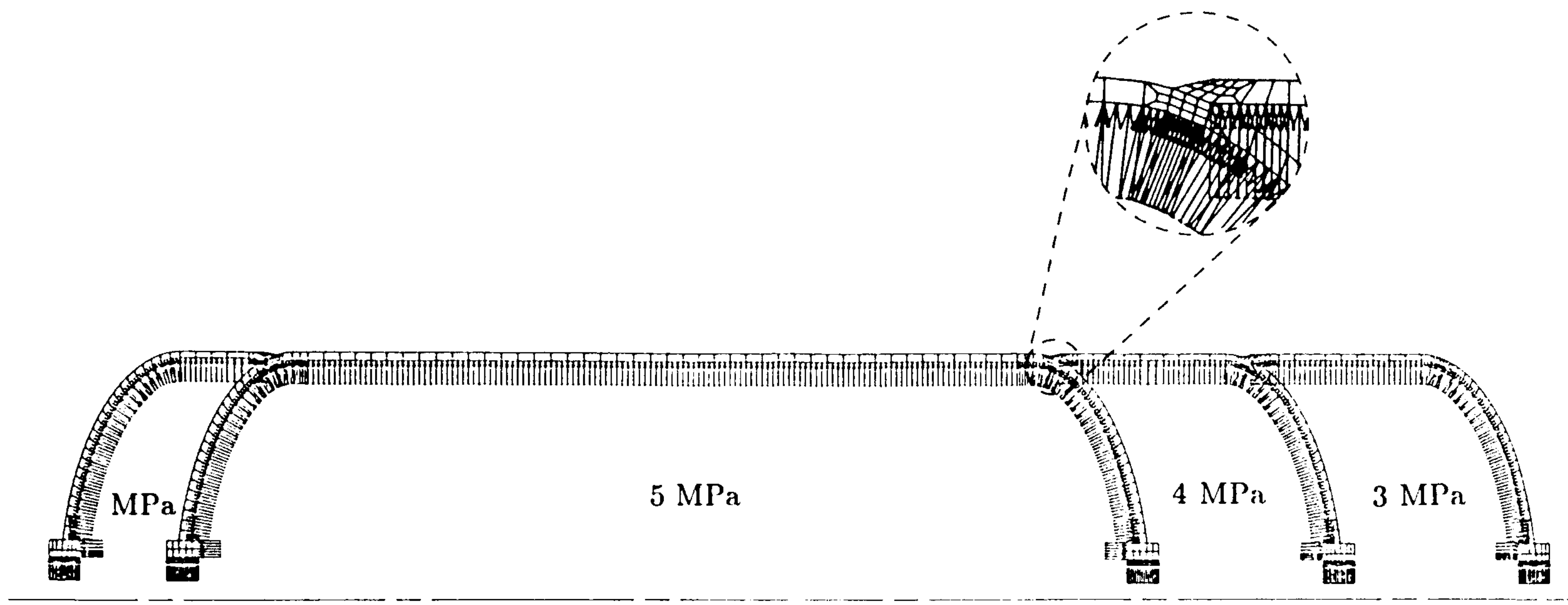
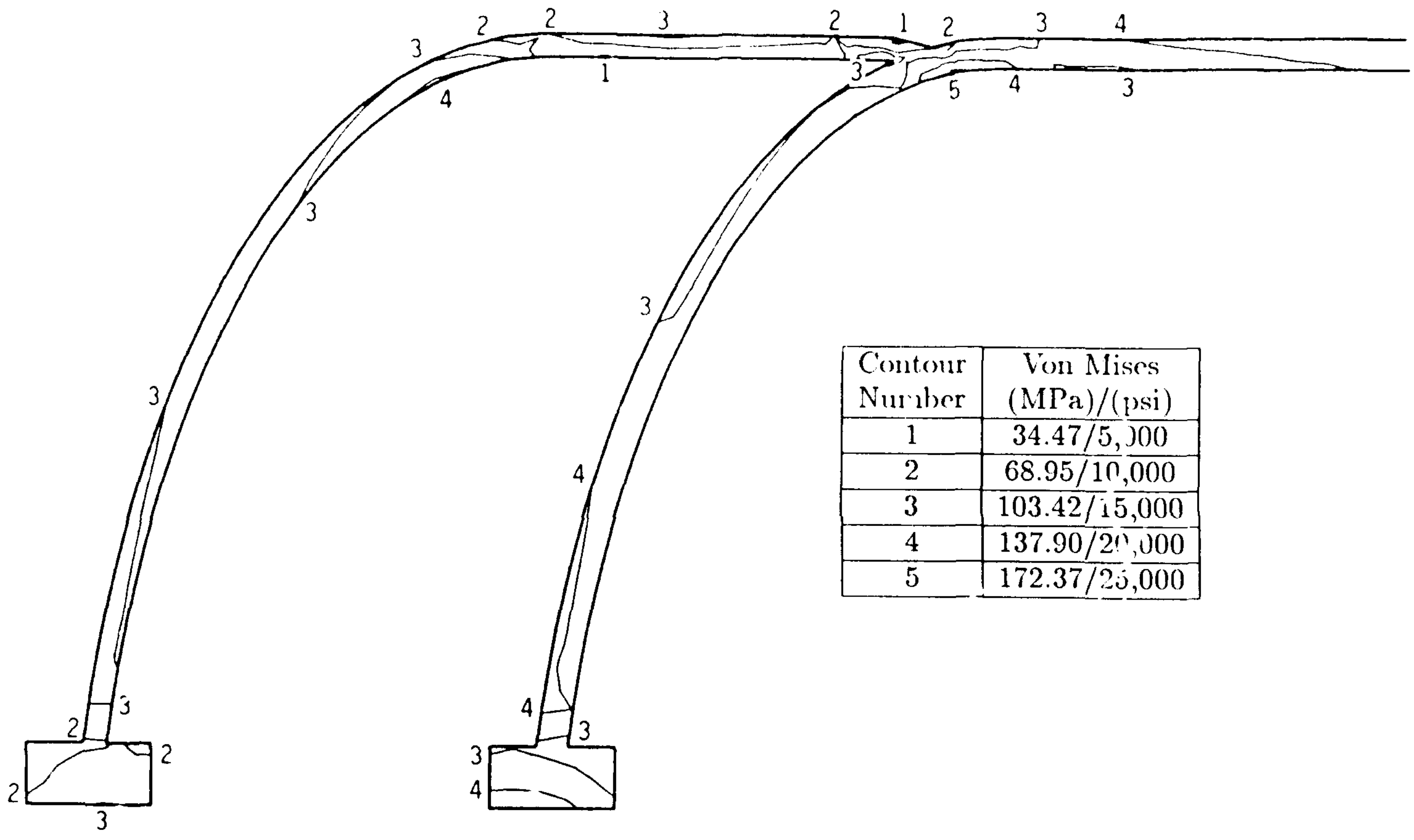
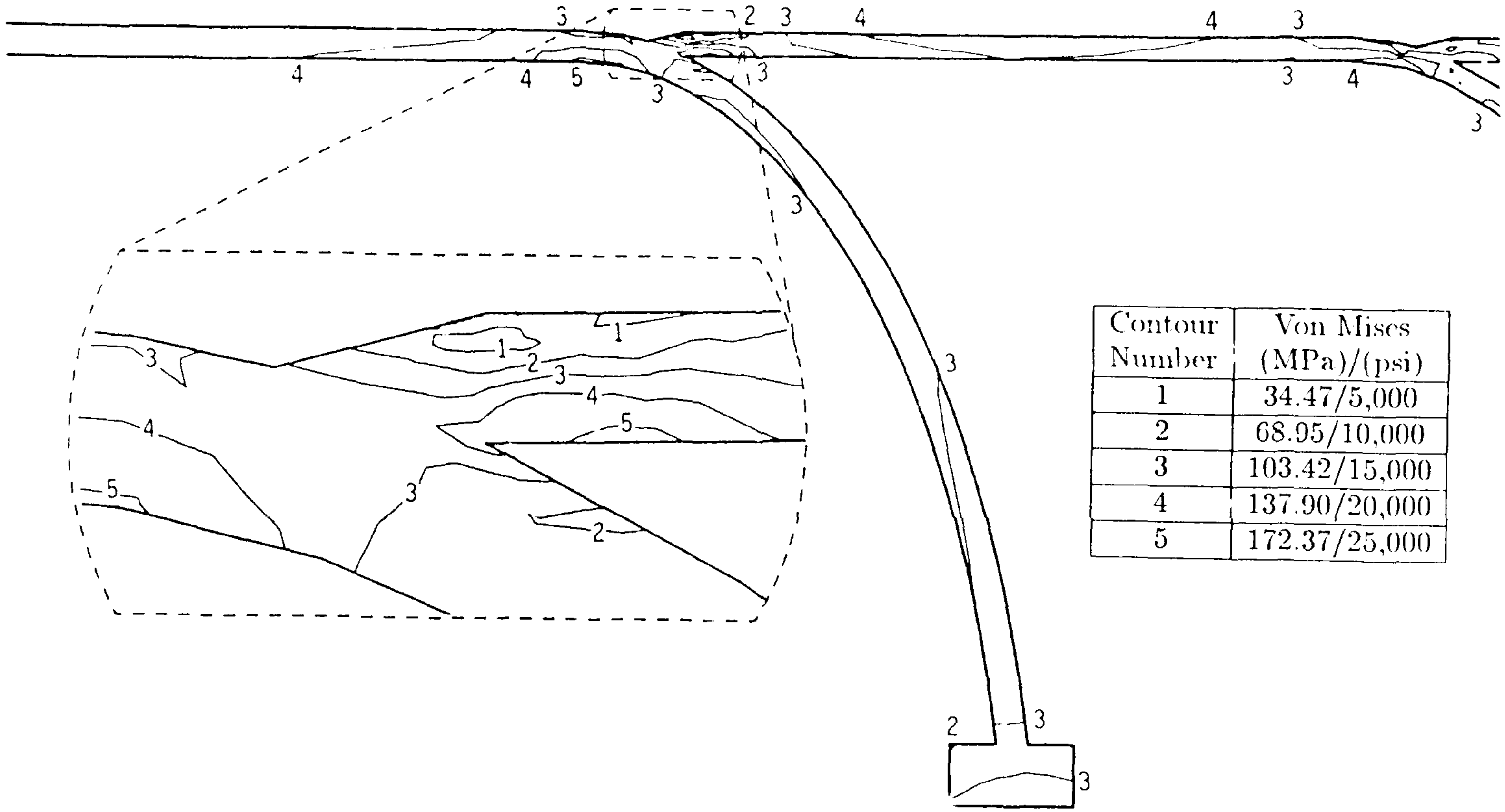


Figure 4. Finite-Element Model of Muffler.



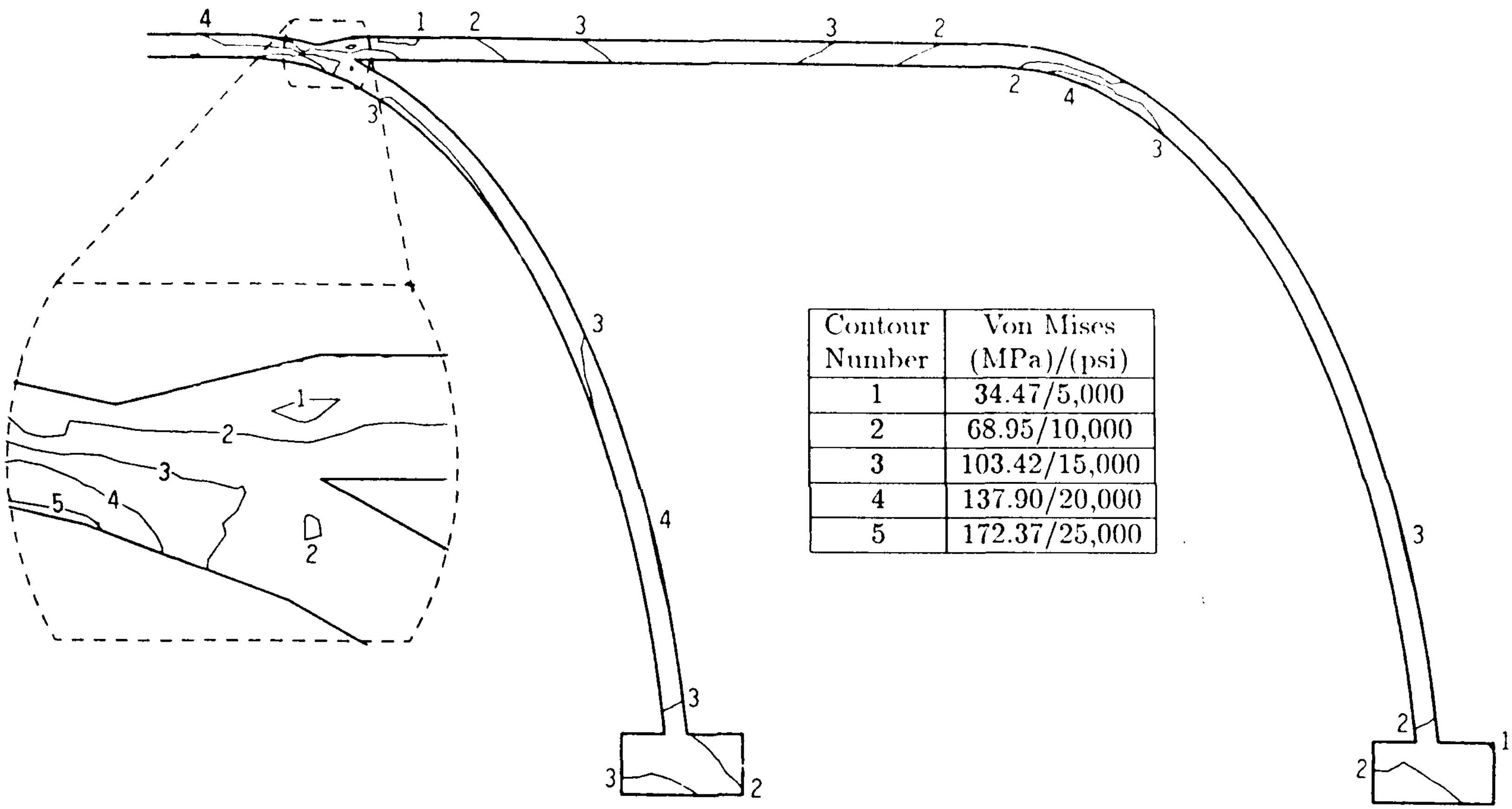
Contour Number	Von Mises (MPa)/(psi)
1	34.47/5,000
2	68.95/10,000
3	103.42/15,000
4	137.90/20,000
5	172.37/25,000

Figure 5a. Von Mises Stress Contours (Rear Two Baffles).



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

Figure 5b. Von Mises Stress Contours (First Front Baffle).



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

Figure 5c. Von Mises Stress Contours (Second and Third Front Baffles).

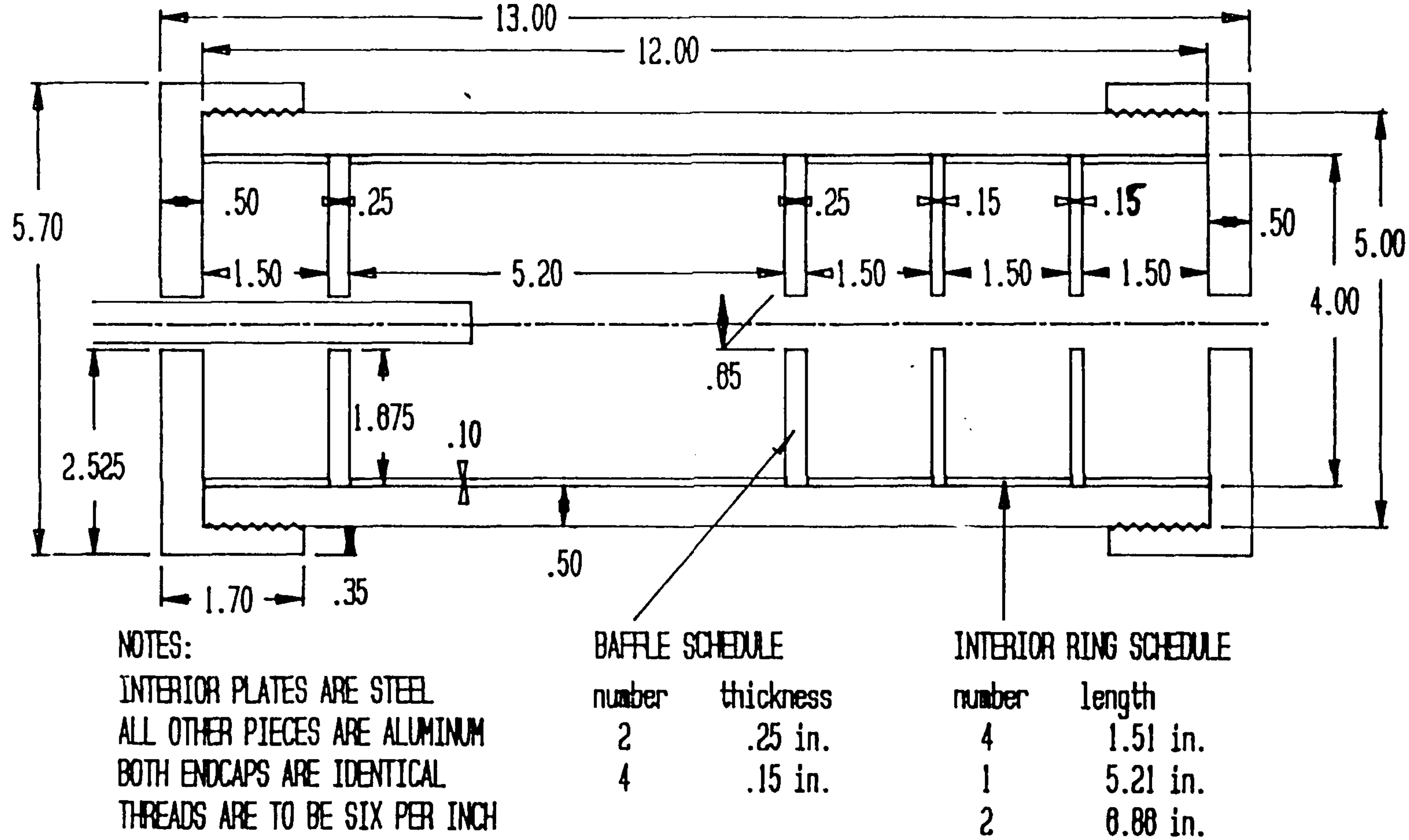


Figure 6. Configurable Scaled Proofing Muffler.

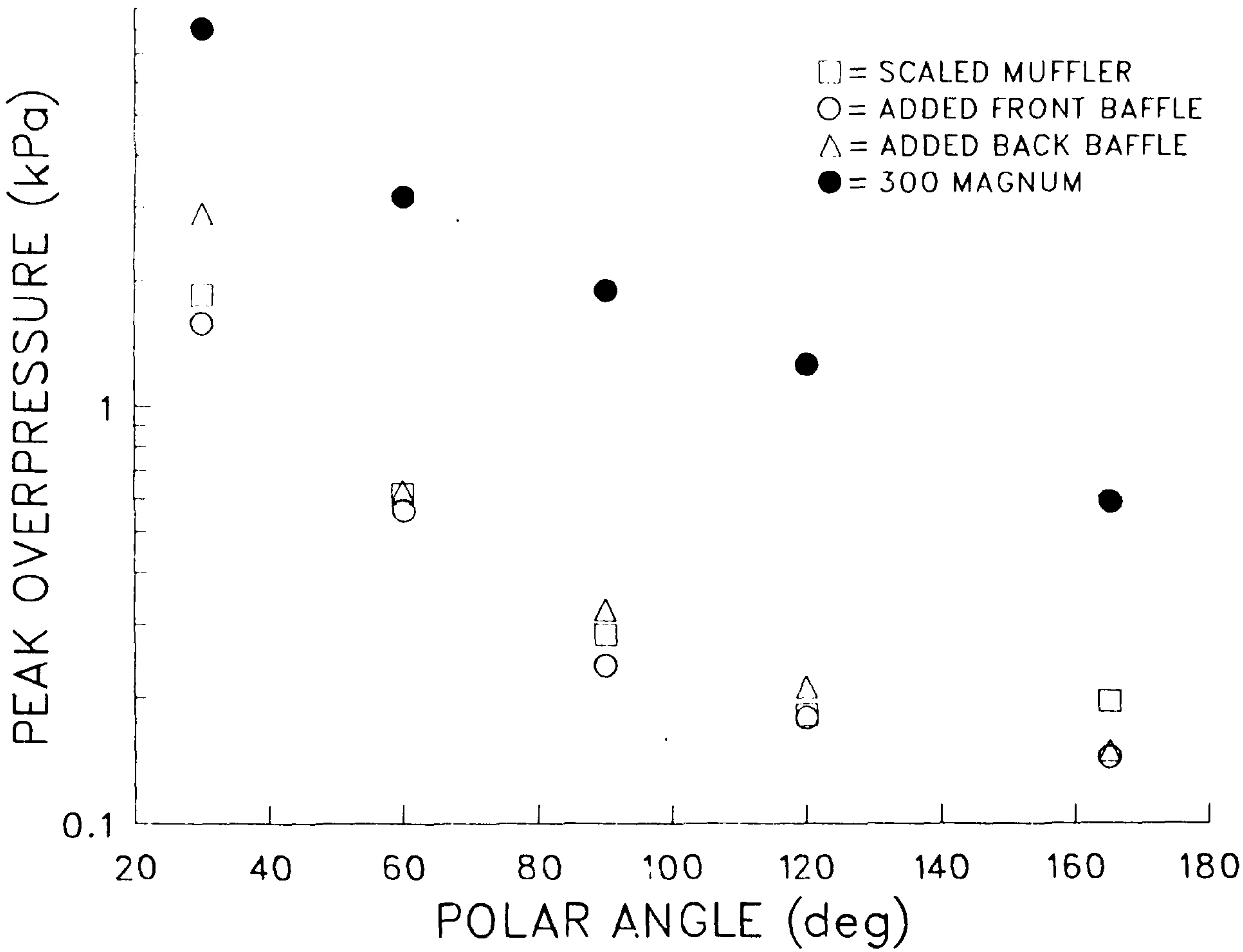


Figure 7. Peak Overpressures for Configurable Scaled Proofing Muffler.

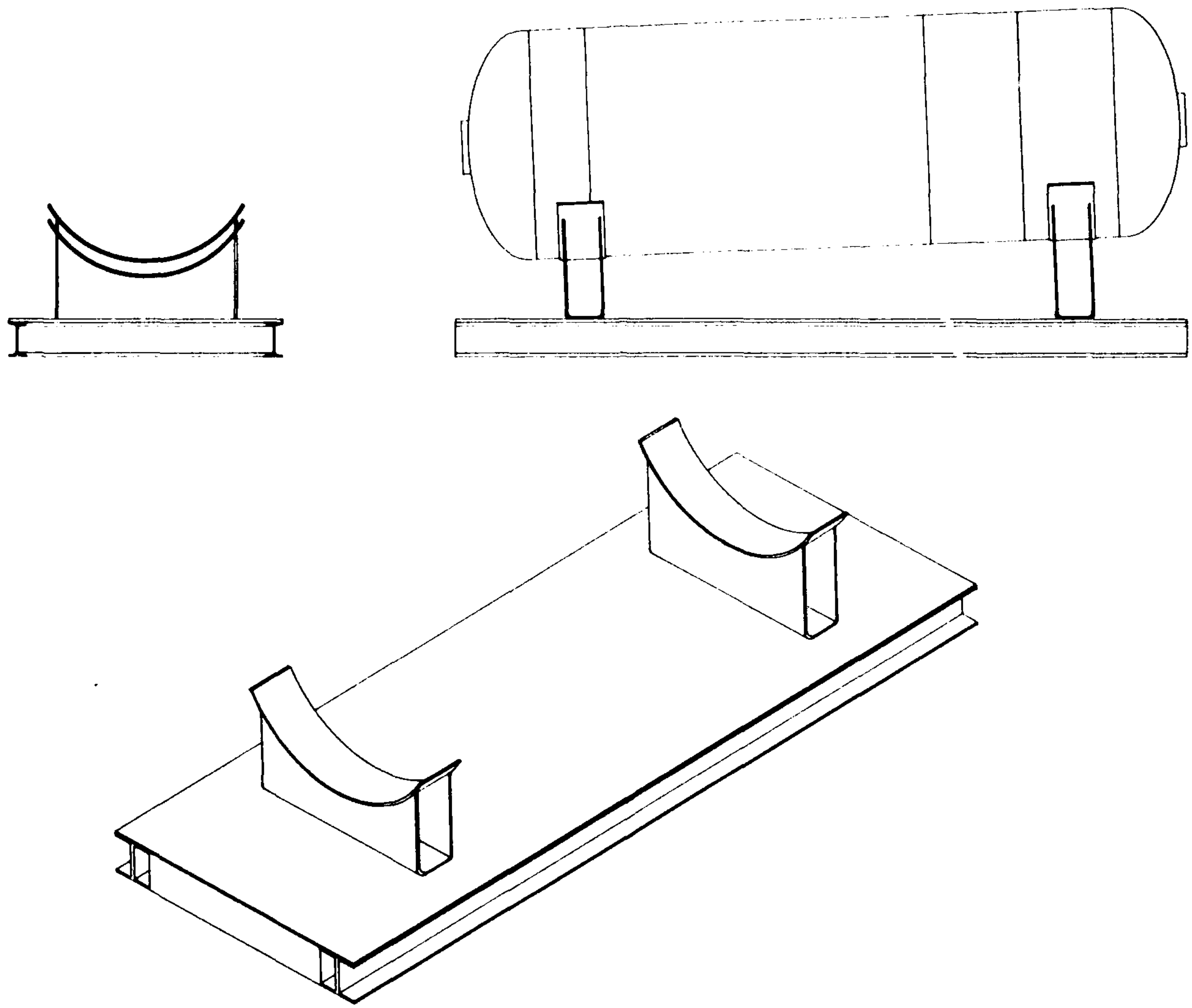


Figure 8. Muffler Mount.

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