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NUMERICAL SIMULATION OF SILENCERS

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SUMMARY

The problem of attenuating the noise from weapons firing is studied experimentally and numerically. As a possible method of attenuating the noise significantly, a silencer with no internal baffles is attached to the M242 cannon. The internal pressures inside the muffler are measured. The near-field overpressures outside the muffler at various polar angles are also measured. A numerical simulation of the flow through the muffler is performed, using Harten's shock-capturing method to solve the Euler equations of ideal compressible flow. The numerical simulation yields a detailed picture of the flow field as displayed by the pressure and Mach contours. Pressure–time curves at selected locations are obtained and compared with experimental data. There is good agreement, except that the numerical simulation generates more vigorous oscillations.

KEY WORDS Silencers Noise attenuation Shock flow Numerical simulation Gas dynamics

1. INTRODUCTION

The firing of gun weapons often generates objectionable levels of noise. Different methods or combinations of methods can be used to attenuate the noise. One possible response is to develop muzzle devices that attenuate the blast in all directions. These muzzle devices are referred to as noise attenuators, silencers or mufflers and are sometimes used with small-calibre rifles and pistols. Noise attenuators suppress noise from guns by reducing the rate of propellant energy being released to generate the muzzle blast.[1–4] No adequate model exists for the flow internal to the muffler; this flow is very complicated and for the larger mufflers is significantly modified by energy transfer of the propellant gases to the body of the muffler. In general, the muffling of the noise increases with the size of the muffling device; attenuation levels up to 40 dB have been claimed. However, the weapons producing the objectionable noise may be larger-calibre guns, such as the 25 mm M242 automatic cannon. It is not practical to scale up the noise attenuators designed for small-calibre guns to the size required for the 25 mm cannon, as the added bulk could compromise system performance by making the larger weapon unwieldy. Although mufflers with many bore and chamber volumes have been investigated, work on smaller mufflers has been neglected because generally higher noise attenuation is desired than can be thus achieved.

The immediate objective of this study is to adequately simulate a simple small silencer by a particular numerical technique. The flow field inside the silencer during the firing cycle is measured experimentally and also simulated numerically. A total variation diminishing (TVD) shock-capturing scheme is employed, with sufficient grid density to yield the necessary flow details.[5] Fluid property contours and pressure–time curves at selected locations are generated.

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2. THEORY AND NUMERICAL SIMULATION TECHNIQUE

Overview of the numerical scheme

The Harten scheme[5] is a TVD, second-order-accurate, upwind-biased method for solving the Euler equations of compressible flow in one dimension. The concept of operator splitting, placed on an analytical foundation by Strang,[6] permits application to higher dimensions and axisymmetric flow problems. Strang's work has been extended to allow the incorporation of source terms into the splitting, while at the same time preserving the second-order accuracy of the method.[7] The resulting shock-capturing algorithm is well documented,[8] with clarifying background material provided.[5,9]

Cannon and muffler description

The simulation is performed for the 25 mm cannon with the silencer attached. The cannon's bore length is 80 calibres; the internal length of the silencer chamber is 7·7 calibres; the exit hole of the silencer is 1·14 calibres in diameter; the exit wall thickness is 0·7 calibres; and the computational domain extends approximately 1·7 calibres downstream of the silencer exit.

Precursor flow and blast wave initialization for the numerical scheme

When the gun is fired, the inbore projectile pushes a column of air with a shock front that constitutes the precursor flow from the barrel. For the numerical simulation it is thought sufficient to assume that the precursor wave inbore is generated by a piston travelling at a constant rate. This results in a pressure of 1·73 MPa and a Mach number of 1·92 with, of course, the inbore precursor's fluid velocity being equal to the projectile velocity. The projectile is simulated by a cylinder three calibres long. The gas dynamic quantities behind the projectile were obtained using Lagrangian interior ballistics and the experimentally measured pressure at projectile exit from the cannon muzzle. A one-dimensional Harten code was used to calculate the flow inbore. Upon projectile exit flow values at the muzzle were

$$p_e = 33{\cdot}4\ \mathrm{MPa}, \qquad v_e = 1050\ \mathrm{m\,s^{-1}}, \qquad M_e = 1{\cdot}52.$$

3. EXPERIMENTAL RESULTS

In this paper experimental results for the muffler will be compared with the corresponding results obtained for a bare muzzle. Figure 1 shows a schematic of the muzzle device tested. The diameter of the exit baffle projectile hole is 2·85 cm or approximately 1·14 calibres. The internal length of the particular muffler simulated was 7·7 calibres. Gauges were inserted into the muffler to obtain pressures for comparison with results from the numerical simulation. The free-field blast overpressure is measured using an array of static transducers located in an arc with its plane vertical and at a distance of 50 calibres away from the projectile exit hole.

4. NUMERICAL RESULTS AND COMPARISONS WITH EXPERIMENT

Flow in the silencer was simulated on a VAX-8600 computer system. Initially, a grid density of 41 points per calibre was employed. Results shown in this report were obtained, for the most part, on this grid. For a feasibility study of calculations on finer grids, a much larger computer is necessary. However, a short run on an 81 points per calibre grid was accomplished, to assess the numerical accuracy. Although some improvement appears to result, the pressure trends were much the same.

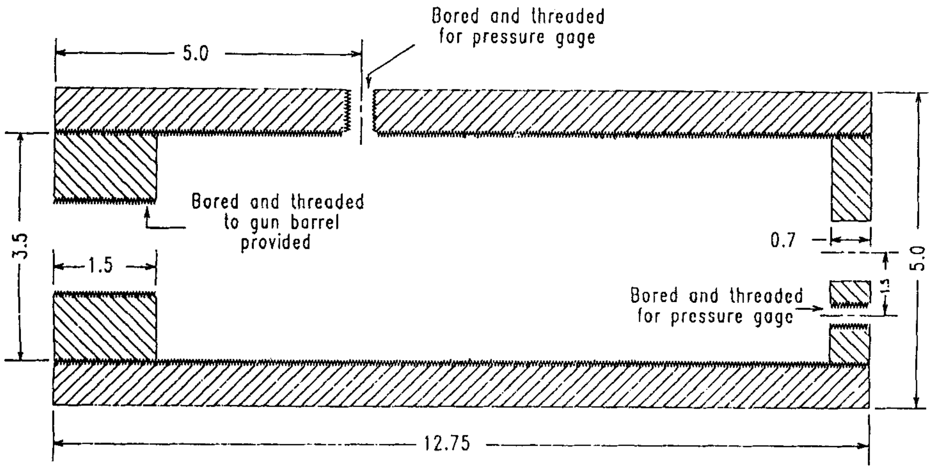

Figure 1. Schematic of BRL preprototype muffler

As mentioned earlier, the precursor flow for the numerical simulation scheme is treated initially as a uniform mass of gas having the velocity of the projectile, which determines its pressure and density. Figure 2 shows the pressure contours at the time immediately before the precursor shock wave hits the front baffle. The position of the inward-facing shock is clearly delineated. The shape of the shock front is a slightly curved line; this curvature is attributed to reflection of the waves from the cylinder walls. Figure 3 shows the pressure contours for the time immediately after the front of the precursor shock wave impinges on the front baffle and is reflected.

Figure 4(a) shows contours of pressure immediately after the shock wave, which is driven by the propellant gas, reaches the front baffle. Figure 4(b) shows Mach contours; the presence of the projectile slows the progress of the inward-facing shock at the positions close to the axis. In the two-dimensional case the shocks are curved, and from Crocco's theorem, the region between this shock and the exit baffle should be filled with recirculating flows, which indeed it is, as seen from the velocity vector plot of Figure 5.

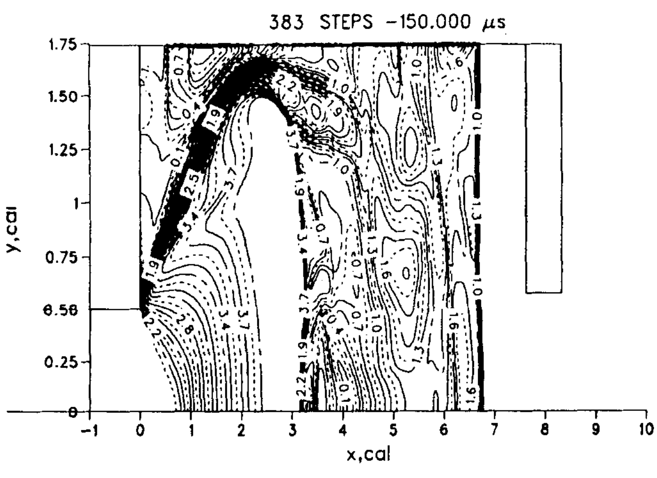

Figure 2. Pressure contours obtained by numerical simulation of precursor flow

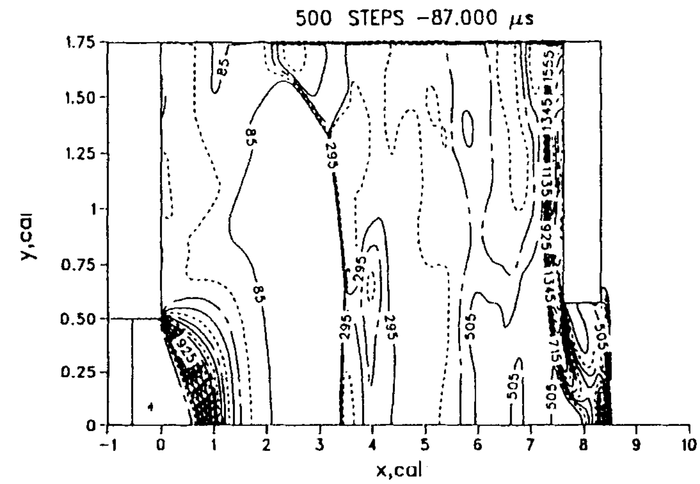

Figure 3. Pressure contours of precursor flow at the time when the shock front hits the wall

In the experimental set-up, internal pressures were obtained at $x = 0{\cdot}5$ calibres on the cylinder side. Here x is the distance forward from the internal rear face of the muzzle plate and r is the radial position from the axis. Figure 6 shows the comparisons between experimental and numerical overpressures obtained at position $x = 0{\cdot}5$ calibres on the side of the cylinder. Good agreement between experiment and simulation is obtained for times from zero to 0·4 ms. Agreement is encouraging until just before 0·7 ms, when the simulation starts yielding more vigorous pressure oscillations. The large pressure jump at 0·5 ms occurs when the reflected wave from the front baffle reaches this position.

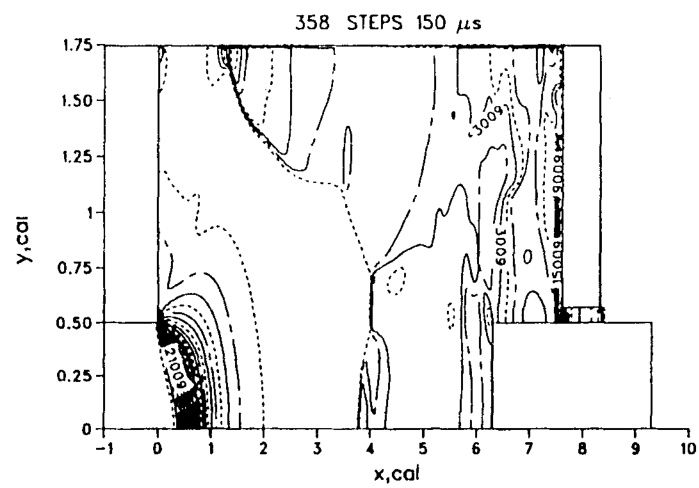

Figure 4(a). Pressure contours (kPa) of propellant flow at the time when the shock front hits the wall

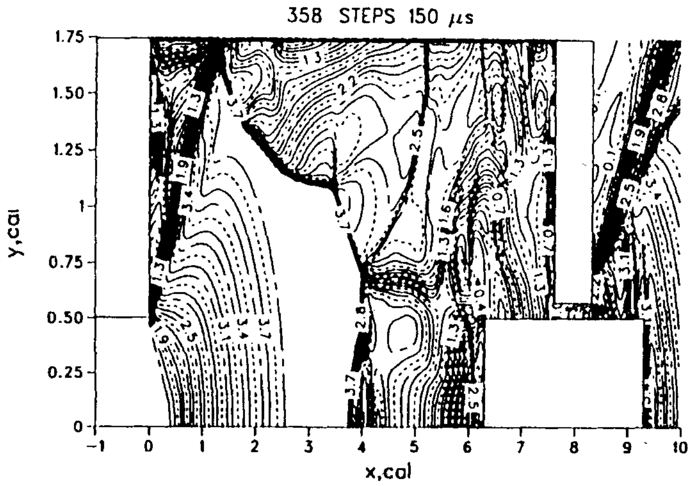

Figure 4(b). Mach contours of propellant flow at the time when the shock front hits the wall

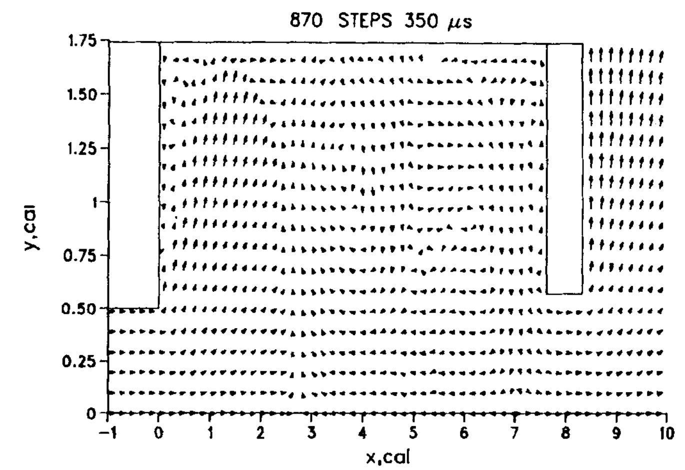

Figure 5. Flow field at 350 ms; velocity vector plot

5. CONCLUSIONS

A numerical simulation scheme was utilized to compute the flow inside the muffler configuration which had no internal baffles and the shortest internal length. These results were compared with pressure histories recorded 0·5 calibres from the rear internal disc on the muffler cylinder wall. The results for the cylinder agree well for the first part of the flow process on the cylinder but show larger variations in pressure than the experimental data for longer times. These excessive oscillation levels might be attenuated by taking viscosity into account. To test this conjecture and to obtain more realistic results, a viscous simulation scheme will be developed that includes viscous terms.

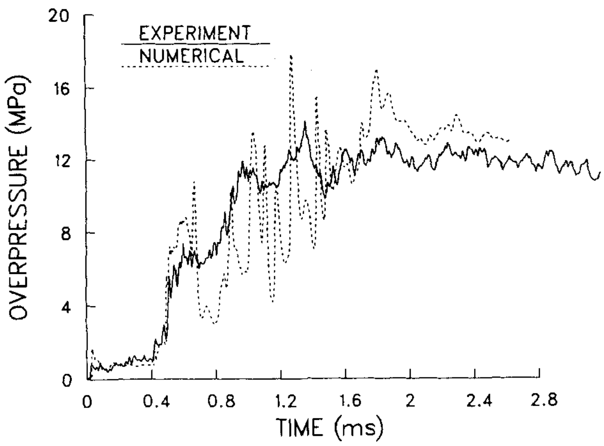

Figure 6. Comparison of experimental and simulation pressure at the cylinder wall 0·5 calibres from the rear muffler wall

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