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PROJECTILE ENVIRONMENT DURING INTERMEDIATE BALLISTICS.(U)
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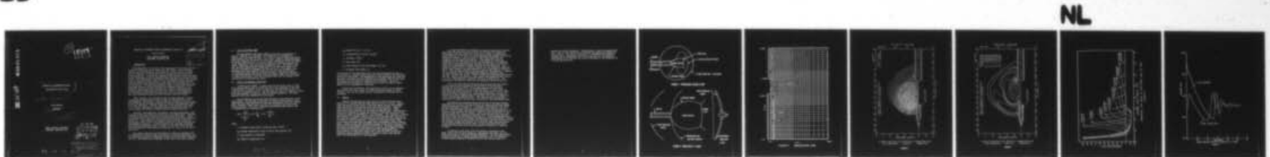

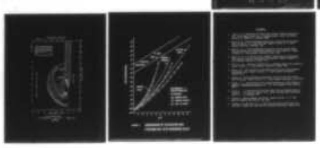

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PROJECTILE ENVIRONMENT DURING INTERMEDIATE BALLISTICS

Glen R. Moore

TTCP MEETING

JUNE 1974

NAVAL WEAPONS LABORATORY
DAHLGREN, VIRGINIA, USA

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I. INTRODUCTION

The development of the flow field associated with the ejection of a projectile from a gun may be broken into two phases. The first phase involves the flow induced by the projectile's in-bore travel, forcing the air initially in the gun tube to be ejected from the muzzle ahead of the projectile. In addition, leakage of high pressure propellant gases around the projectile due to imperfect obturation may occur during in-bore travel. The resulting gas flow ahead of the projectile forms the precursor free jet and blast field, figure 1. The second phase results from the uncorking of the high pressure propellant gases as the projectile leaves the gun muzzle. The high pressure gases induce a strong traveling shock wave whose velocity initially exceeds the projectile velocity. The propellant gases expand from the muzzle as a highly underexpanded jet bounded by an oblique shock and Mach disc, figure 2. The projectile must transverse through both the precursor blast field and propellant gas flow field before entering uniform exterior ballistic flight.

Until recently, only limited success had been achieved in either calculating or measuring the blast or flow near the muzzle of a gun. Experimentally, the problem is complicated by the highly transient nature of the flow and the extreme conditions of pressure and temperature which exist near the muzzle. However, knowledge of the gun blast flow field is of critical importance in designing and developing new projectiles such as those with frangible rotating bands or stabilizing fins.

Recently, two-dimensional axisymmetric unsteady hydrodynamic codes have been used to calculate the blast field from several guns. Reference 1 through 5 represent one-material calculations of gun blasts. These calculations use a single gas for both the propellant gas and surrounding ambient air. Multi-material calculations have also been carried out (references 6 and 7) which allow better simulation of the propellant gas thermodynamic properties. A solid projectile has also been introduced into the grid to determine both its effect on the blast field and the blast environment on the projectile (references 4, 6 and 7) as it leaves the muzzle.

This paper summarizes the development of numerical techniques for the computation of gun blasts by the Research and Technology Branch, Test and Evaluation Department at the Naval Weapons Laboratory (NWL), Dahlgren, Virginia. The project was originated in 1971 and is currently on-going.

II. FINITE DIFFERENCE CODE

The hydrodynamic code used at NWL for gun blast calculations is SHELLTC. SHELLTC is an inviscid, two-dimensional or axisymmetric, compressible, pure Eulerian code. It is one of several second generation codes evolving from the particle-in-cell (PIC) computing method developed by Harlow (reference 8) et al. at Los Alamos, New Mexico in the mid 1950's. It has been used to solve a variety of problems including hypervelocity impact, supersonic flow, blast wave propagation, etc. The SHELLTC code uses the basic computational scheme used in the PIC codes except that the mass distribution throughout the Eulerian grid is considered to be continuous with mass transport from cell to cell being accomplished as a continuum rather than as discrete particles. Numerous blast-wave calculations have been performed using the SHELLTC codes (see reference 9 for other calculations), thus the discussion here will be limited to its application to calculating gun blasts.

III. INITIAL AND BOUNDARY CONDITIONS

A starting code CLAMTC, is used to set up the finite mesh of fixed cells used by SHELLTC and to initialize the fluid properties in each cell. A typical mesh is shown in figure 3 which utilizes the codes ability for using cells of nonuniform size. The left boundary (axis of symmetry), barrel walls and projectile surface are made reflective boundaries. All other boundaries are made transmissive to the gases.

The calculations are started with the base of the projectile at the muzzle plane. The gun tube is initially filled with high pressure, high temperature gas with approximately the same properities (ratio of specific heats, molecular weight, etc.) as exists in the actual gun tube at projectile ejection. The initial pressure distribution along the gun tube is assumed given by (reference 10):

$$p(x) = \frac{12RT_o}{g\,\{\frac{V_t - n}{W_c}\}} \{1.0 + \frac{W_c}{6W_p} \quad (1.0 - \frac{3A^2X^2}{V_t^2})\}$$

where,

P = pressure at any point x along the bore, lb/in^2,

T_o= average temperature of gas at projectile ejection, ^oR,

R = gas constant, $ft\text{-}lb/lb/^oR$,

W_c= weight of propellant, lb,

W_p = weight of proj[illegible]le, lb,

g = acceleration of gravity, ft/sec^2,

η = covolume, in^3/lb,

A = bore area, in^2,

V_t = total volume of bore and chamber, in^3 and

x = distance from breech, in.

The velocity of the propellant gas at the time the projectile base is at the muzzle is assumed linear from zero at the breech to the projectile velocity at the muzzle. The temperature of the propellant gas along the gun tube is assumed initially uniform at the average value for the total propellant gas at projectile ejection from the muzzle. The cells surrounding the gun tube are filled with air (ratio of specific heats equal to 1.4) at atmospheric conditions.

During the calculations, the properties of each cell are computed during every time step, except for those completely bounded by solid surfaces. Thus the flow both internal and external of the gun tube is calculated.

IV. RESULTS

Several calculations have been carried for the 5"/54 Naval gun, because of its current interest and utility in the U. S. Navy. Figure 4 shows the velocity field from a 5"/54 NACO charge at 0.91 milliseconds after ejection of the projectile base from the gun muzzle. Figure 5 shows the pressure contours for the 5"/54 at the same time. These calculations were done with the one-material SHELLTC code. The projectile motion was simulated by jumping the projectile such that the base of the projectile always corresponded to a cell boundary. This technique, although the simpliest to program, creates artifical disturbances near the base of the projectile making it not particularly desirable for base pressure data or forces on finned projectiles. Elsewhere in the blast field, these calculations have shown good agreement with experimental pressure measurements. Figure 6 shows the calculated pressure verses radial distance from the muzzle at 26.9 degrees from the line-of-fire. The quasi-stationary position of the Mach disc from figure 6 is seen to be at about 70 inches (12 calibers) from the muzzle which agrees with experimental data. The projectile in these calculations was a semi-infinite cylinder,not blunted or shapely pointed as shown in figures 4 and 5, thus the bow shock from the projectile is not predicted.

An alternate method was developed to produce the projectile motion which does not unrealistically disturb the flow near the projectile. This method fixes the projectile to the grid, imposes a uniform background velocity on the grid with equal magnitude but opposite sign of the projectile velocity. The gun barrel is then moved away from the projectile at the projectile velocity. This method of fixing the coordinate grid to the projectile has the advantage that the boundary conditions at the projectile base and nose are more easily written and there are no approximate boundary condition on the projectile. This method can easily handle a blunted cylinder for the projectile shape but cannot easily handle a pointed projectile such as portrayed in figures 4 and 5. This technique predicts the bow shock off the projectile. However, its disadvantage lies in the approximate boundary condition used at the tube wall near the muzzle. Figure 7 shows the calculated base pressure and first lateral cell pressure (1.03 inches from projectile base) for a U. S. Army 105mm Howitzer, projectile velocity of 1635 ft/sec. The calculations (reference 5) were with the projectile fixed to the grid.

All of the calculations discussed about have omitted the effects of the precursor blast preceeding the projectile from the muzzle. Although the precursor blast is very weak compared with the blast produced by the uncorking of the propellant gases, it does effect the main traveling shock, particularly near the projectile's line of flight. Schmidt and Shear (reference 11) have recently published an extensive collection of spark shadow graphs of the blast field from a 5.56mm M-16 rifle including the precursor flow. This data presents an excellent opportunity to compare the numerical calculations with experimental data.

Calculations are presently being carried out at the Naval Weapons Laboratory for an M-16 rifle muzzle blast for comparison with the shadow graphs presented in reference 11. At present, the precursor flow field has been calculated for times up to projectile base ejection from the muzzle. Figure 8 shows the calculated pressure field corresponding to the projectile nose being at the muzzle. Figure 9 shows the position of the precursor Mach disc, contact surface and traveling shock wave from both the calculations and experiment (reference 11). The calculated Mach disc location is seen to be in excellent agreement with the experimental location. The location of the contact surface and traveling shock do not agree as well. The agreement between calculations and experiment could have been better if the in-bore projectile motion input to the calculations had better approximated the actual M-16 in-bore projectile velocity as a function of time.

In addition to the blast field calculations discussed in this paper, other areas of work related to intermediate ballistics are also being carried out at the Naval Weapons Laboratory. Gun jump coupled with projectile balloting is presently being analyzed using a six degree-of-freedom dynamics program to determine initial yaw and yaw rates of a projectile leaving the muzzle. The gun jump is input from experimental data. Work is also beginning to determine the projectile response to the gun blast. The overall objective is to determine the projectile response during intermediate ballistics with gun jump and balloting contributing to determining the initial conditions of the projectile as it exits the gun muzzle.

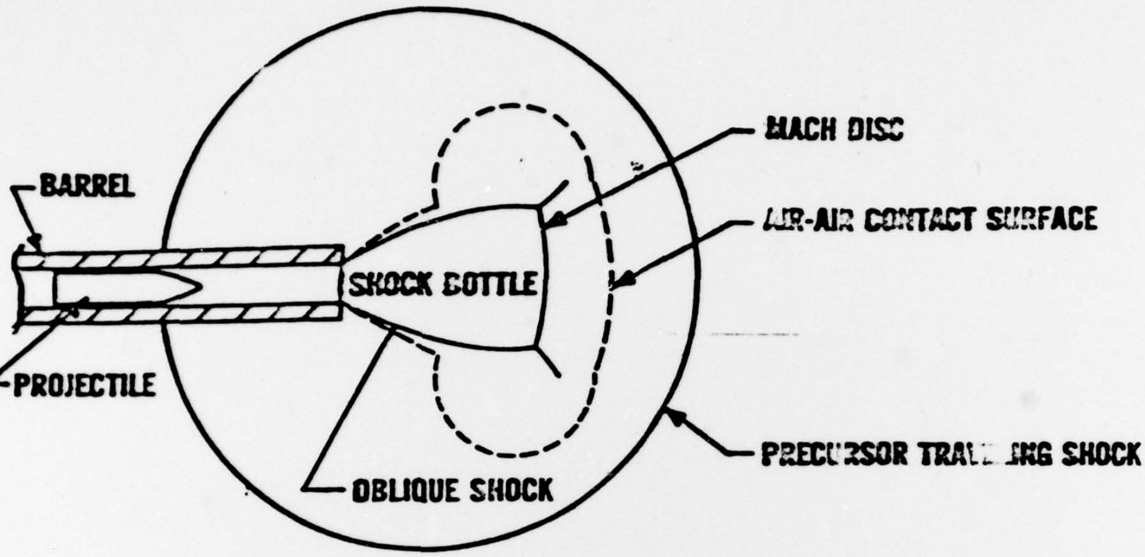


FIGURE 1 PRECURSOR MUZZLE FLOW

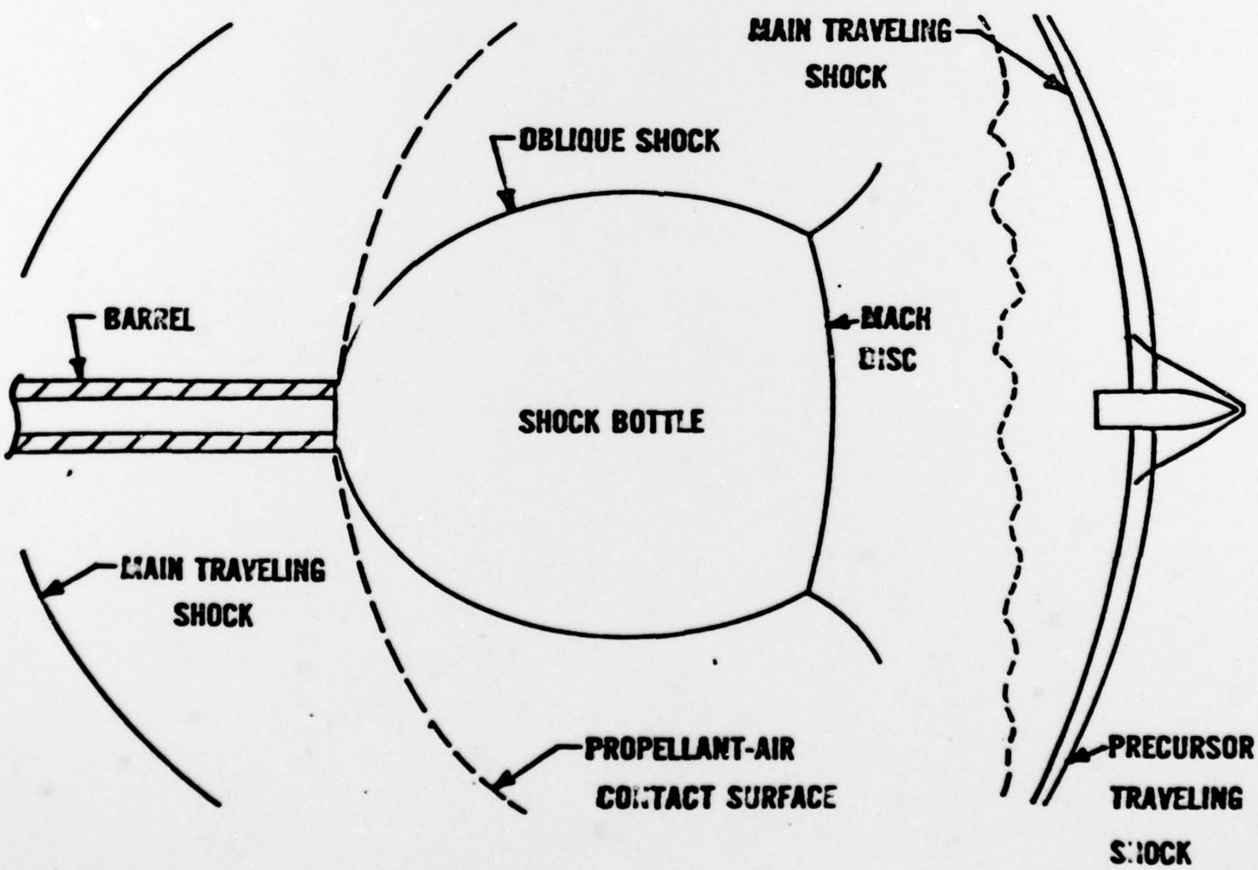


FIGURE 2 MAIN MUZZLE FLOW

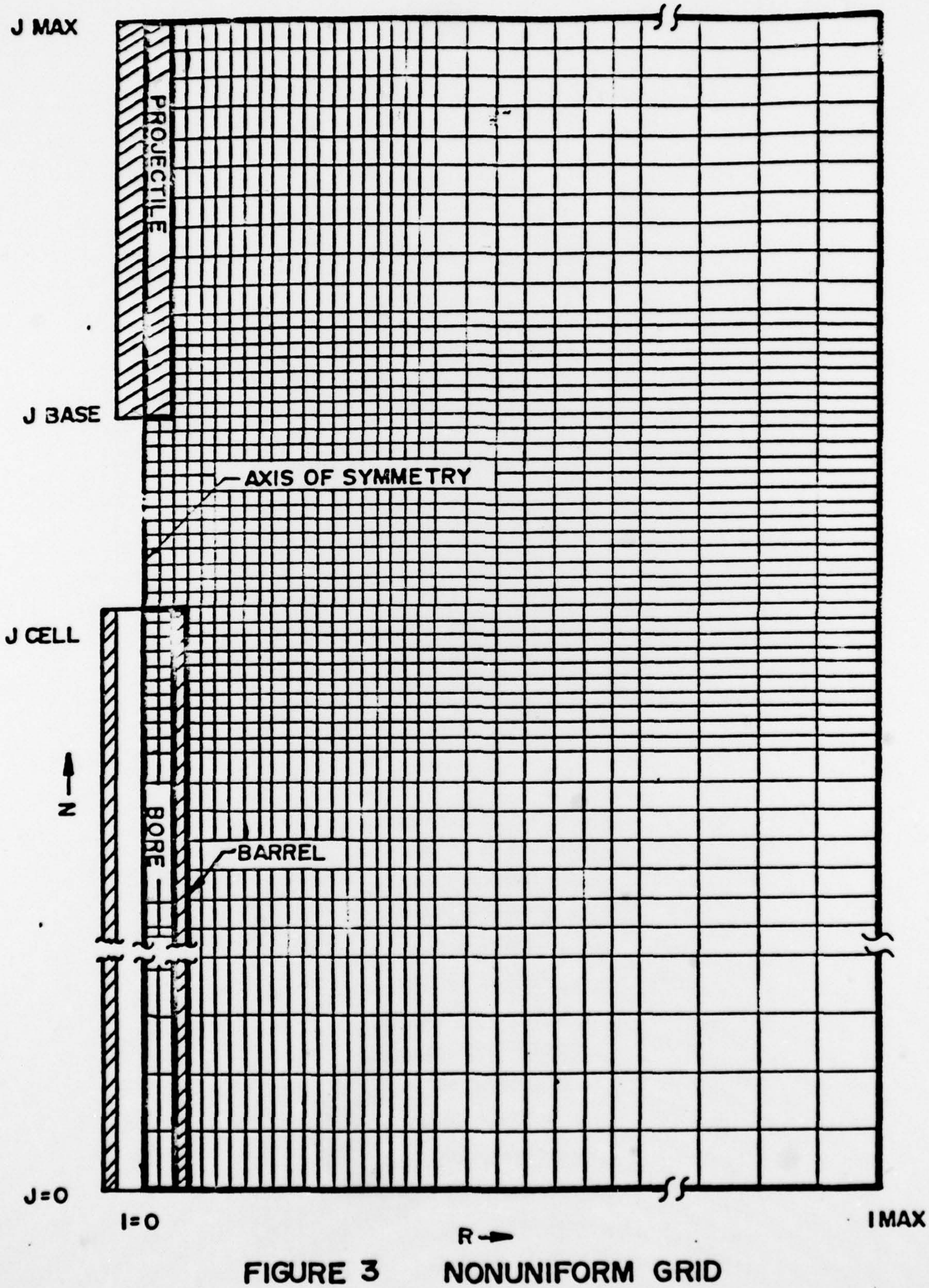
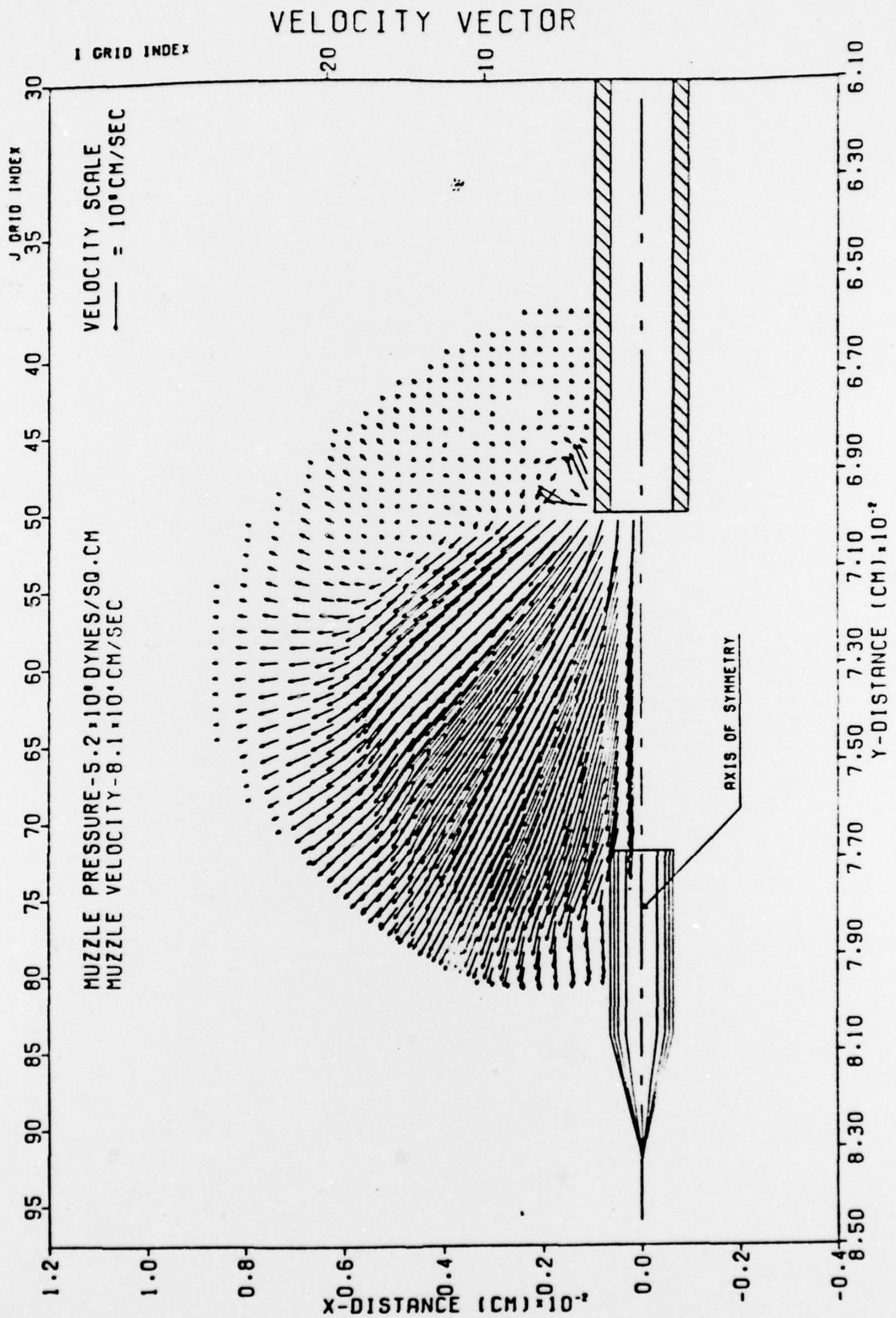


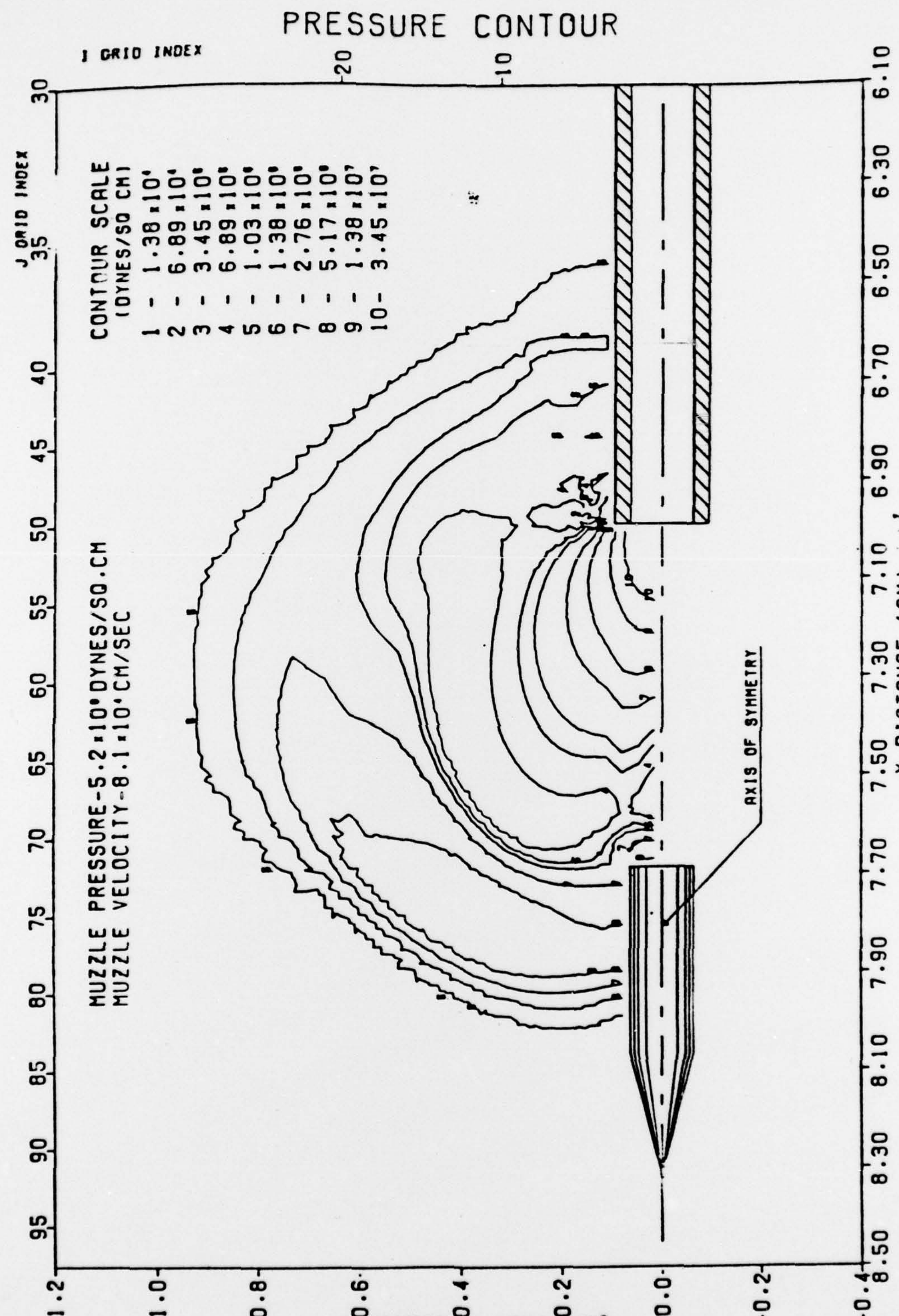
FIGURE 3 NONUNIFORM GRID



5 INCH/54 GUN BLAST WITH PROJECTILE (NONUNIFORM GRID)

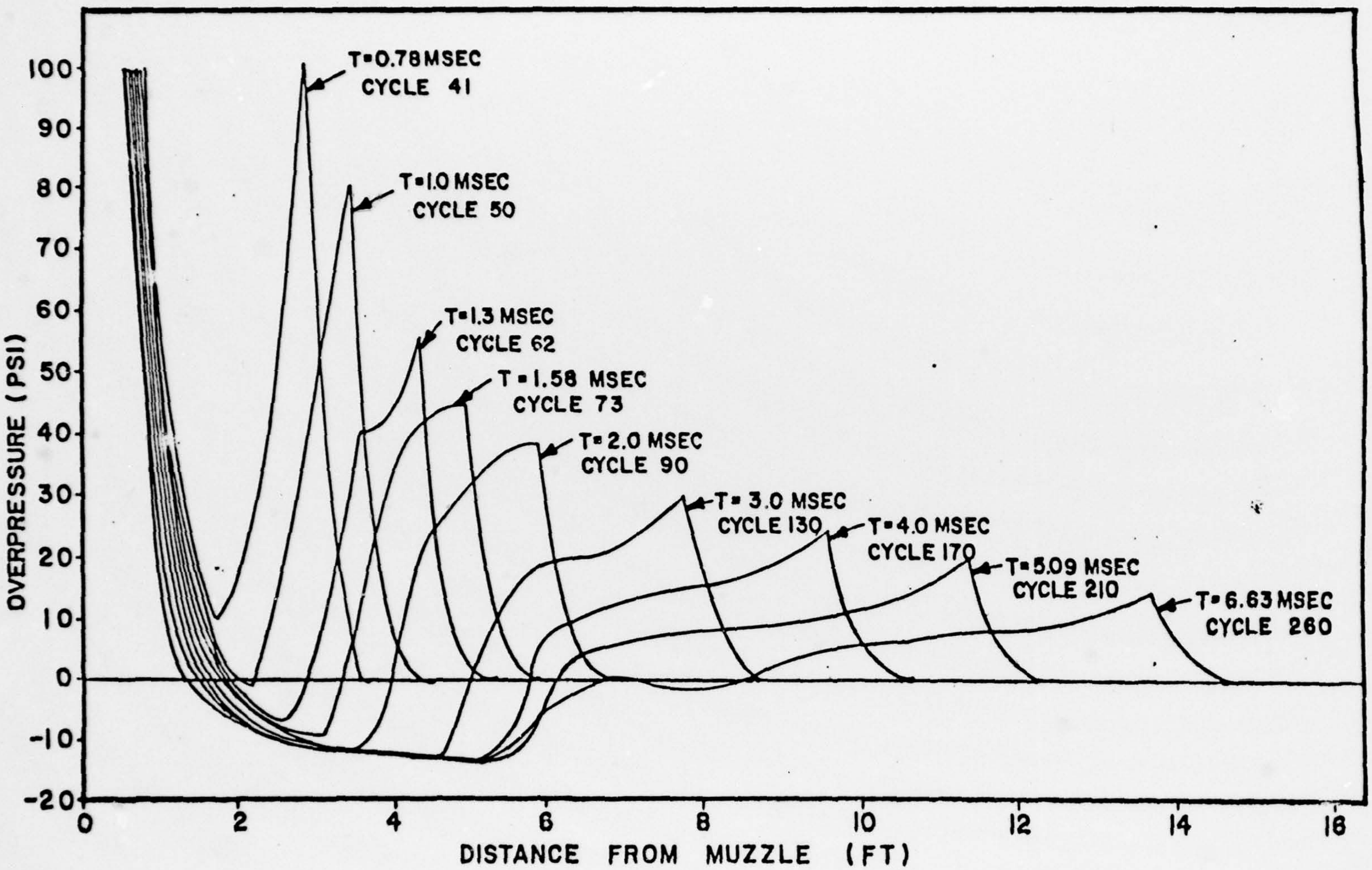
TIME 0.000910 SEC CYCLE 95 PROBLEM 854

FIGURE 4



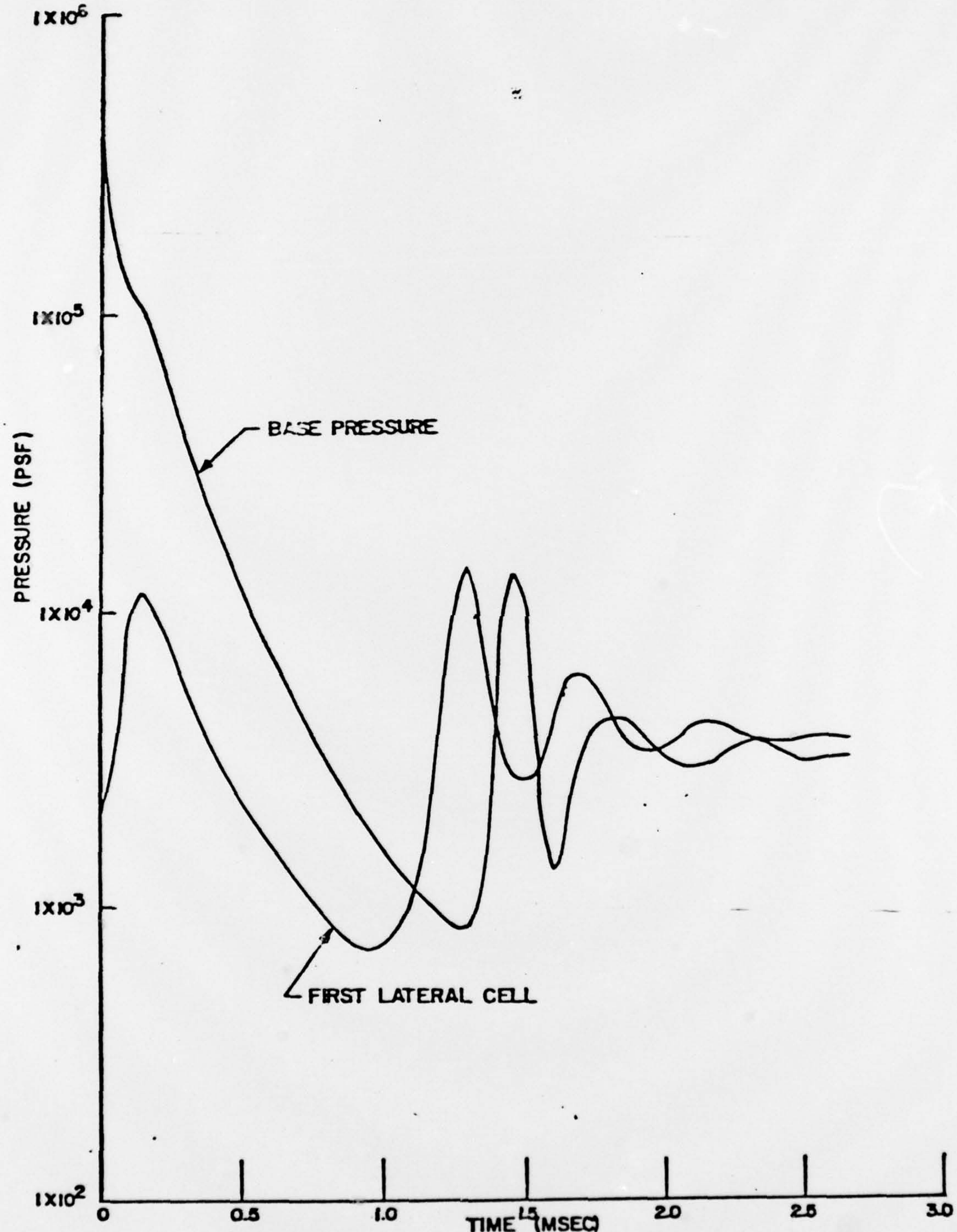
5 INCH/54 GUN BLAST WITH PROJECTILE (NONUNIFORM GRID)
TIME 0.000910 SEC CYCLE 95 PROBLEM 854

FIGURE 5



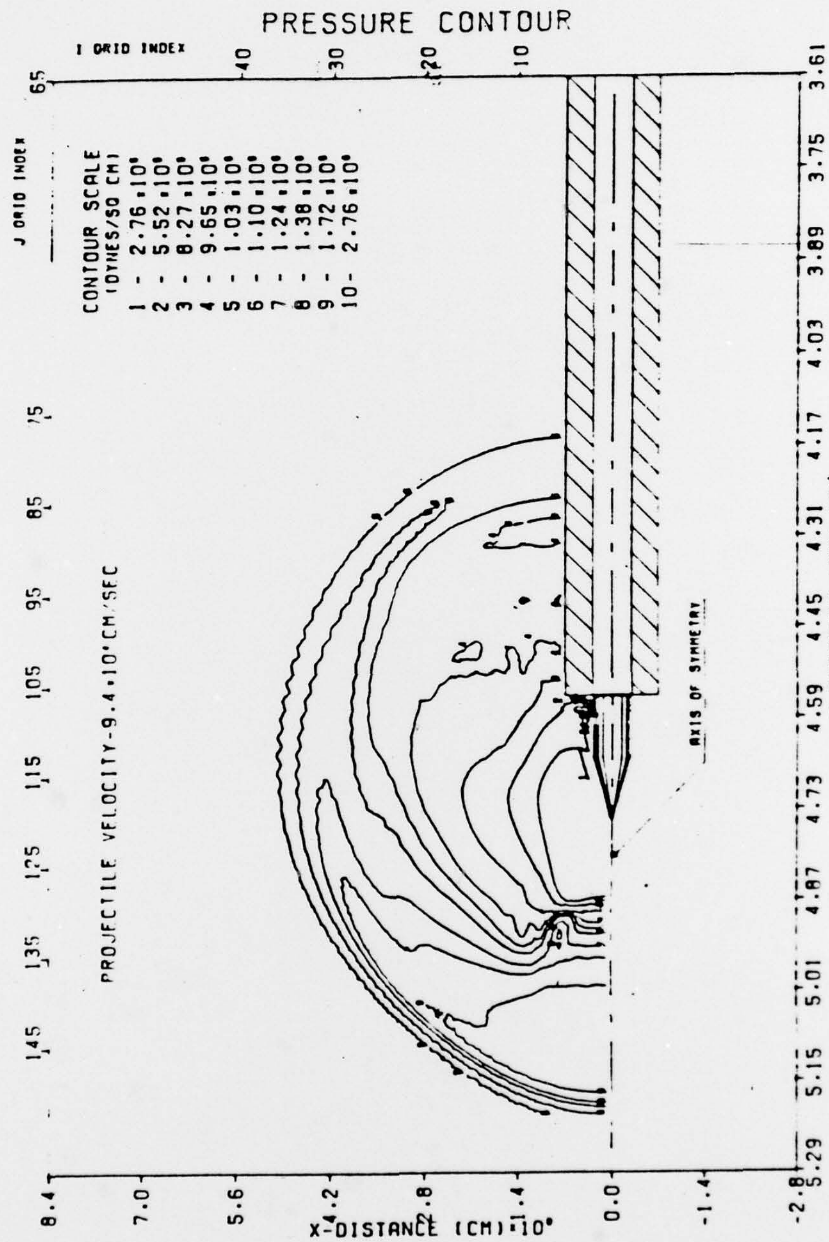
THEORETICAL GUN BLAST AT 26.9° FROM LINE OF FIRE

FIGURE 6



105MM BASE CELL AND FIRST LATERAL CELL PRESSURE

FIGURE 7



M-16 PRECURSOR BLAST

TIME 0.000879 SEC CYCLE 677 PROBLEM 1601

FIGURE 8

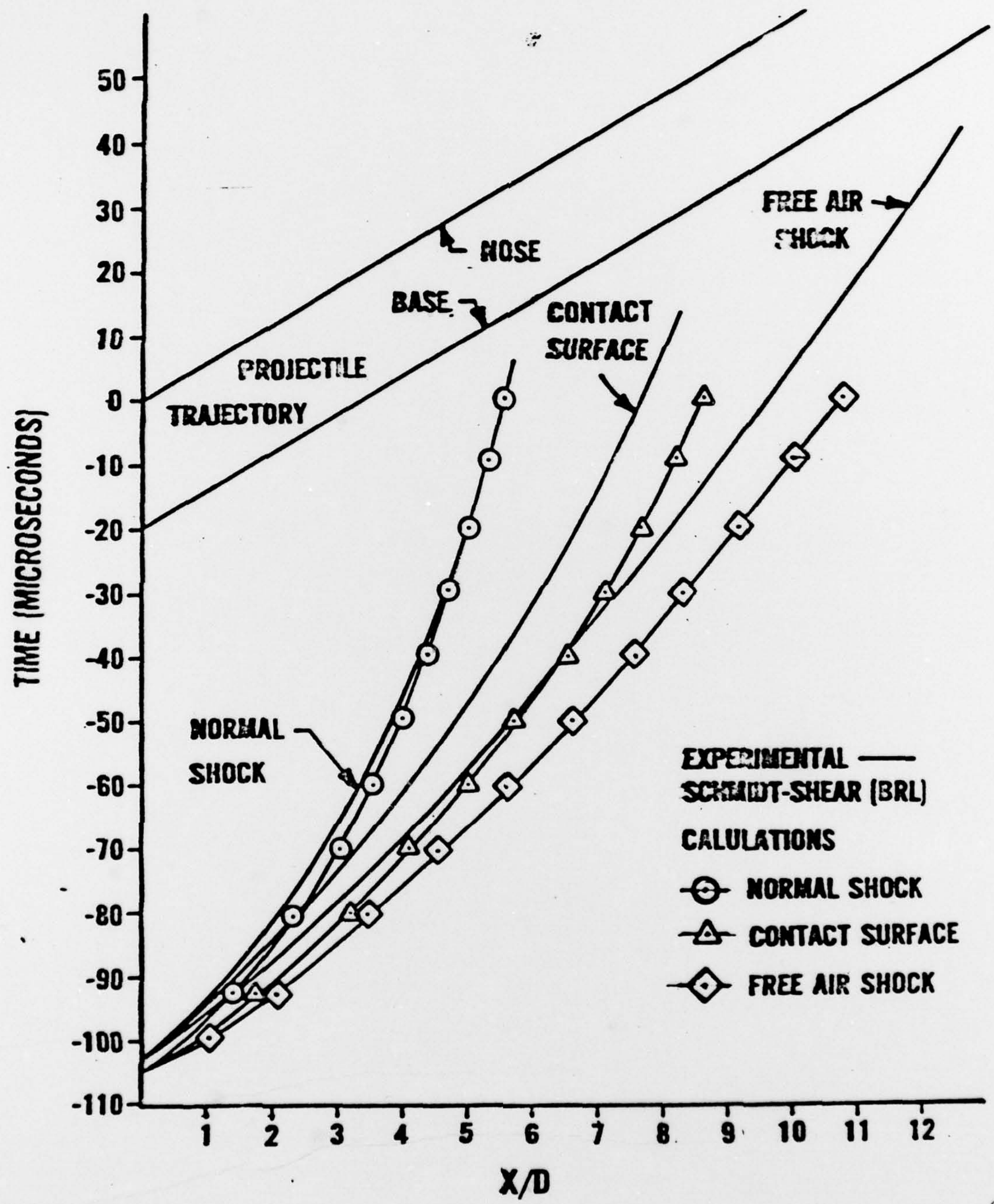


FIGURE 9 COMPARISON OF CALCULATED AND EXPERIMENTAL M-16 PRECURSOR BLAST

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