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APPLICATION OF FLUX-CORRECTED TRANSPORT TO TTCP JOINT  
LAUNCH BLAST COMPUTATIONAL EFFORT(U) NAVAL RESEARCH LAB  
WASHINGTON DC P S KAMATH ET AL. 31 DEC 85 NRL-NR-5781

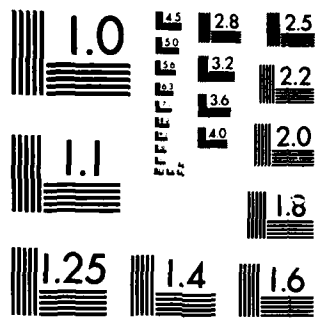
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NRL Memorandum Report 5701

# Application of Flux-Corrected Transport to TTCP Joint Launch Blast Computational Effort

P. S. KAMATH, S. EIDELMAN AND M. A. FRY  
*Science Applications International Corporation  
McLean, VA 22102*

J. D. BAUM AND D. L. BOOK  
*Laboratory for Computational Physics*

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December 31, 1985

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10-A163 332

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			Approved for public release; distribution unlimited.		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 5701			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Naval Research Laboratory		6b. OFFICE SYMBOL (if applicable) Code 4040	7a. NAME OF MONITORING ORGANIZATION Office of Naval Research		
6c. ADDRESS (City, State, and ZIP Code) Washington, DC 20375-5000			7b. ADDRESS (City, State, and ZIP Code) Arlington, VA 22217		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Office of Naval Research		8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) Arlington, VA 22217			10. SOURCE OF FUNDING NUMBERS		
PROGRAM ELEMENT NO. 61153N	PROJECT NO.	TASK NO. RR011-09-43	WORK UNIT ACCESSION NO. DN280-069		
11. TITLE (Include Security Classification) Application of Flux-Corrected Transport to TTCP Joint Launch Blast Computational Effort					
12. PERSONAL AUTHOR(S) Kamath, P.S.,* Eidelman, S.,* Fry, M.A.,* Baum, J.D. and Book, D.L.					
13a. TYPE OF REPORT Interim		13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) 1985 December 31		15. PAGE COUNT 136
16. SUPPLEMENTARY NOTATION *Science Applications International Corporation, McLean, VA 22102					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Muzzle blast Shock waves		
			Launch blast Flux-corrected transport		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) A general-purpose Flux-Corrected Transport (FCT) hydrocode has been used to treat two muzzle blast test problems. Analysis of the results and comparison with data indicates that the results are physically realistic and, within the modeling assumptions, highly accurate. The FCT simulation model used runs on the Cray-1 and on smaller mainframe computers including the VAX and the multitasking array processors in our Graphical and Array Processing System.					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL David L. Book			22b. TELEPHONE (Include Area Code) (202) 767-2078		22c. OFFICE SYMBOL Code 4040

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## APPLICATION OF FLUX-CORRECTED TRANSPORT TO TTCP JOINT LAUNCH BLAST COMPUTATIONAL EFFORT

### INTRODUCTION

The method of Flux-Corrected Transport (FCT) was developed about ten years ago (Boris and Book, 1973; Book et al., 1975; Boris and Book, 1976) as a means for solving systems of hyperbolic equations in such a way that physically positive quantities like mass and energy density remain positive. Its principal application has been to compressible fluids, i.e., fluids in which some of the flow speeds are comparable with or greater than the local speed of propagation of waves in the medium. Examples include plasmas, combusting systems, and gas-dynamic flows. Applications of FCT to muzzle blast problems were first made by Townend and Edwards (1982).

During the past decade the method has been extended and generalized in a number of important respects. These include the construction of general-purpose algorithms for solving fluid equations on moving nonuniform grids in a curvilinear coordinate system (Boris 1976), strictly multidimensional FCT algorithms (as opposed to timestep-splitting of one-dimensional algorithms, Zalesak 1979), and variants on these. In addition, numerous techniques have been developed by other workers which incorporate the positivity-preserving property in other ways (Harten, 1978; Van Leer, 1979; Collela and Woodward, 1984). The weight of opinion among computational scientists who deal with problems of compressible flow now strongly affirms the superiority of positivity-preserving methods (e.g., Total Variation Diminishing or TVD) over conventional ones. The advantages are improved robustness, flexibility, resolution, and freedom from nonphysical numerical artifacts.

Manuscript approved October 9, 1985.

FAST2D (Boris 1976) is an FCT code for solving the two-dimensional fluid equations in Cartesian or r-z geometry. It employs timestep-splitting to permit the use of JPBFACT, a general-purpose one-dimensional convective equation solver for both coordinate sweeps in all of the fluid equations.

To explain what this means, let us describe a class of FCT algorithms which includes JPBFACT as a particular case. To advance the one-dimensional continuity equation

$$\frac{\partial \rho}{\partial t} = - \frac{\partial}{\partial x} (\rho v) \quad (1)$$

one timestep on a uniform mesh with a given flow velocity  $v$ , we suppose the old cell-centered values  $\rho_j^o$  and  $v_j$  are known. A three-point conservative finite-difference operator acting on  $\rho_j^o$  can be written in the form

$$\rho_j^T = \rho_j^o - \epsilon_{j+1/2} \rho_{j+1/2} + \epsilon_{j-1/2} \rho_{j-1/2}, \quad (2)$$

where  $\rho_{j+1/2} = \frac{1}{2} (\rho_j + \rho_{j+1})$ . To obtain a first-order approximation to Eq. (1), we must define  $\epsilon_{j+1/2}$  to be the Courant number  $v_{j+1/2} \delta t / \delta x$ , where  $v_{j+1/2} = \frac{1}{2} (v_j + v_{j+1})$ . In FCT a numerical diffusion is then applied to  $\rho_j^T$  in flux form according to

$$\rho_j^{TD} = \rho_j^T + v_{j+1/2} (\rho_{j+1}^o - \rho_j^o) - v_{j-1/2} (\rho_j^o - \rho_{j-1}^o). \quad (3)$$

Next we act to eliminate this excess diffusion. If we simply applied another diffusion operation, this time with the opposite sign, it would cancel the diffusion terms already present in  $\rho_j^{TD}$ . Instead we define new densities  $\rho_j^n$

$$\rho_j^n = \rho_j^{TD} - \phi_{j+1/2}^c + \phi_{j-1/2}^c, \quad (4)$$

where the "corrected" fluxes  $\phi_{j+1/2}^c$  differ from the "raw" fluxes  $\phi_{j+1/2} = u_{j+1/2} (\rho_{j+1}^o - \rho_j^o)$  in two ways: we use  $\{\rho_j^T\}$  instead of  $\{\rho_j^o\}$  in the definition of the raw fluxes (this allows us to optimize some property in the difference scheme, as will be seen shortly); and we correct the fluxes, so that the antidiffusion process (which evidently tends to make all gradients steeper) can enhance no extrema already present in  $\{\rho_j^{TD}\}$ , nor introduce any new ones. The simplest formula for achieving this in all possible situations is that used in "strong flux limiting":

$$\phi_{j+1/2}^c = S \cdot \{ \max[0, \min(|\phi_{j+1/2}|, \Delta_{j-1/2}, \Delta_{j+3/2})] \} , \quad (5)$$

where  $S = \text{sign } \phi_{j+1/2}$  and  $\Delta_{j+1/2} = \rho_{j+1}^{TD} - \rho_j^{TD}$ .

At most points in a gently varying profile no correction is required and  $\phi_{j+1/2}^c = \phi_{j+1/2}$ . In that case we can perform a Von Neumann analysis, calculating the complex propagator or amplification factor  $A = A_r + iA_i = \rho_j^n / \rho_j^o$  for a sinusoidal density profile  $\rho_j^o = \exp(ijk \delta x)$ , where  $k$  is the wave number. Writing  $\beta = k\delta x$  and  $\epsilon = v\delta t / \delta x$ , we expand the amplification in powers of  $\beta$

$$A = 1 + A_2 \beta^2 + A_4 \beta^4 + \dots \quad (6)$$

and the relative phase error

$$R = \frac{1}{\beta\epsilon} \tan^{-1} (A_i / A_r) - 1 = R_2 \beta^2 + R_4 \beta^4 + \dots \quad (7)$$

It is easy to show that the condition that  $A_2$  vanish is

$$v - u = \frac{1}{2} \epsilon^2 . \quad (8)$$

The condition that  $R_2$  vanish is

$$\mu = \frac{1}{6} - \frac{1}{6} \epsilon^2 . \quad (9)$$

While other choices of  $\nu$  and  $\mu$  are possible, Eqs. (8) and (9) lead to the most useful general-purpose algorithm within this class and have been used in a wide variety of supersonic flow problems. Besides producing small phase and amplitude errors, as shown above, this choice of the diffusion and antidiffusion coefficients  $\nu$  and  $\mu$  treats shocks very accurately, unlike schemes where  $\nu$  and  $\mu$  are small.

Generalizing this scheme to handle the momentum and energy equations presents no problem as the treatment of the driving terms  $-\nabla p$ , etc., and  $-\nabla \cdot p v$  is not very sensitive. Extension to nonuniform meshes and curvilinear geometry is also straightforward. When fully vectorized and optimized for a particular machine (in the present case, the Cray-1) it runs at about 2  $\mu s$  per zone per timestep per equation per coordinate direction.

## RESULTS

### Case I: Flow From the Open End of a Shock Tube

Figure 1 reproduces the BRL drawings defining the geometry of the shock tube and prescribing the computational domain to be used (Schmidt, 1985). Although it would be of interest to model the entire length of the shock tube (including the 0.673 m driver section and the whole 3.044 m driven section), this would necessitate a calculation with a computational region approximately ten times as long as that specified for the case. In our calculation we used a grid with 200 zones in the radial and 400 zones in the axial direction, with mesh sizes  $\Delta r = \Delta z = 0.228$  cm. Although temperature and density do not deviate too widely from standard conditions and  $\gamma = 1.4$

holds approximately, we used a real-air equation of state. Reflecting boundary conditions were employed at  $r = 0$ , and outflow conditions (valid for supersonic flow) at maximum radial and axial displacement. The conditions at  $z = 0$  were maintained at their initial values, which is valid until disturbances propagating out of the driver region reach the computational domain.

Timesteps were limited to 0.5 times the value imposed by the Courant condition and averaged about a microsecond. The calculation ran 1618 cycles, with dumps being obtained at times  $t = 0.025, 0.05, 0.1, 0.2, 0.5, 1.0$  and  $1.5$  ms. Using these dumps we generated velocity vector plots and contours of constant density, pressure, and Mach number. In addition, time histories of pressure, density, and Mach number were generated at stations situated at a distance of 1.5 times the tube diameter  $D = 0.152$  m from the center of the tube exit along the  $0, 30, 60, 90, 120, 130,$  and  $138.2$  degree rays. These locations are indicated by the dots in Fig. 1c. Since the station along the  $0^\circ$  ray was of particular interest in connection with determining the location of the backward-facing shock, ten additional stations were located in the neighborhood of the station along this ray.

Figures 2-8 show the overall flow at the plotting times specified above. In each figure we have four plots: contours of (a) pressure, (b) density, and (c) Mach number; and (d) velocity vector plots. Note that by 0.5 ms (Fig. 6) several well-defined gasdynamic discontinuities have developed. These include a disk-shaped backward-facing shock which terminates at its outer radius in a compression fan. The latter is rolled up into a vortex ring. At a radius of approximately 0.05 m a cylindrical slip surface (which shows up as a discontinuity in density but not pressure) intersects this shock, producing a kink. By 1.5 ms (Fig. 8), when the primary shock has

reached the end of the mesh, the vortex ring has expanded out to about 0.1 m in radius.

Figures 9 - 16 are station plots, each showing (a) overpressure, (b) density, and (c) Mach number at the prescribed locations. The flow behind the shock is of course subsonic everywhere. All stations show a pressure (and density) peak at shock arrival time, followed by a rarefaction wave. The stations located off the center line (all except no. 1) reach pressures less than ambient. Comparison with digitized traces of pressure measurements (Figs. 17 - 33) shows good agreement between calculated and recorded values except at station no. 1. There the calculated values (labelled with "A") are close to the measured ones (labelled with "B") until about 1 ms. Thereafter the latter peak up above the calculation by about 20 kPa and then drop below by about 60 kPa. We attribute this discrepancy to slight errors in defining the location of the backward-facing shock, probably caused by an increase in the effective flow velocity from the opening of the shock tube as a result of the formation of a boundary layer there. Rather than try to model this boundary layer, we introduced ten additional stations on the axis between 0.662 m and 0.683 m from the opening. The waveform which agrees best with the observed trace is that calculated at station no. 10 (Fig. 26,  $y = 0.667$  m). Nevertheless, the unsteady behavior of the shock in the experimental setup precludes perfect agreement for these features.

#### Case II: 105 mm Muzzle Flow

In this problem the geometry is complicated by the addition of a baffle located downstream from the muzzle, and by the presence of the projectile at early times. No attempt was made to model the latter (although it is not difficult to do) because it has no influence on the flow near the muzzle

except at very early times. Otherwise the same boundary conditions were used as in Case I.

The zone size was  $\Delta r = \Delta z = 0.3$  cm. For this problem two fluid mass densities were propagated according to the continuity equation, using a single flow velocity field. One fluid, air, initially filled the entire grid outside the muzzle and the solid walls. The other fluid, representing detonation products from the propellant, expands out from the muzzle with the prescribed exit velocity of 1050 m/s. Partial pressures were obtained using respectively a real-air equation of state and a constant-gamma law ( $\gamma = 1.25$ ) for the two fields.

Figures 34 - 38 shows contours of (a) pressure, (b) density, and (c) Mach number, and (d) velocity vector plots at the prescribed times  $t = 0.025, 0.05, 0.1, 0.5,$  and  $1.0$  ms, respectively. Note that by  $0.1$  ms part of the shock wave has reached the baffle and been deflected away. The central portion passes through the hole and begins to diffract around to the back of the baffle. By  $0.5$  ms the shock has left the top of the grid. Thereafter the solution quickly relaxes to a steady state, maintained by the propellant gases emerging from the howitzer muzzle.

Figures 39 - 47 show waveforms of (a) pressure, (b) density, and (c) Mach number at the nine prescribed stations. Stations (1) - (3), located on the front of the baffle, show slightly different peak values at shock arrival time and saturate at slightly different values at late times, reflecting their varying distances from the muzzle. The stations in front of, alongside, and behind the muzzle show variations which can readily be interpreted in terms of geometry. It is seen that although the flow is deflected by the baffle, beyond it (at distances  $\gtrsim D$ ) the baffle has little effect on most features in either contour or station plots.

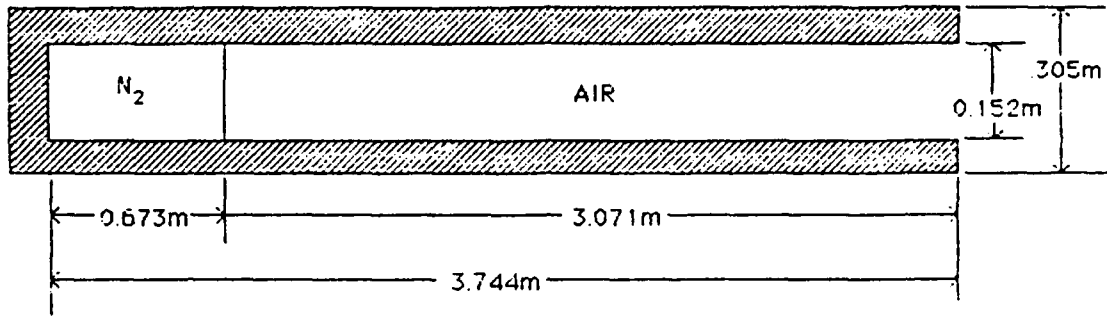
Since the flow is subsonic, the mesh boundaries should permit inflow of the surrounding ambient atmosphere at late times, and this should come to equilibrium with the emerging flow of propellant gases. Because we kept the same outflow boundary conditions as in Case I, inflow cannot take place, and at late times the pressures and densities near the outer boundary become unphysically low. For this reason we have plotted station histories only out to 1 ms.

## CONCLUSION

We have carried out two test muzzle blast calculations using the FCT code FAST2D. Numerous simplifications have been introduced to minimize the programming effort required, and considerable improvement could be made in our treatment of (i) viscous boundary layers (in Case I); (ii) inflow and projectile boundary conditions (in Case II); and (iii) the propellant gas equation of state. Nevertheless, the agreement with the data in Case I and the physical plausibility and internal consistency of both cases strongly support the validity of this modeling approach and suggest that FCT hydrocodes can make a valuable contribution to the muzzle blast modeling effort.

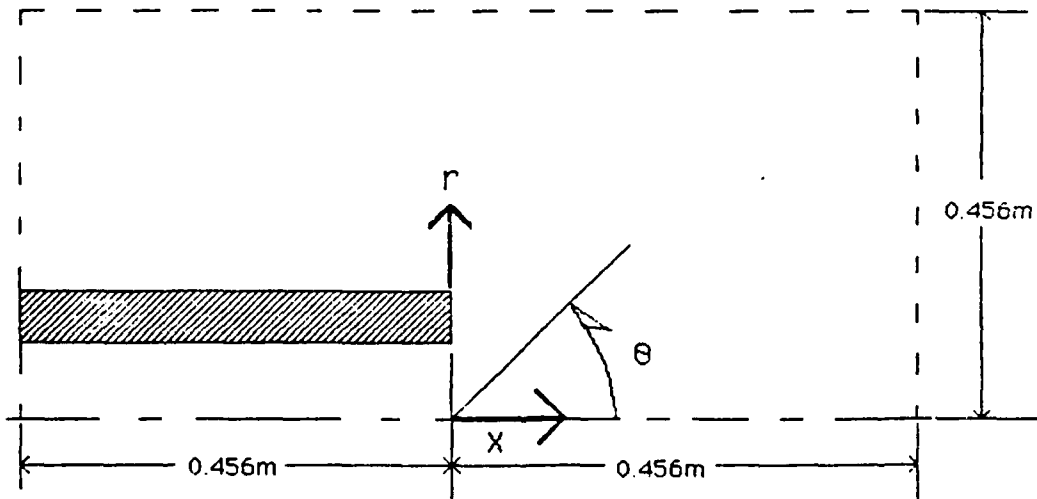
Although the calculations described here were carried out on a Cray-1 supercomputer, it is worth noting that the computing requirements for FAST2D are actually very modest. The Laboratory for Computational Physics has assembled a Graphical and Array Processing System (GAPS) consisting of a VAX 11/780, two FPS 5305 array processors working in tandem (up to 10 APs are possible), an Aptec DPS 2400 I/O computer, and a Tektronix 4115B high-speed graphics device. This system is running a comparable two-dimensional hydrocode, programmed entirely in FORTRAN, at speeds of  $\sim 0.2$  ms per mesh point per timestep, in either batch or interactive mode. In the latter it produces color plots of the evolving simulation approximately every 5 seconds with DICOMED hard copy capability. This is about  $1/8$  the speed of a single processor Cray X-MP. A sample frame from a muzzle blast calculation done using the RFM hydrocode on the GAPS is reproduced as Fig. 48. It is important to stress that such a system is small and can be maintained in a secure self-contained facility, where it can be dedicated entirely to muzzle blast or similar energetic gasdynamic calculations if so desired. The cost of the basic system is  $\sim$  \$220K.

SHOCK TUBE CONFIGURATION:



(a)

COMPUTATIONAL DOMAIN:



(b)

Figure 1

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.00000E+00 SEC., STEP 1. DUMP TUBB0001 DENSITY 1. KG/M3

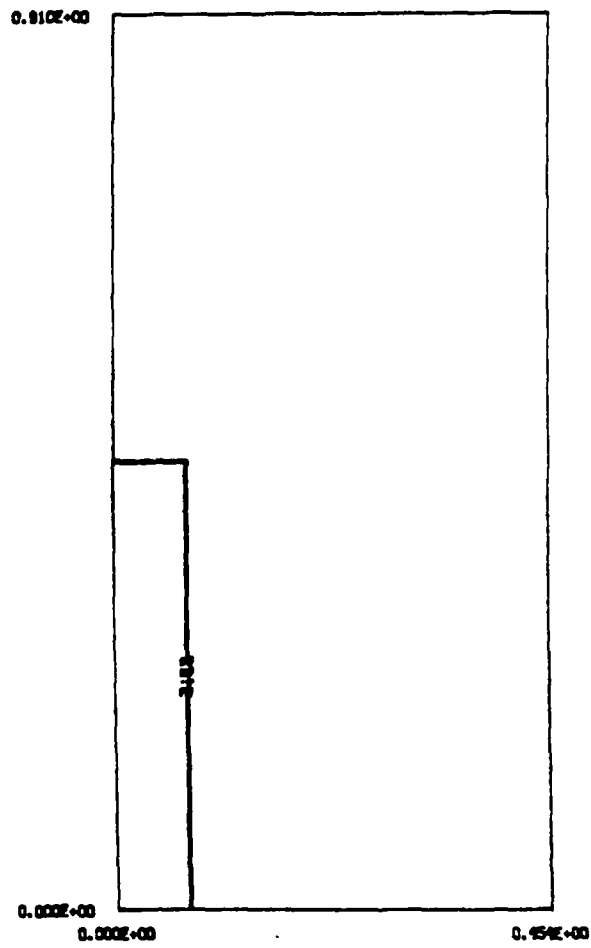


Figure 1b

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.00000E+00 SEC.. STEP 1. DUMP TUBB0001 PRESSURE. NEWTONS/M<sup>2</sup>

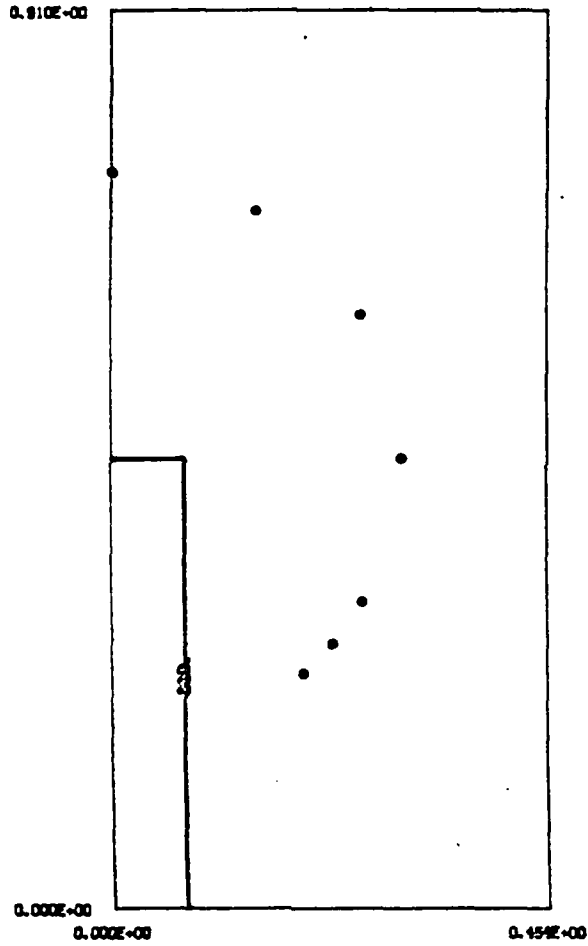


Figure 1c

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.00000E+00 SEC. STEP 1. DUMP TUBB0001 MACH NUMBER

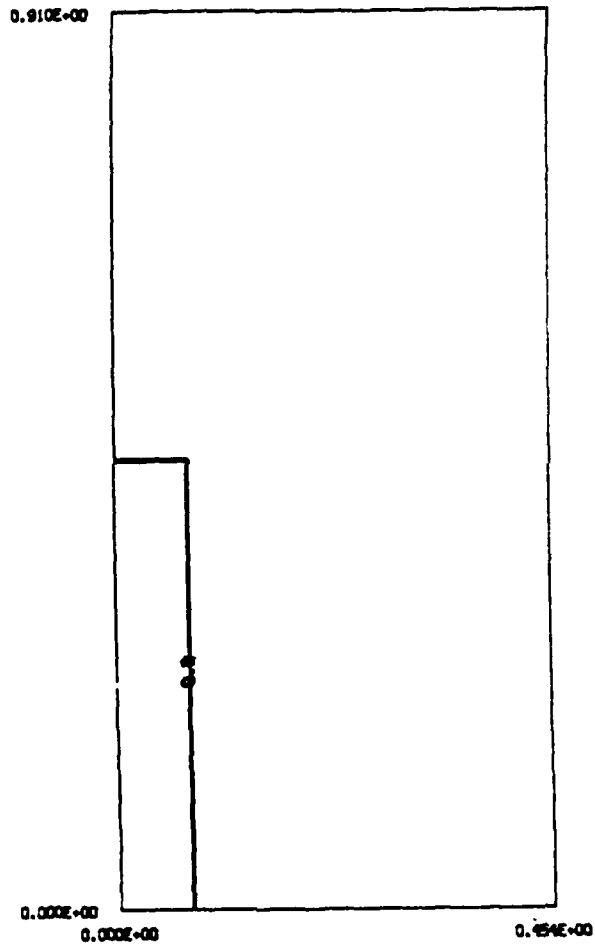
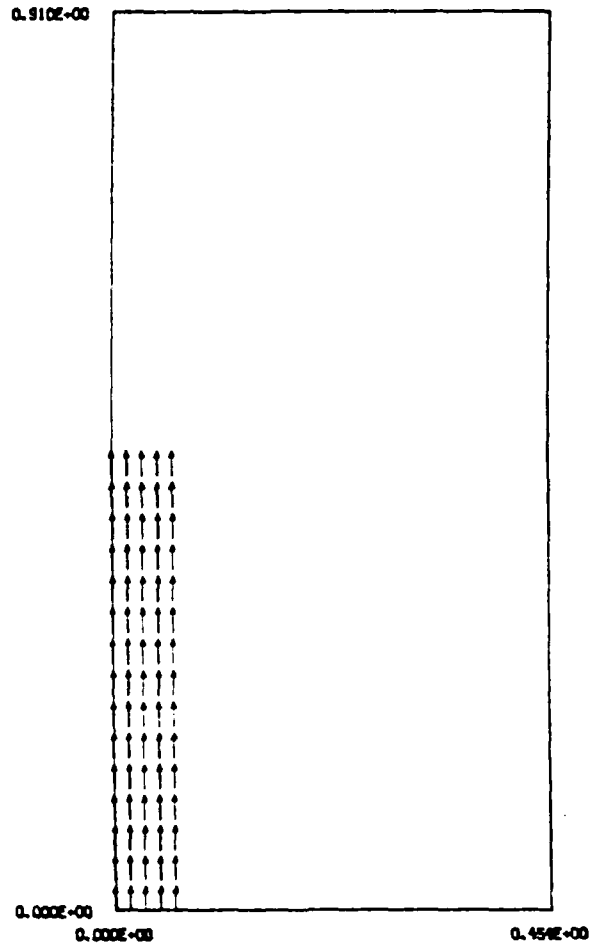


Figure 1c

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.00000E+00 SEC. STEP 1. DUMP TUBB0001 VELOCITY. M/SEC



0.300E-00  
NON-FINAL PLOT

Figure 1d

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.25649E-04 SEC.. STEP 86. DUMP TUBB0002 PRESSURE. NEWTONS/M<sup>2</sup>

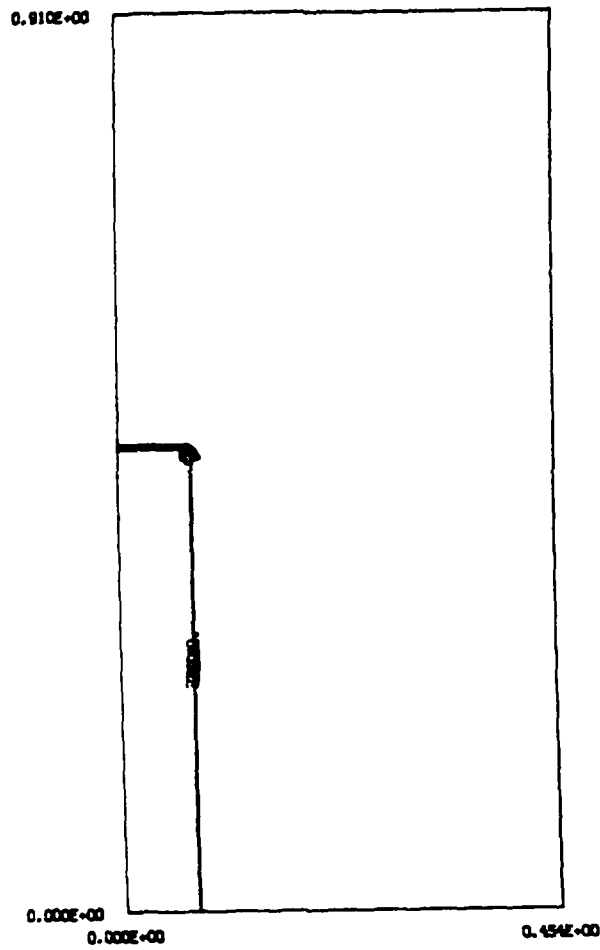


Figure 2a

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.25649E-04 SEC., STEP 86. DUMP TUB0002 DENSITY 1. KG/M3

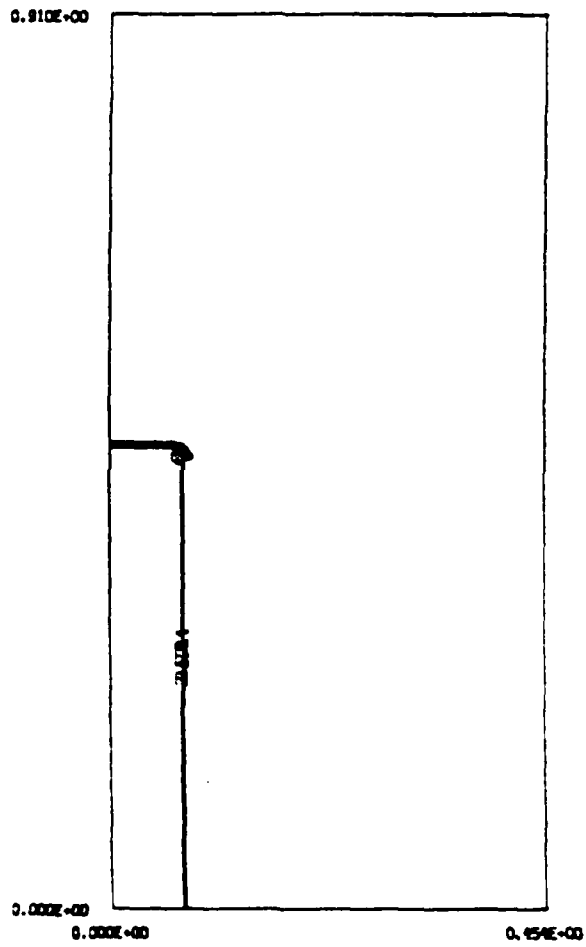


Figure 2b

BLAST DIFFRACTION FROM SHOCK TUBE

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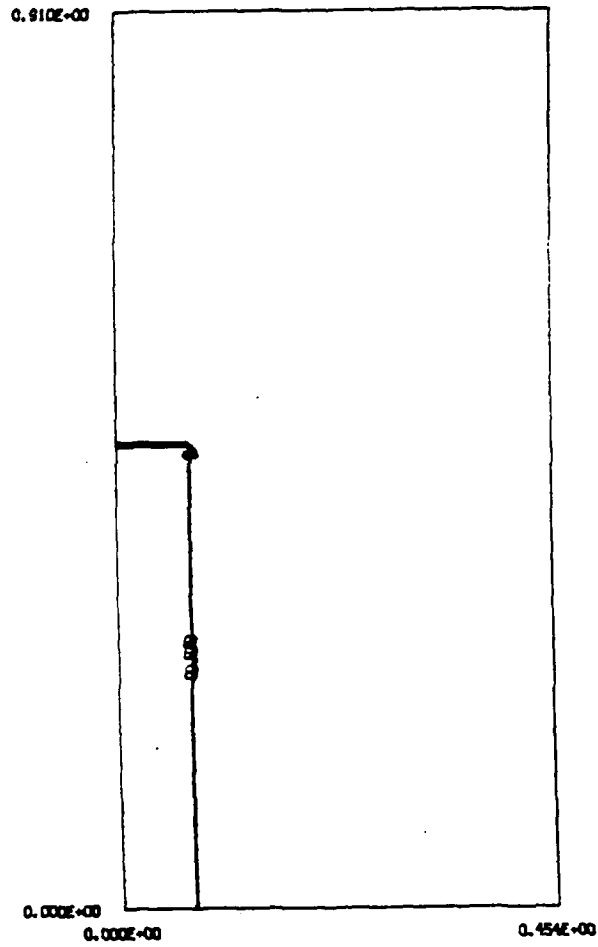
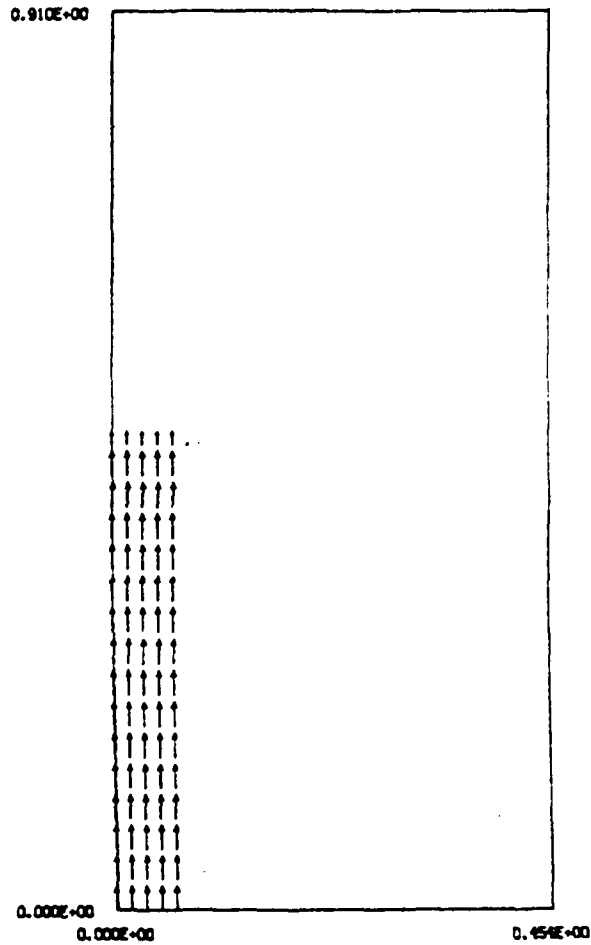


Figure 2c

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.25649E-04 SEC.. STEP 86. DUMP TUBB0002 VELOCITY. M/SEC



0.338E+03  
MAXIMUM VELOCITY

Figure 2d

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.50172E-04 SEC. STEP 107. DUMP TUBB0003 PRESSURE, NEWTONS/M<sup>2</sup>

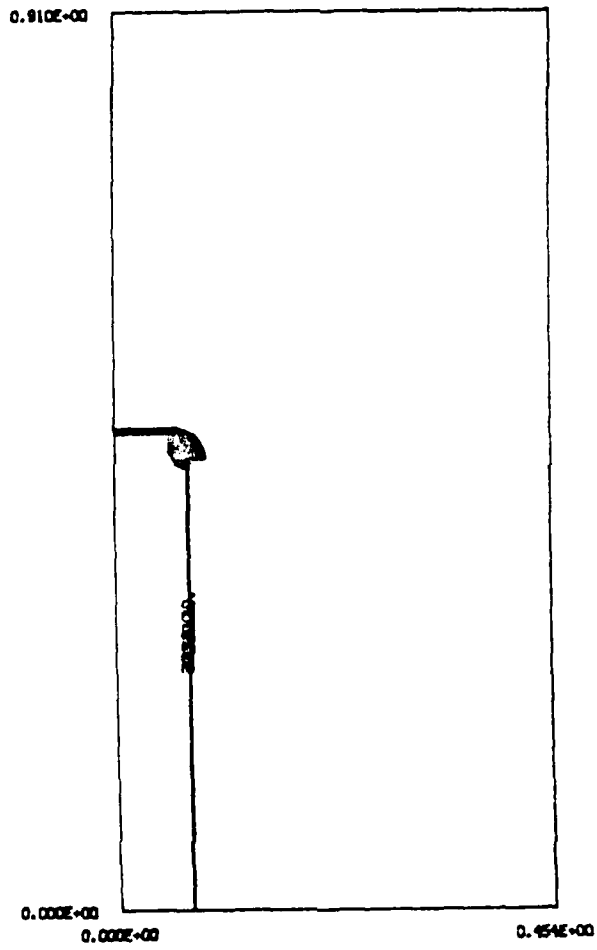


Figure 3a

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.50172E-04 SEC. STEP 107. DUMP TUBB0003 DENSITY 1. KG/M3

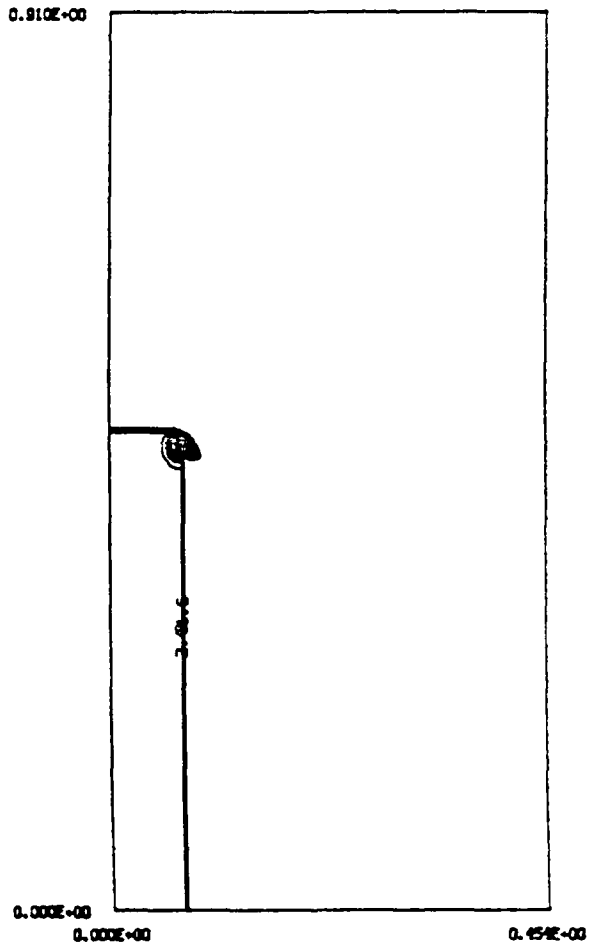


Figure 3b

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.50172E-04 SEC.. STEP 107. DUMP TUBB0003 MACH NUMBER

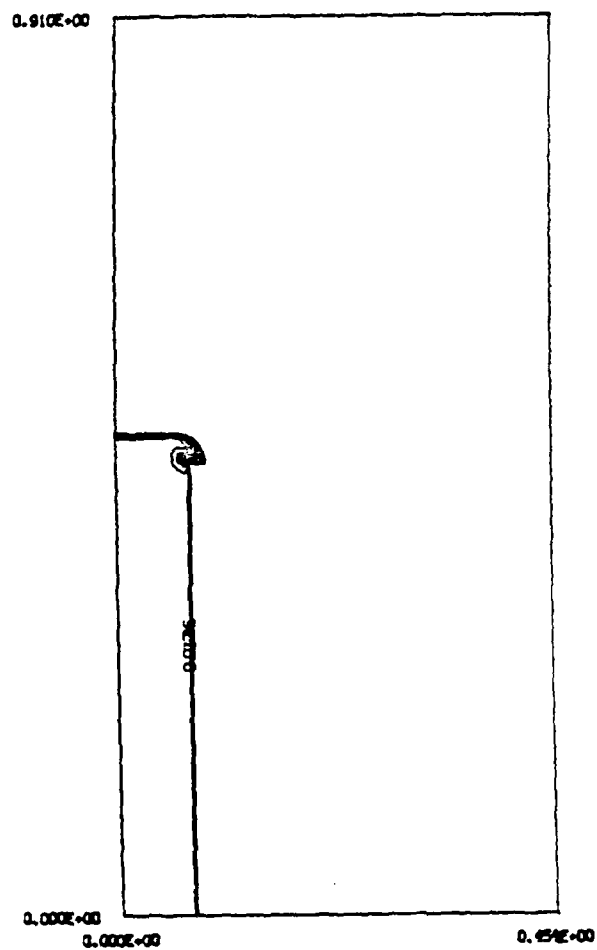


Figure 3c

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.50172E-04 SEC.. STEP 107. DUMP TUB80003 VELOCITY. M/SEC

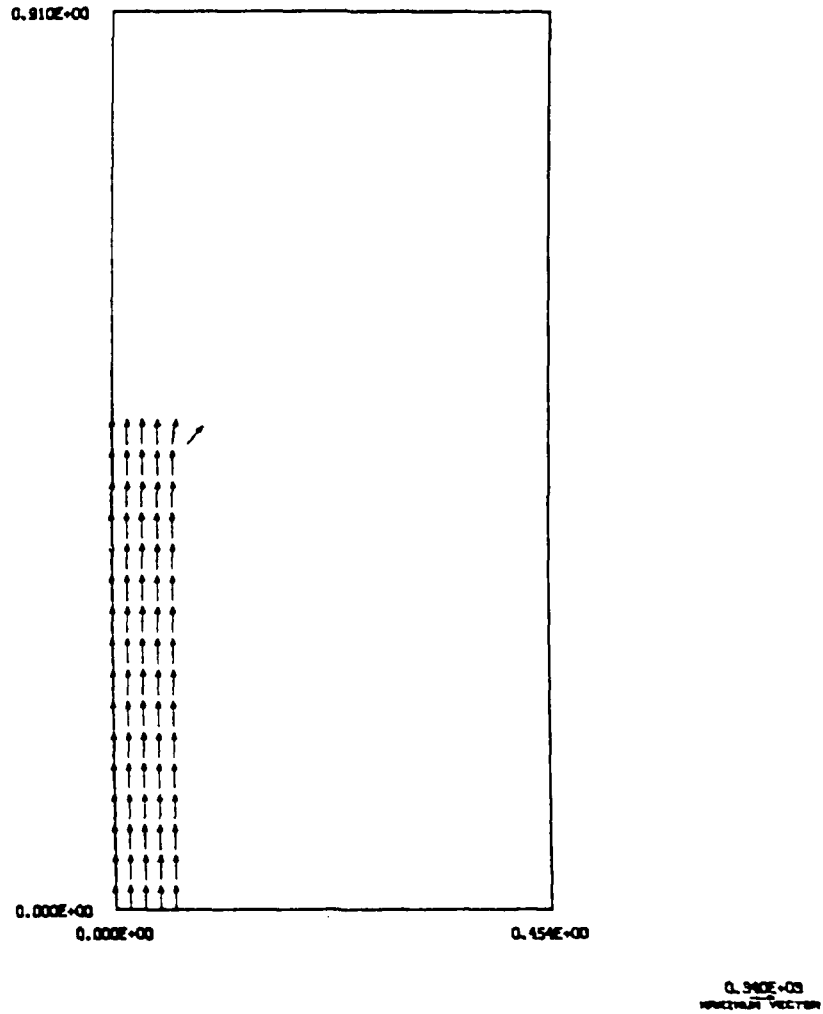


Figure 3d

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.10014E-03 SEC., STEP 152. DUMP TUBB0004 PRESSURE, NEWTONS/M<sup>2</sup>

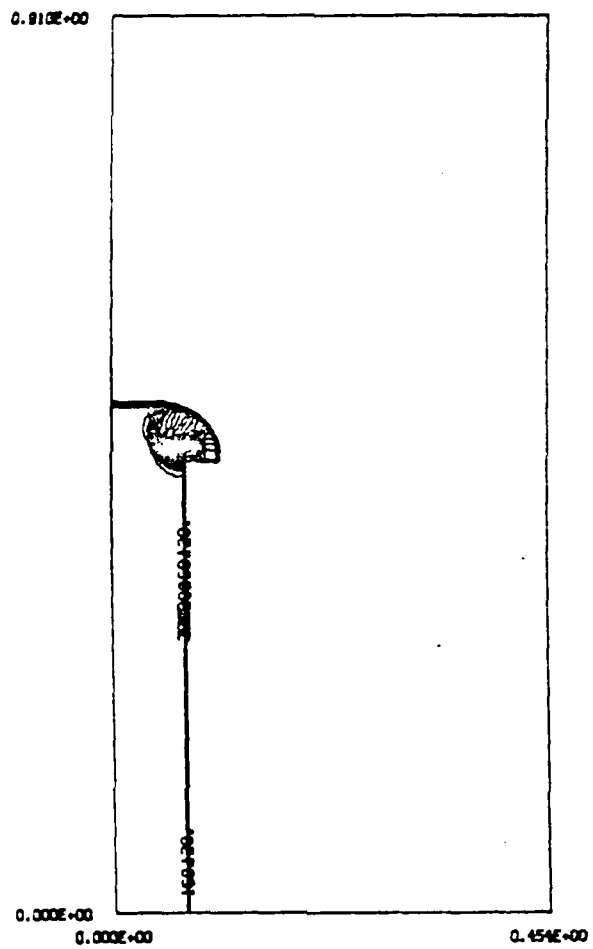


Figure 4a

BLAST DIFFRACTION FROM SHOCK TUBE

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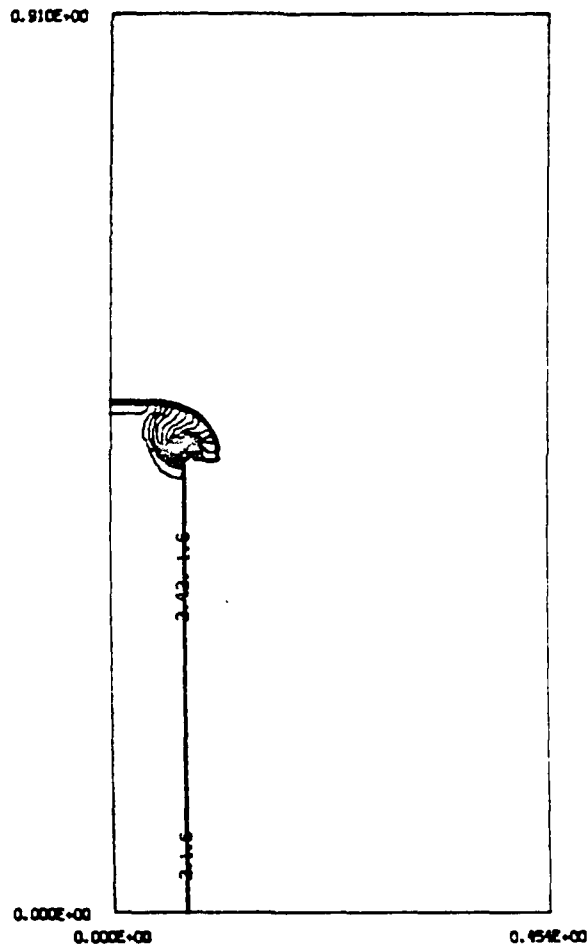


Figure 4b

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.10014E-03 SEC.. STEP 152. DUMP TUB80004

MACH NUMBER

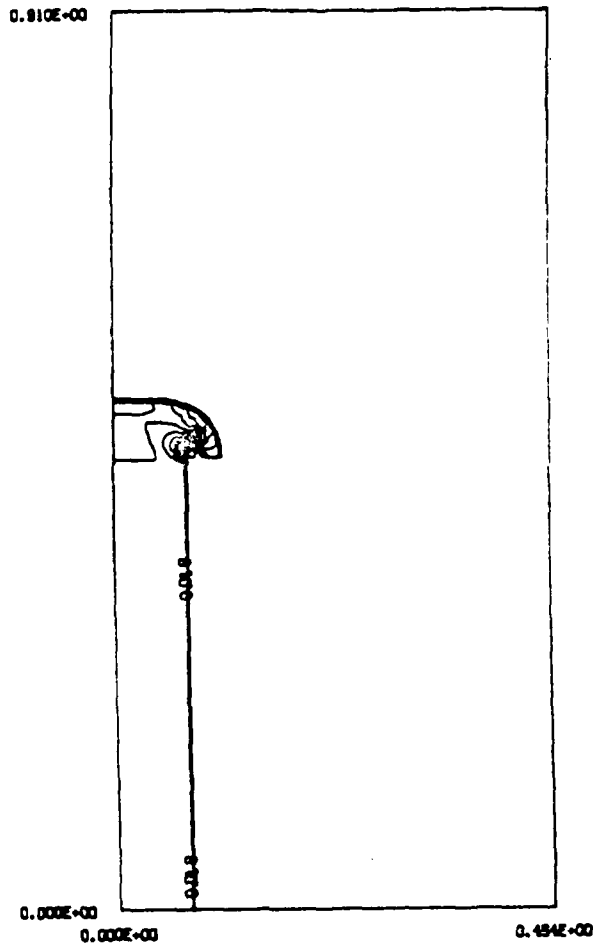
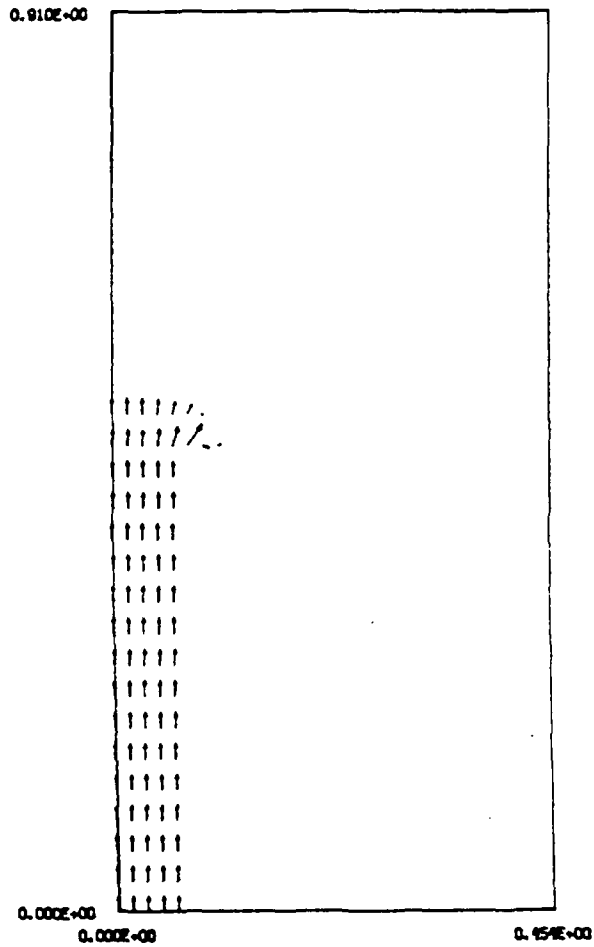


Figure 4c

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.10014E-03 SEC., STEP 152. DUMP TUBB0004 VELOCITY. M/SEC



0.500E+03  
MAXIMUM VELOCITY

Figure 4d

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.20090E-03 SEC., STEP 247. DUMP TUBB0005 PRESSURE, NEWTONS/M<sup>2</sup>

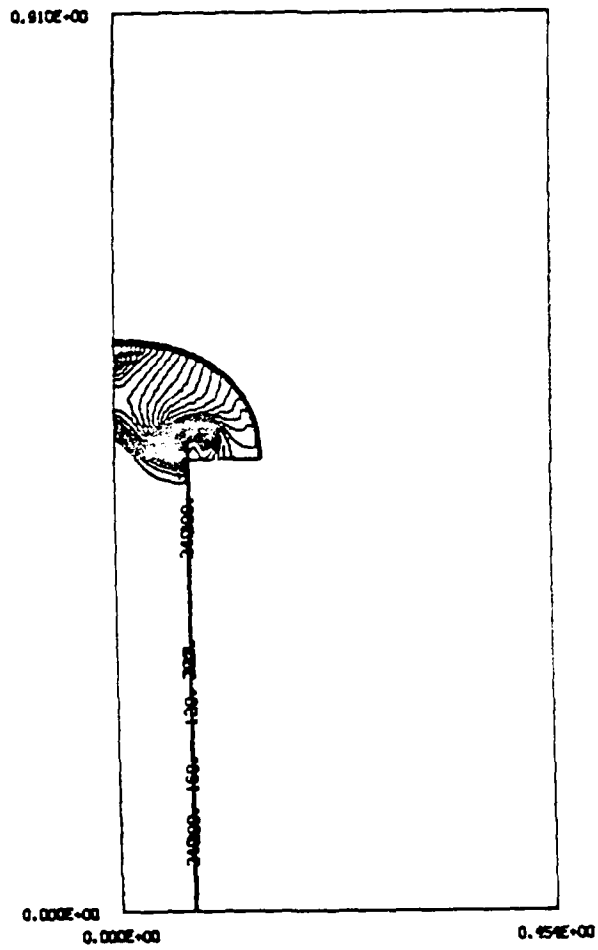


Figure 5a

BLAST DIFFRACTION FROM SHOCK TUBE  
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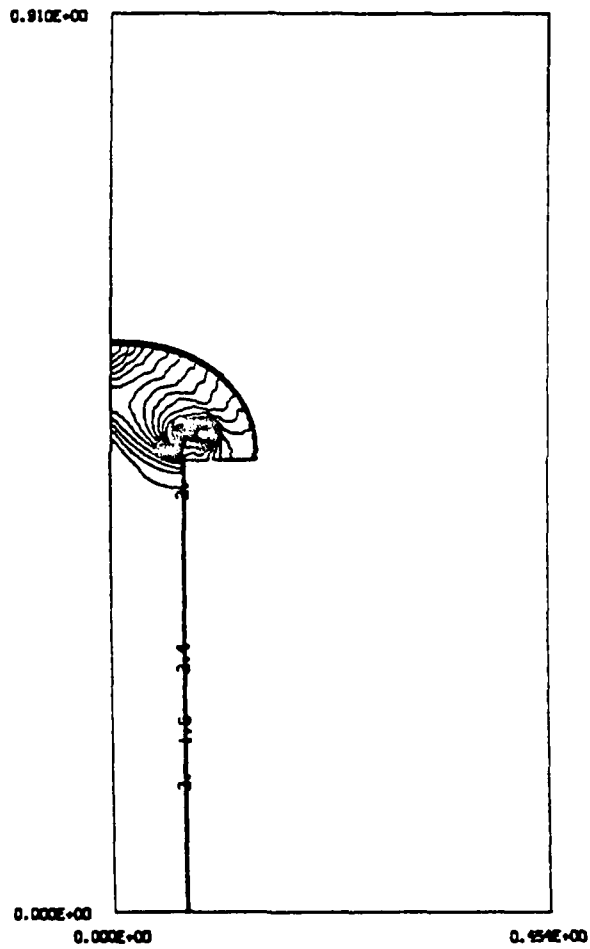


Figure 5b

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.20090E-03 SEC., STEP 247, DUMP TUB80005

MACH NUMBER

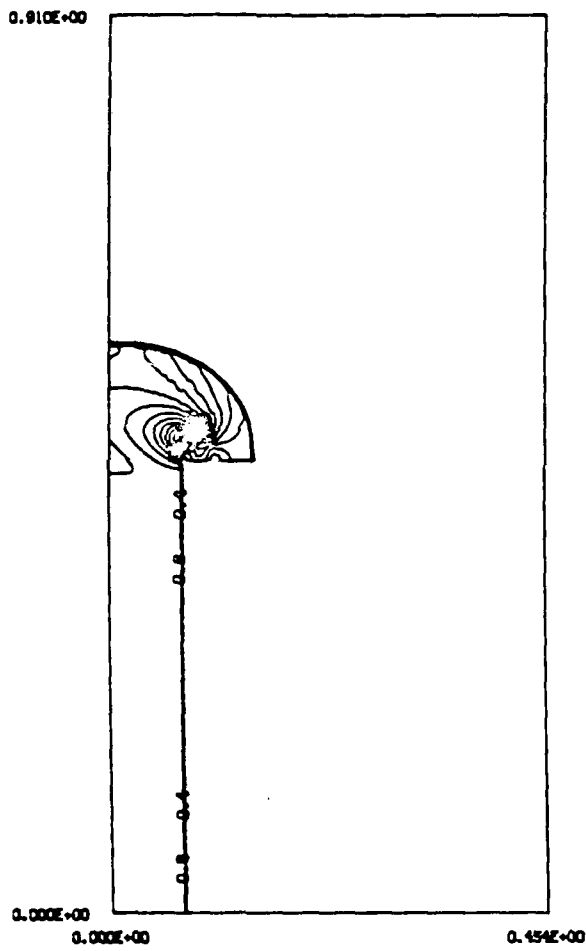


Figure 5c

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.20090E-03 SEC., STEP 247, DUMP TUBB0005 VELOCITY, M/SEC

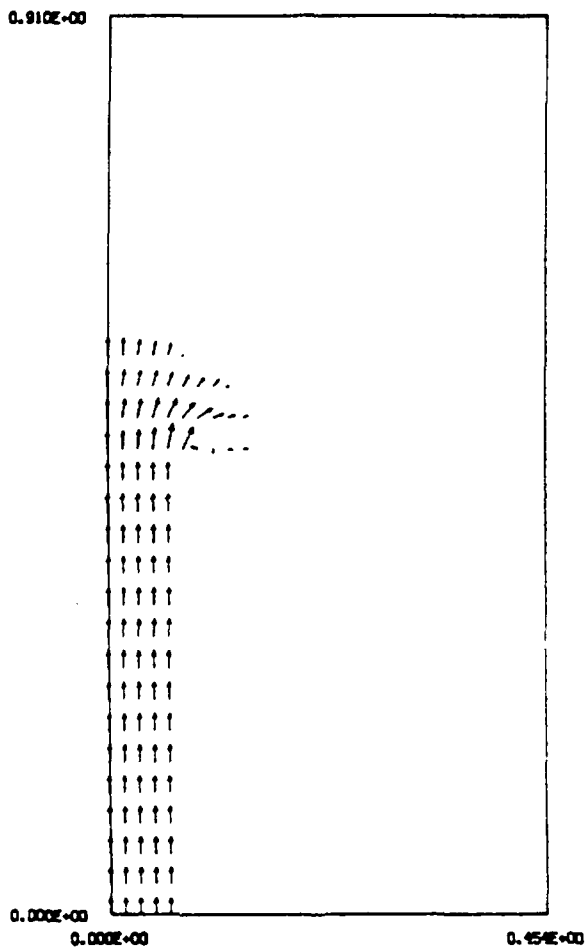


Figure 5d

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.50093E-03 SEC., STEP 534. DUMP TUB80006 PRESSURE. NEWTONS/MM<sup>2</sup>

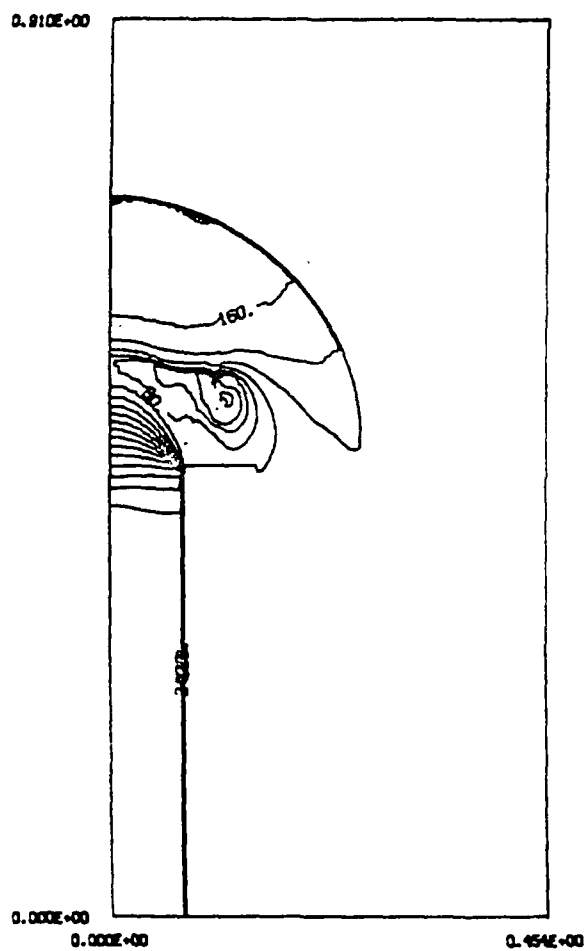


Figure 6a

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.50093E-03 SEC.. STEP 534. DUMP TUBB0006 DENSITY 1. KG/M3

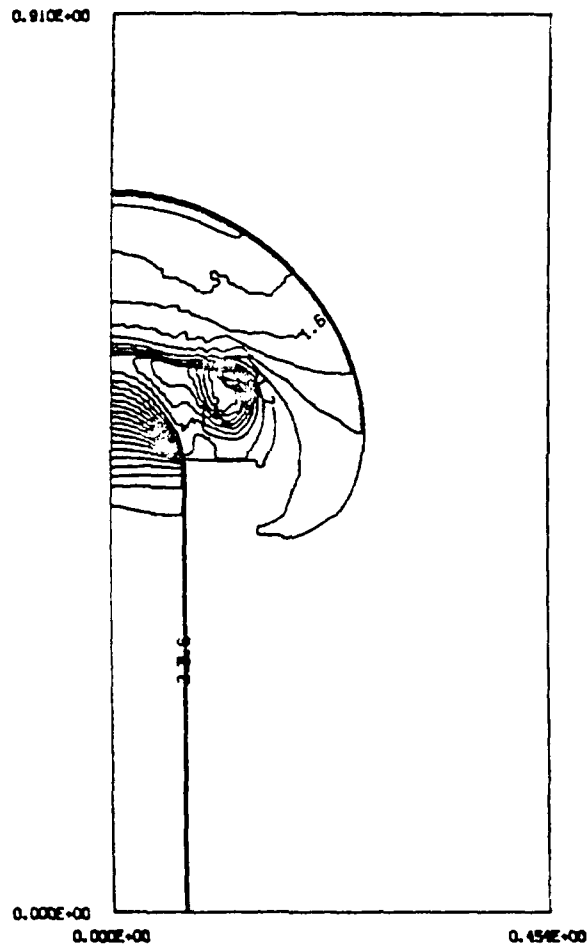


Figure 6b

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.50093E-03 SEC., STEP 534. DUMP TUBB0005 MACH NUMBER

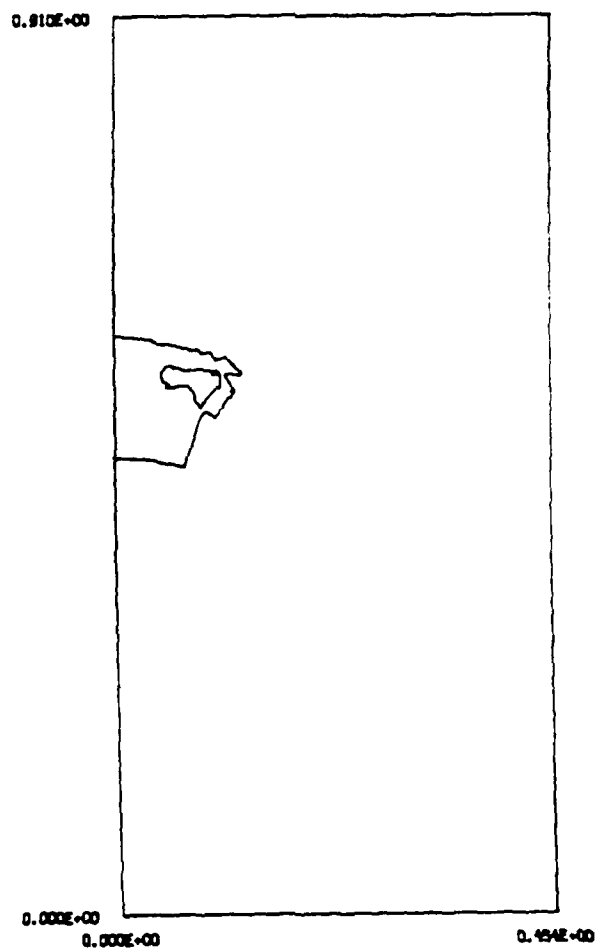


Figure 6c

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.50093E-03 SEC., STEP 534. DUMP TUBB0006 VELOCITY. M/SEC

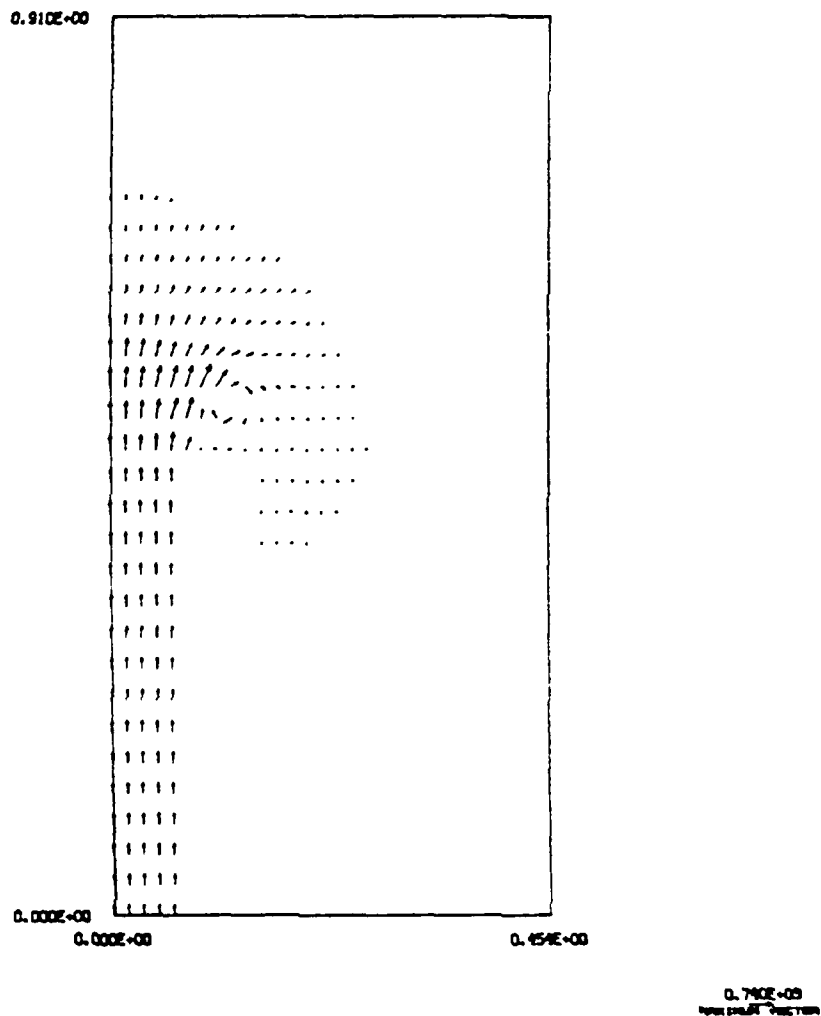


Figure 6d

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.10007E-02 SEC.. STEP 1063. DUMP TUB80007 PRESSURE, NEWTONS/M<sup>2</sup>

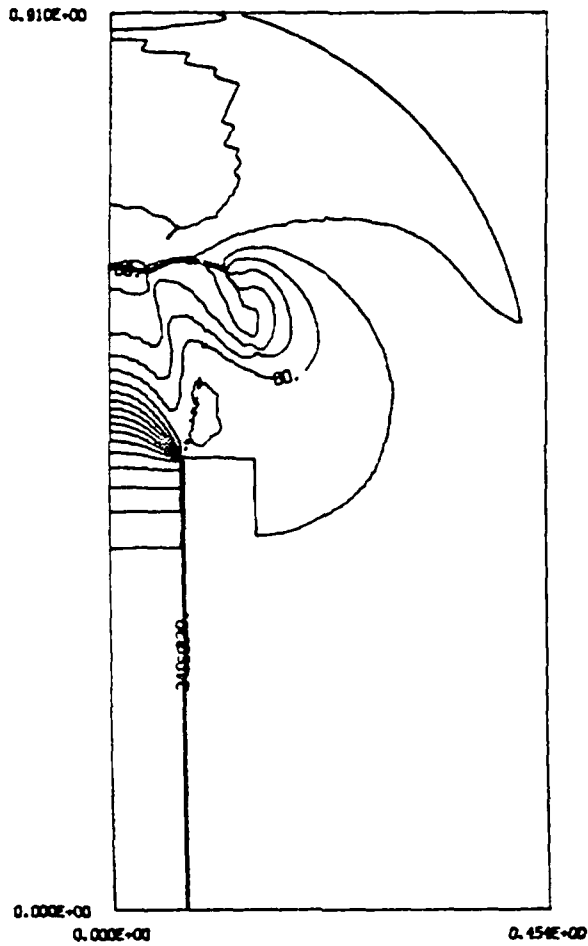


Figure 7a

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.10007E-02 SEC., STEP 1063. DUMP TUBB0007 DENSITY 1. KG/M3

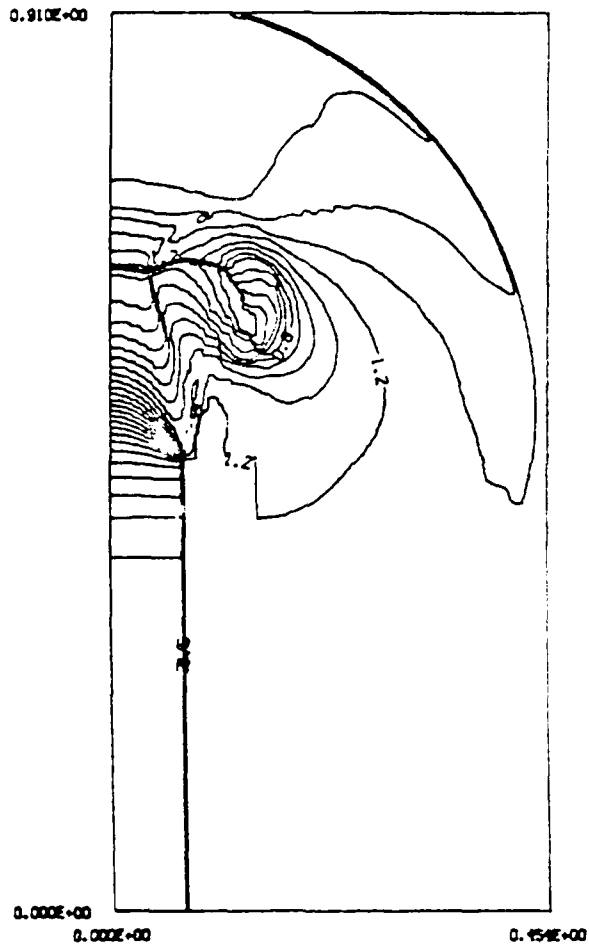


Figure 7b

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.10007E-02 SEC.. STEP 1063. DUMP TUB80007

MACH NUMBER

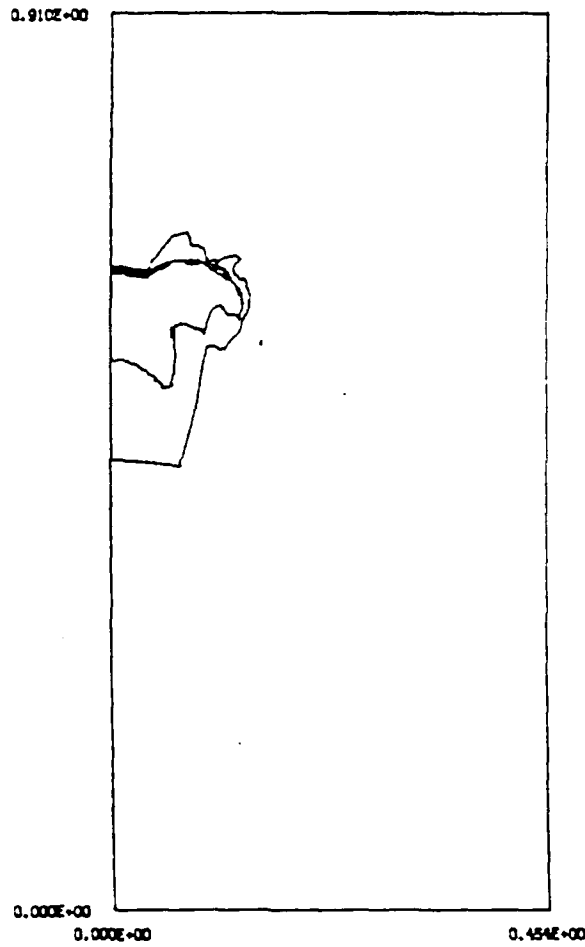
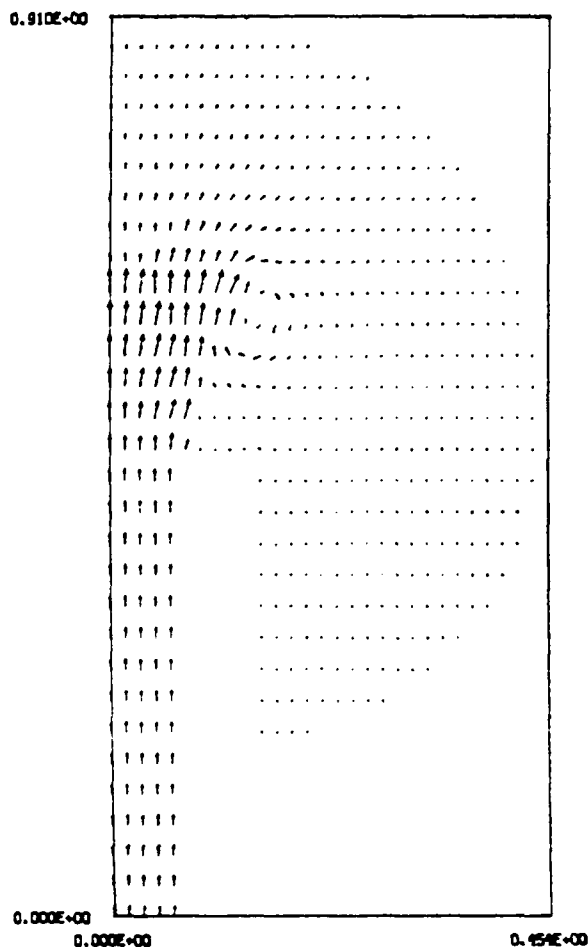


Figure 7c

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.10007E-02 SEC.. STEP 1063. DUMP TUBB0007 VELOCITY. M/SEC



0.793E+00  
WINDMILL VECTOR

Figure 7d

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.15009E-02 SEC., STEP 1618. DUMP TUBB0008 DENSITY 1. KG/M3

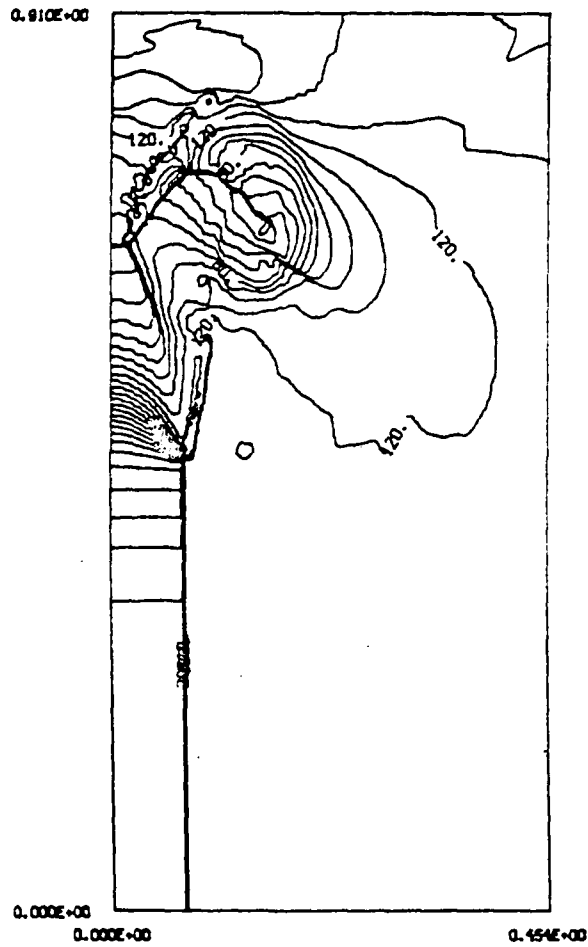


Figure 8a

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.15009E-02 SEC.. STEP 1618. DUMP TUBB0008 PRESSURE, NEWTONS/M<sup>2</sup>

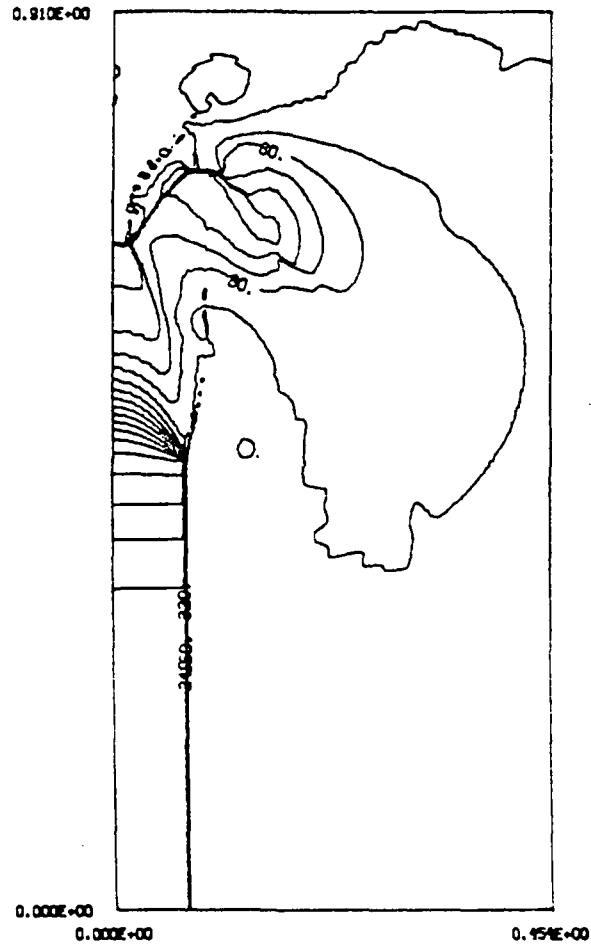


Figure 8b

BLAST DIFFRACTION FROM SHOCK TUBE  
TIME= 0.15009E-02 SEC.. STEP 1618. DUMP TUB80008 MACH NUMBER

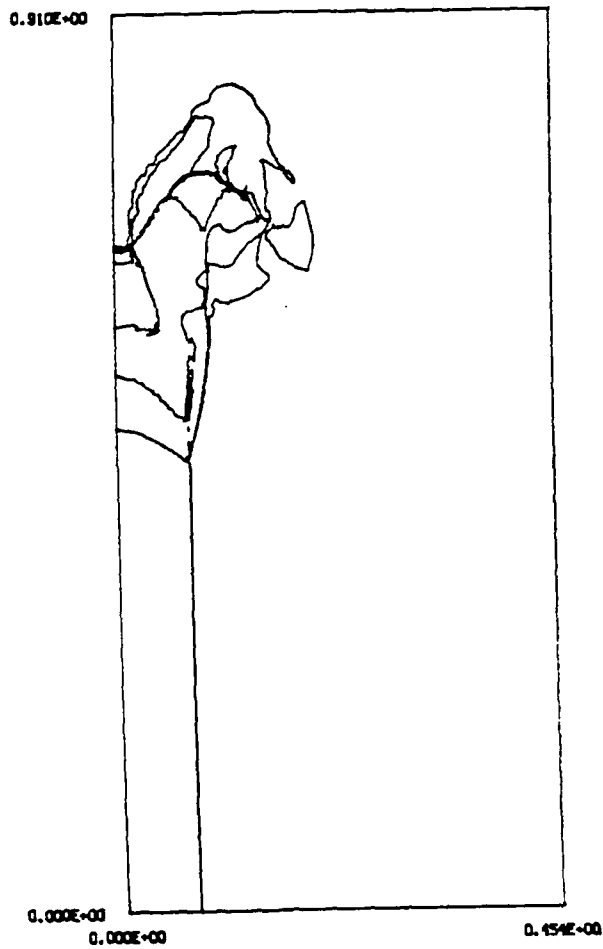


Figure 8c

BLAST DIFFRACTION FROM SHOCK TUBE

TIME= 0.15009E-02 SEC., STEP 1618. DUMP TUBB0008 VELOCITY. M/SEC

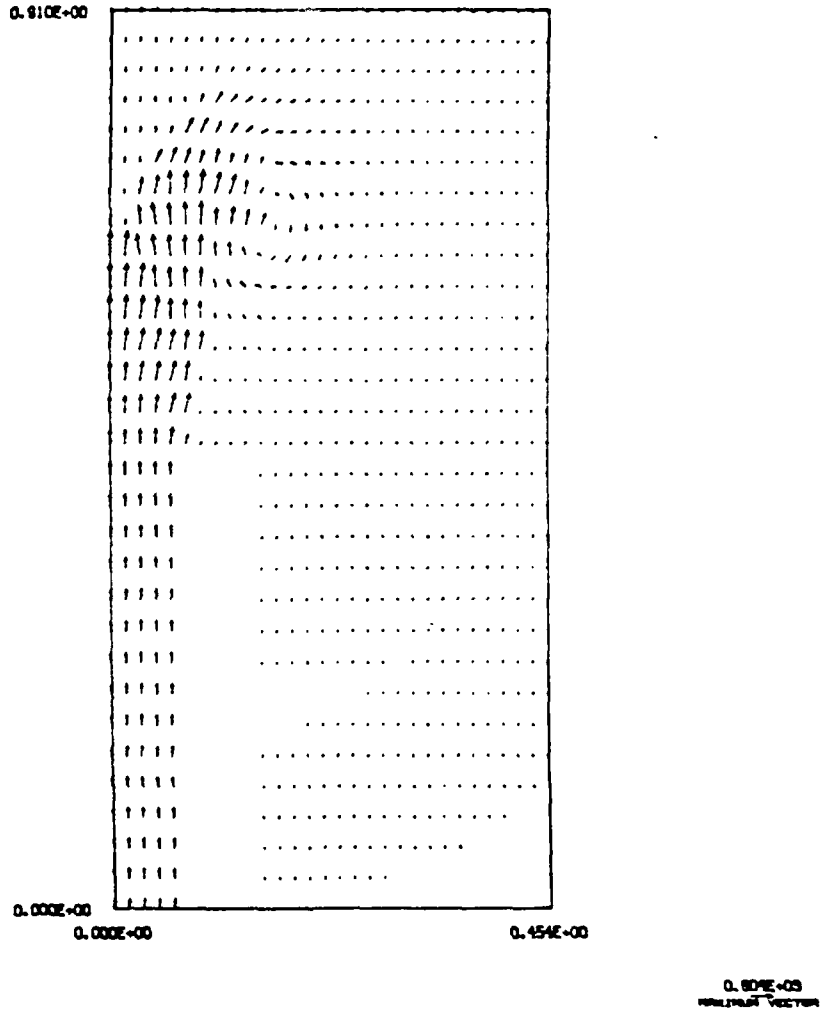
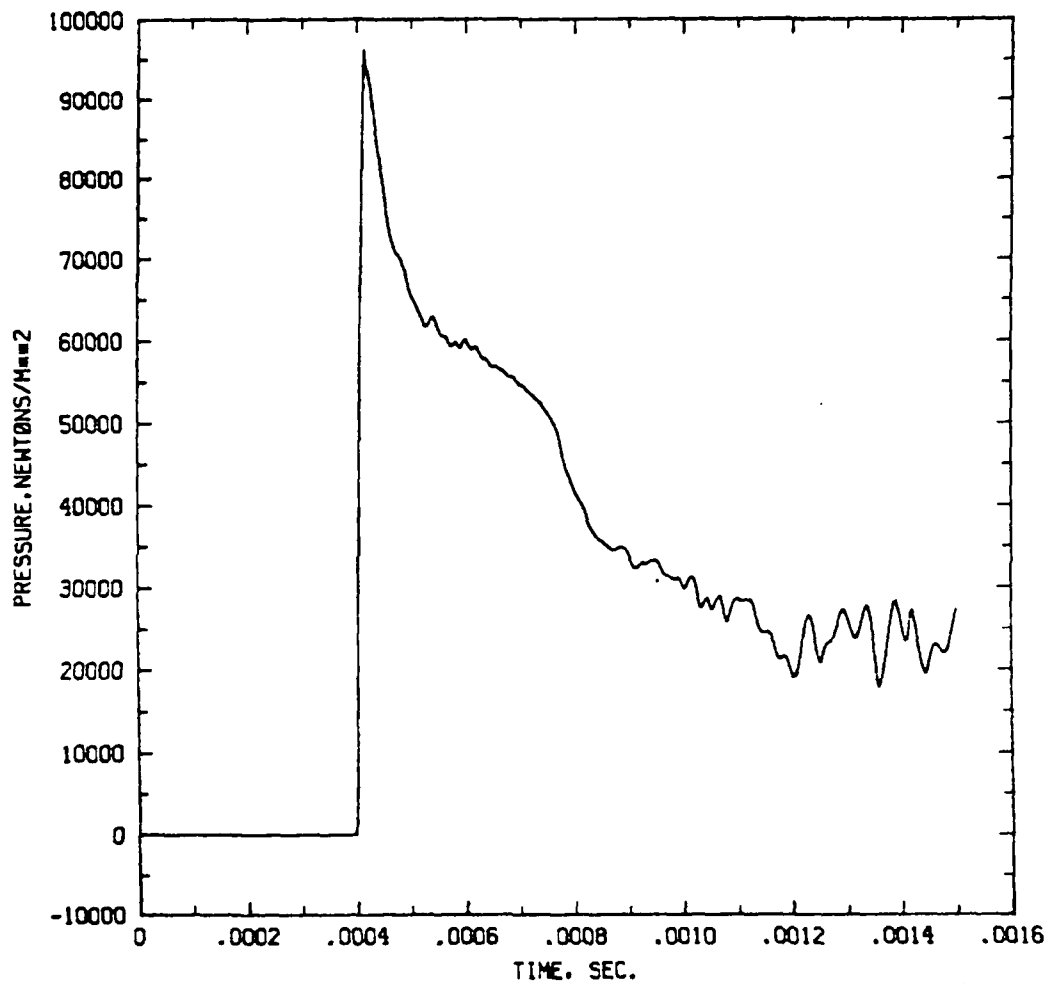


Figure 8d

STATION 1, XS.YS= 0.115E-02 0.684E+00 M

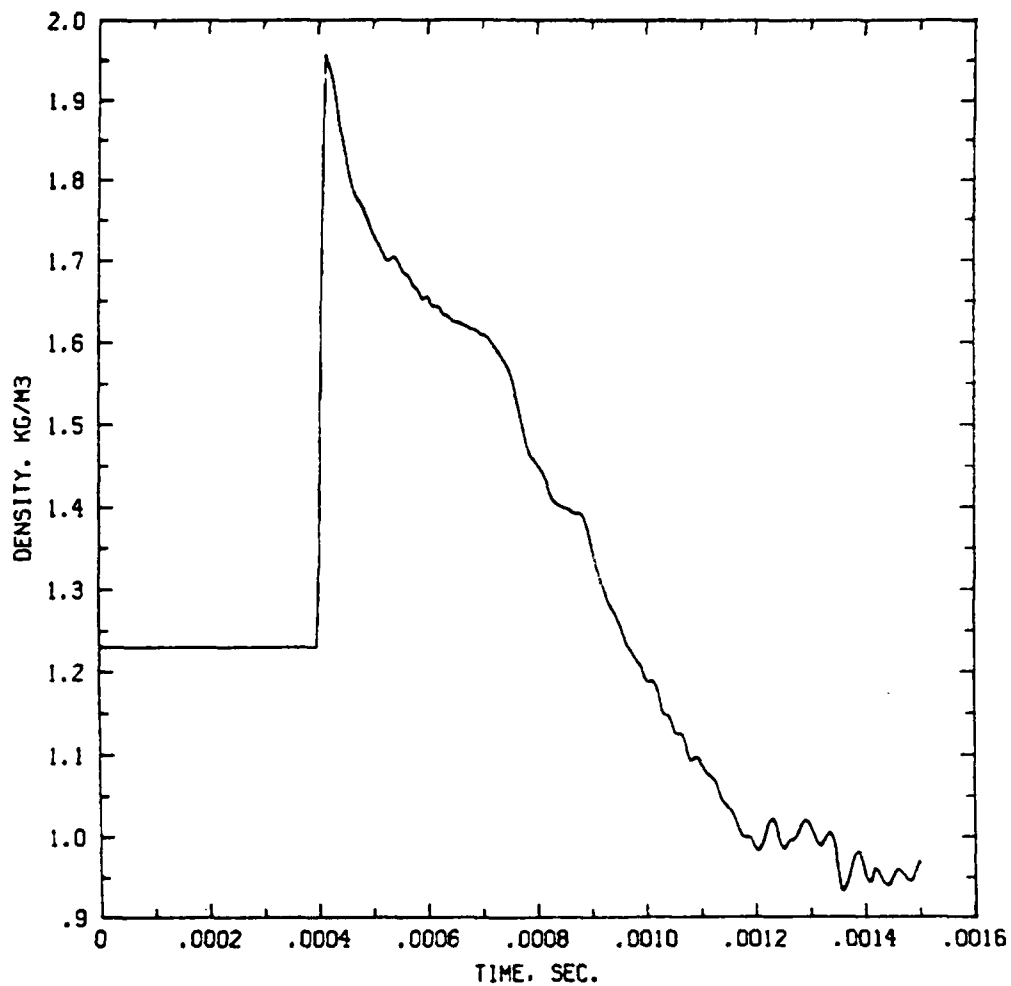


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS T0.000008

Figure 9a

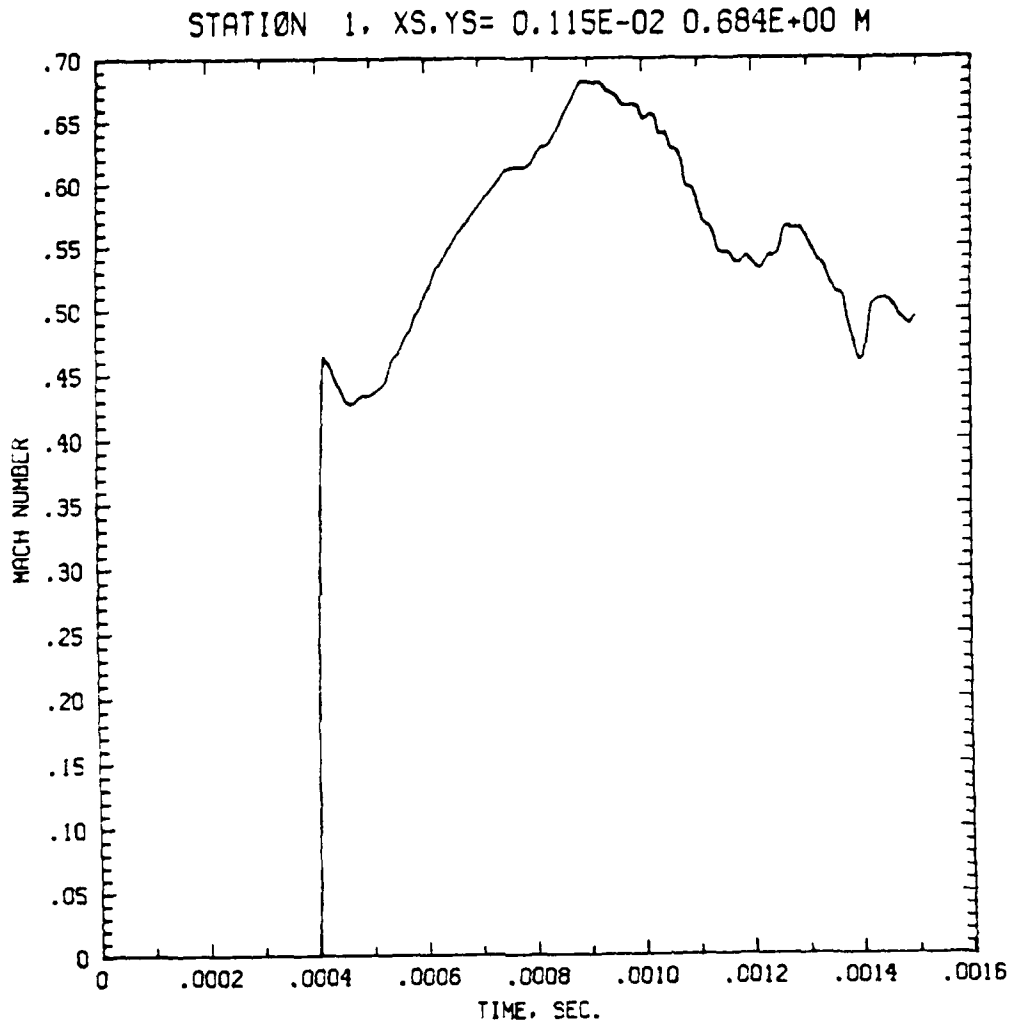
STATION 1. XS,YS= 0.115E-02 0.684E+00 M



BLAST DIFFRACTION FROM SHOCK TUBE

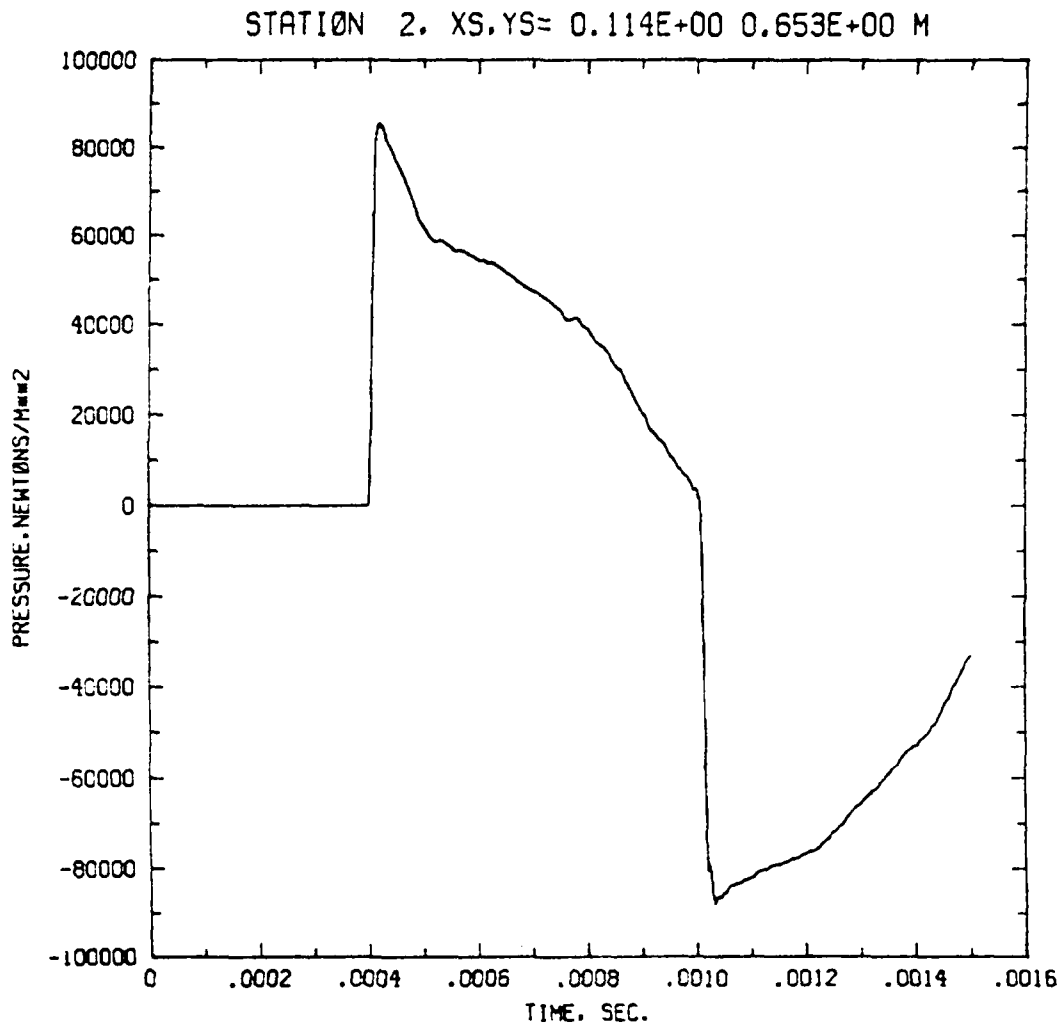
7 DUMPS. LAST DUMP IS TUBS0008

Figure 9b



BLAST DIFFRACTION FROM SHOCK TUBE  
7 DUMPS. LAST DUMP IS TUB00008

Figure 9c

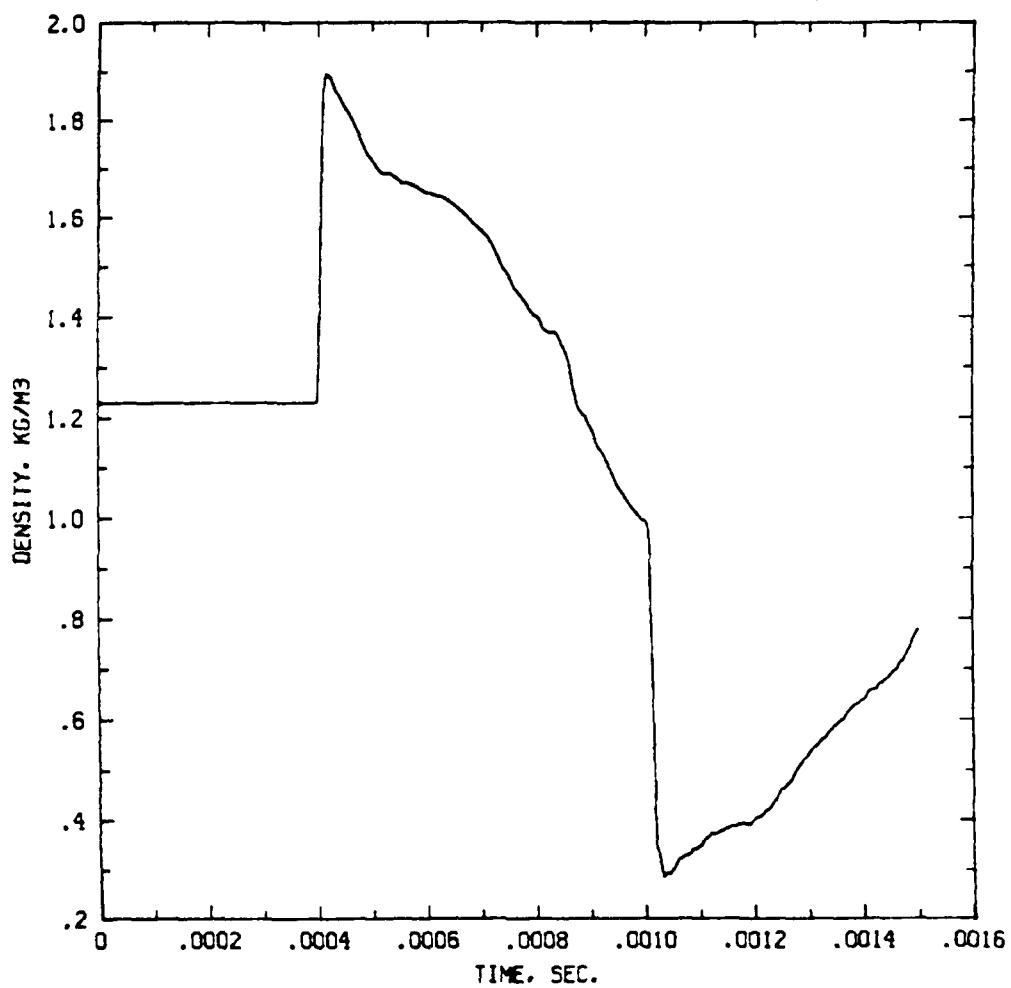


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUBS0008

Figure 10a

STATION 2, XS,YS= 0.114E+00 0.653E+00 M

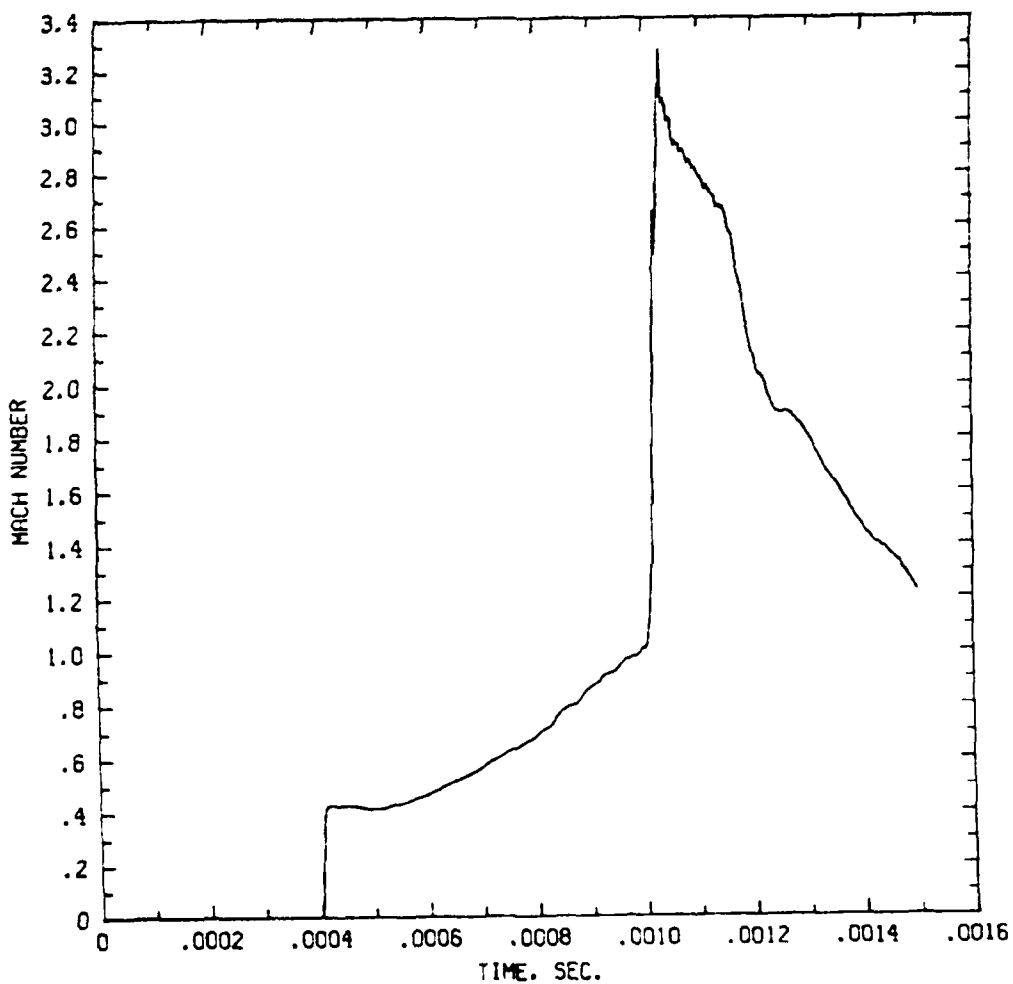


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB80008

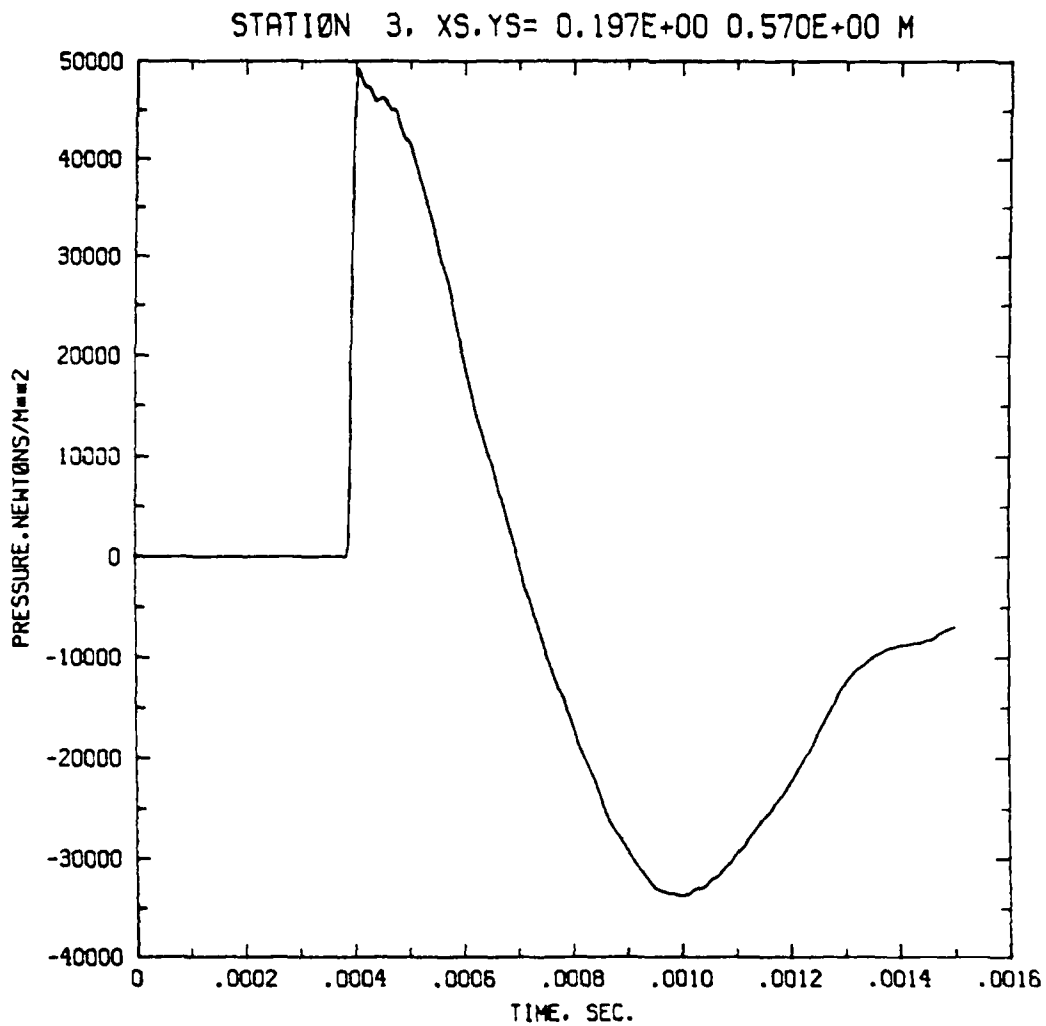
Figure 10b

STATION 2, XS,YS= 0.114E+00 0.653E+00 M



BLAST DIFFRACTION FROM SHOCK TUBE  
7 DUMPS. LAST DUMP IS TUB0006

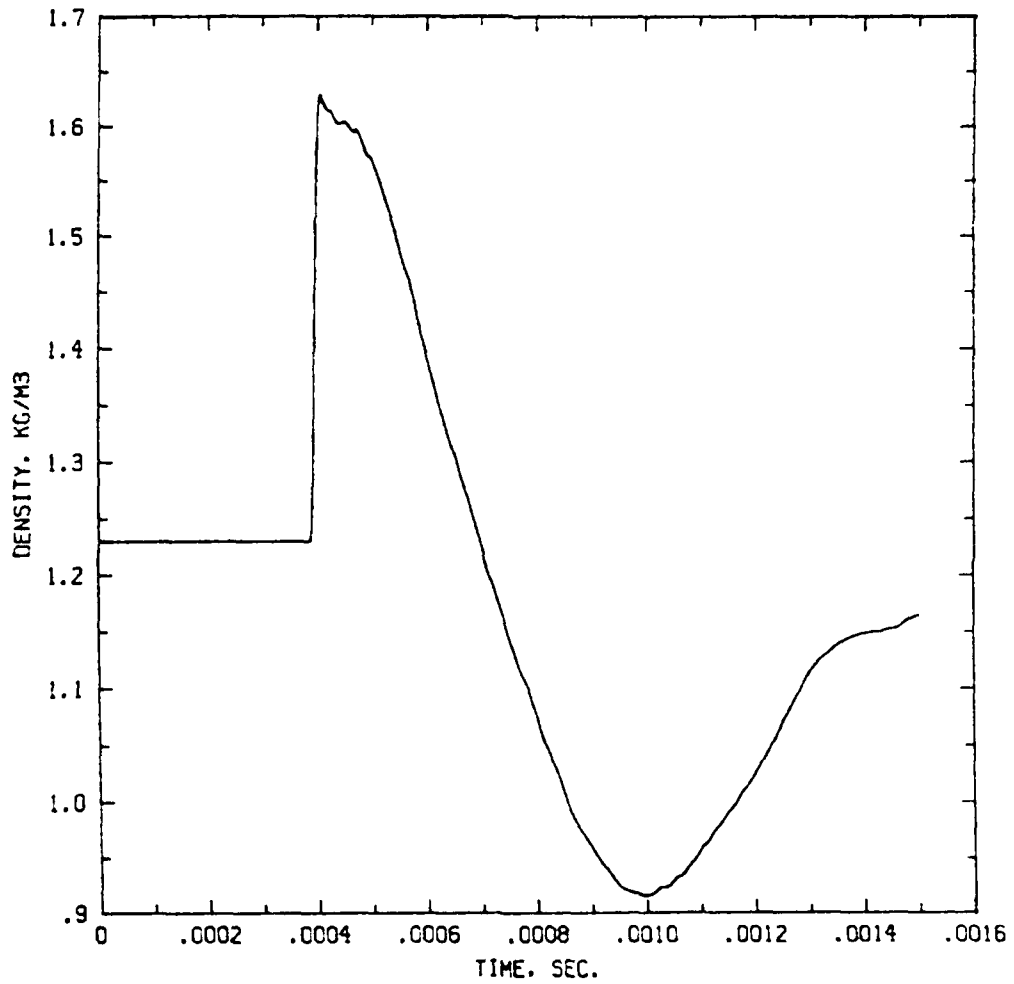
Figure 10c



BLAST DIFFRACTION FROM SHOCK TUBE  
7 DUMPS. LAST DUMP IS TUB00008

Figure 11a

STATION 3. XS,YS= 0.197E+00 0.570E+00 M

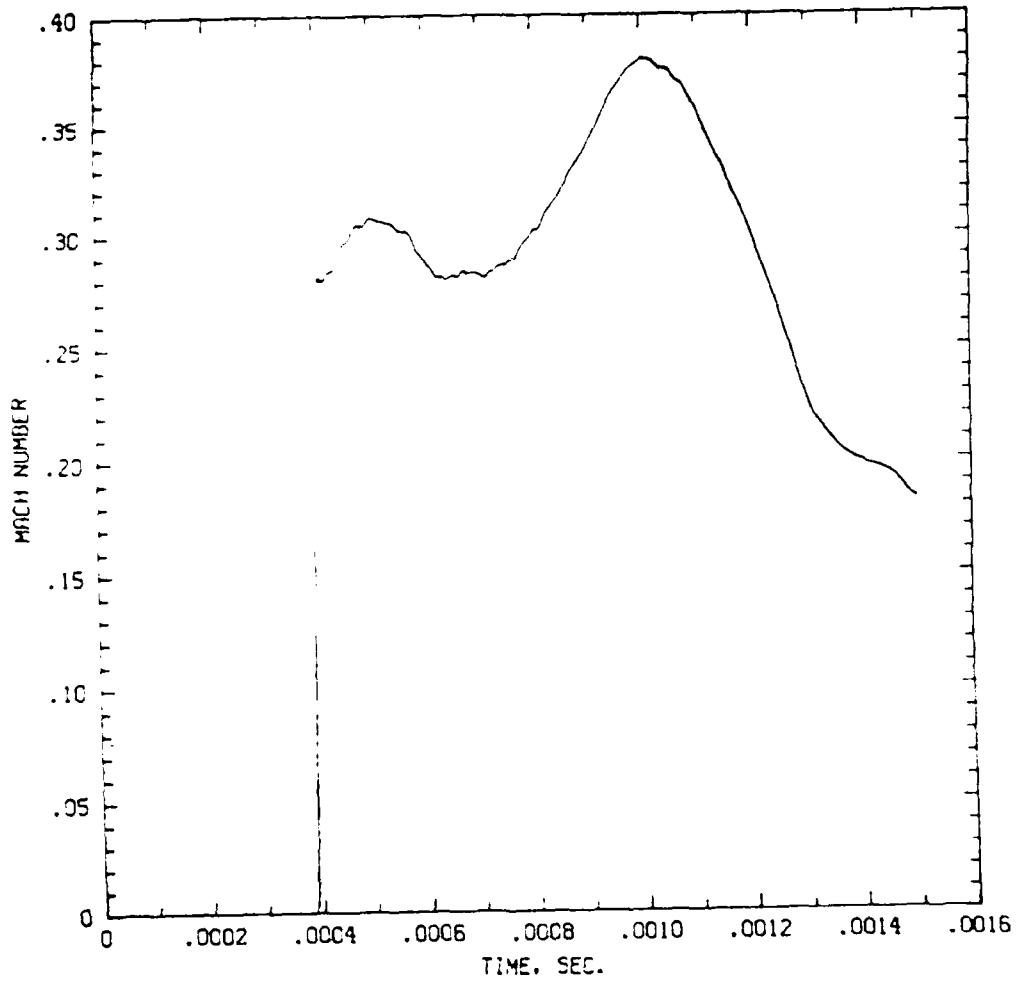


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUBS0008

Figure 11b

STATION 3. XS.YS= 0.197E+00 0.570E+00 M

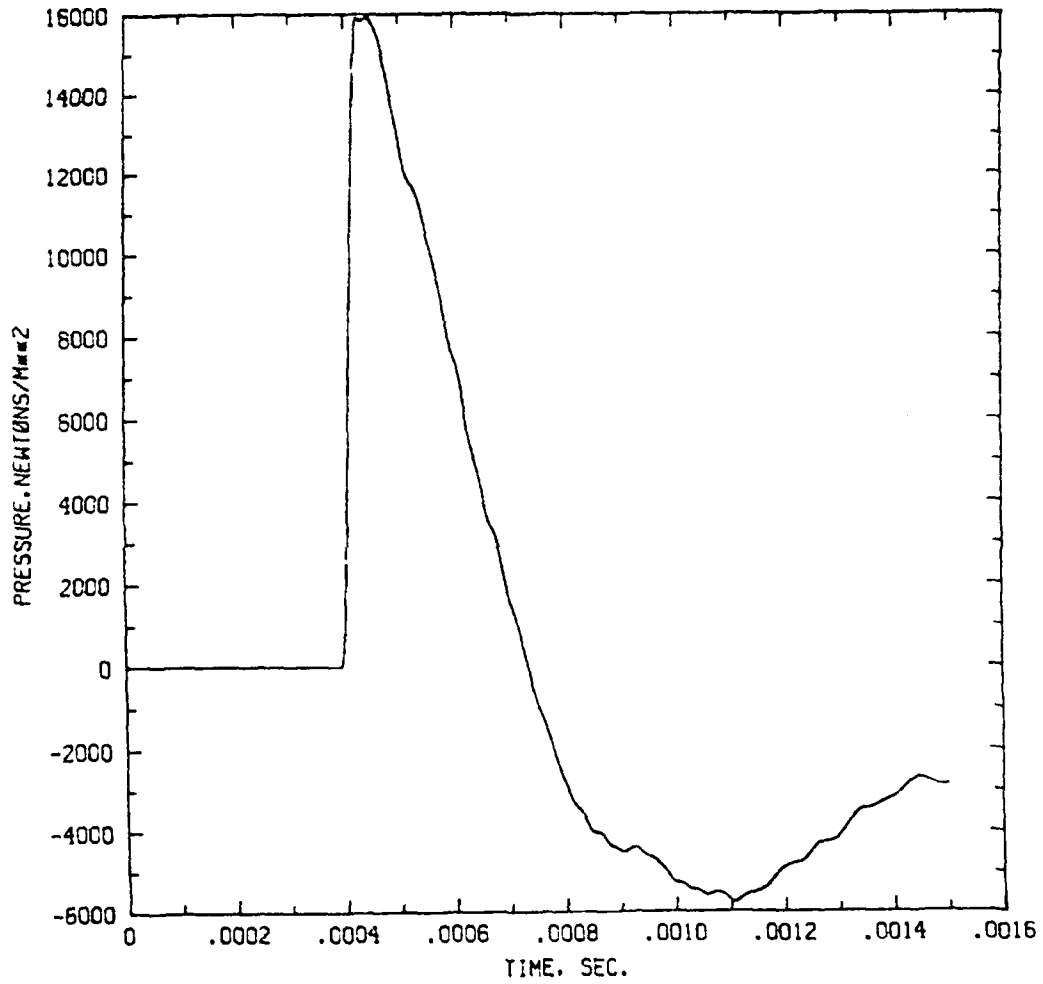


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TRIGGER

Figure 11c

STATION 4. XS,YS= 0.228E+00 0.456E+00 M

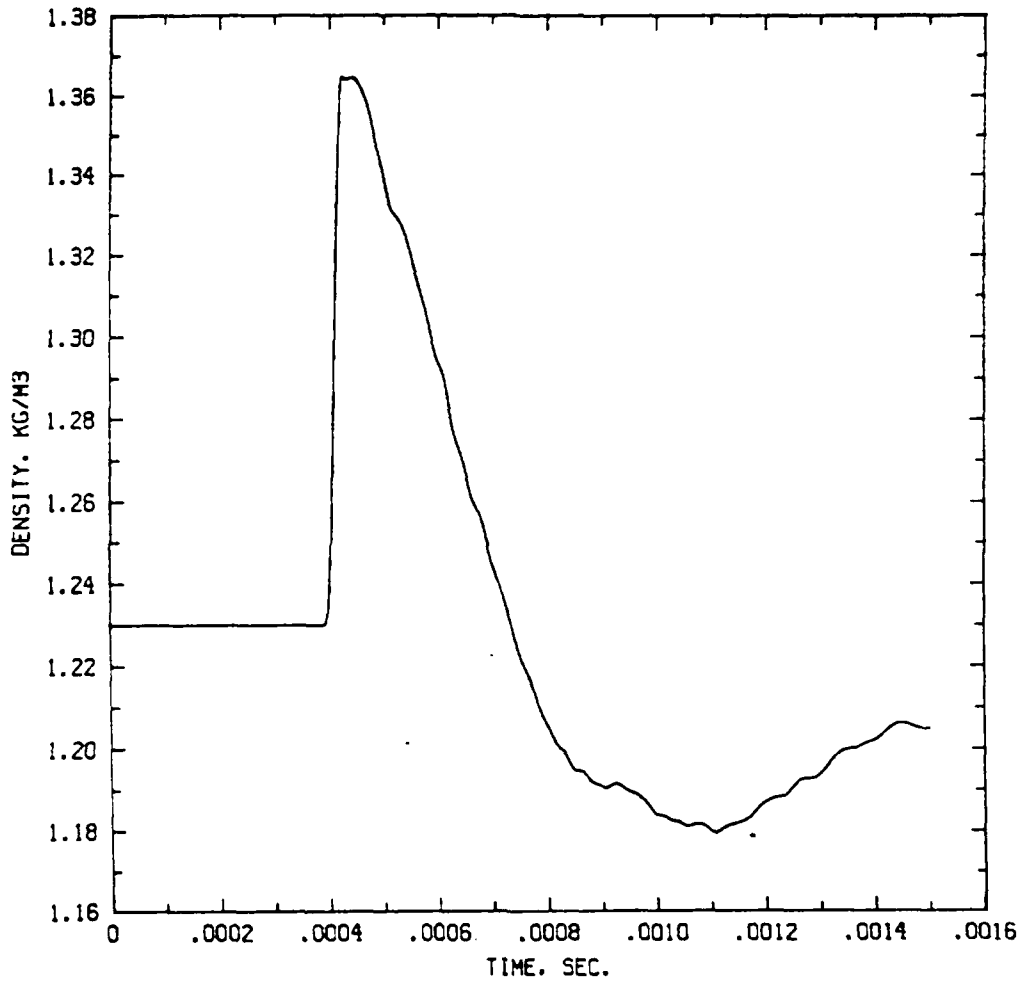


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB80008

Figure 12a

STATION 4, XS,YS= 0.228E+00 0.456E+00 M

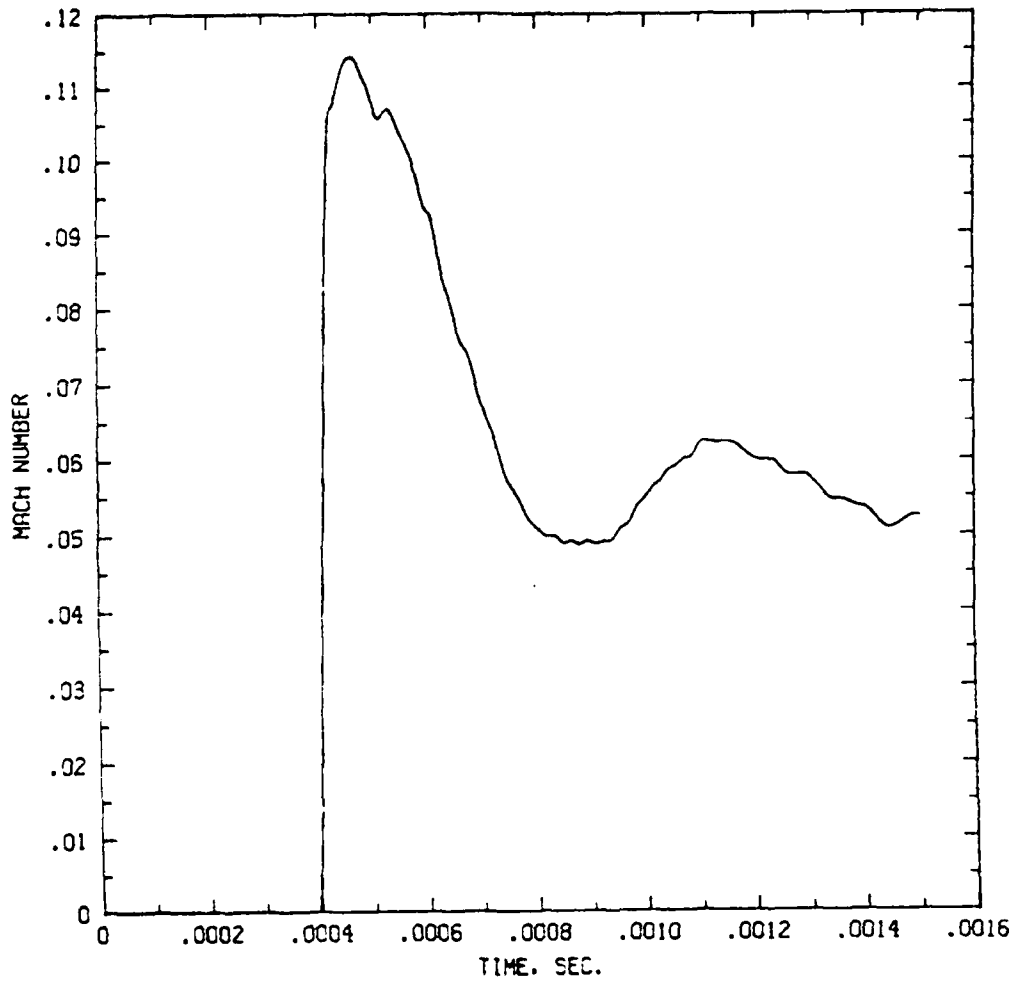


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUBS0008

Figure 12b

STATION 4. XS.YS= 0.228E+00 0.456E+00 M

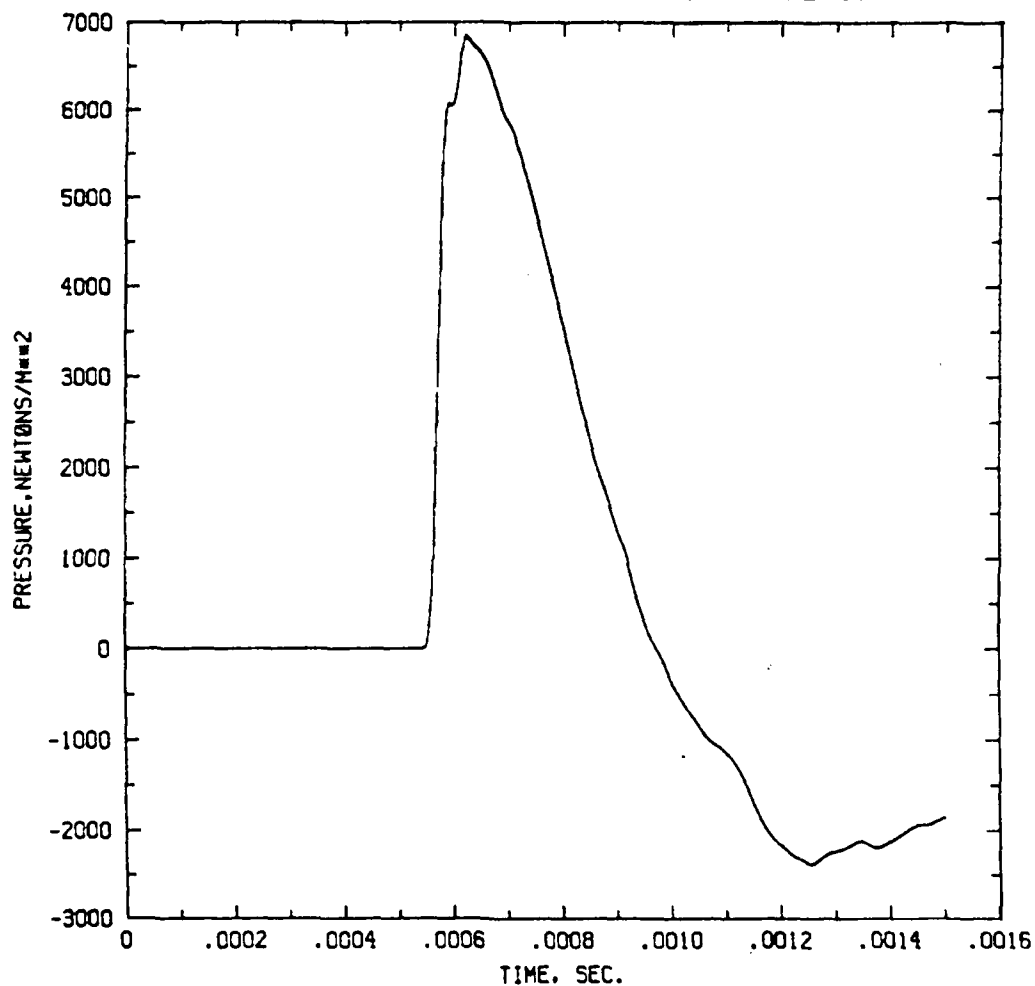


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB80008

Figure 12c

STATION 5, XS,YS= 0.197E+00 0.342E+00 M

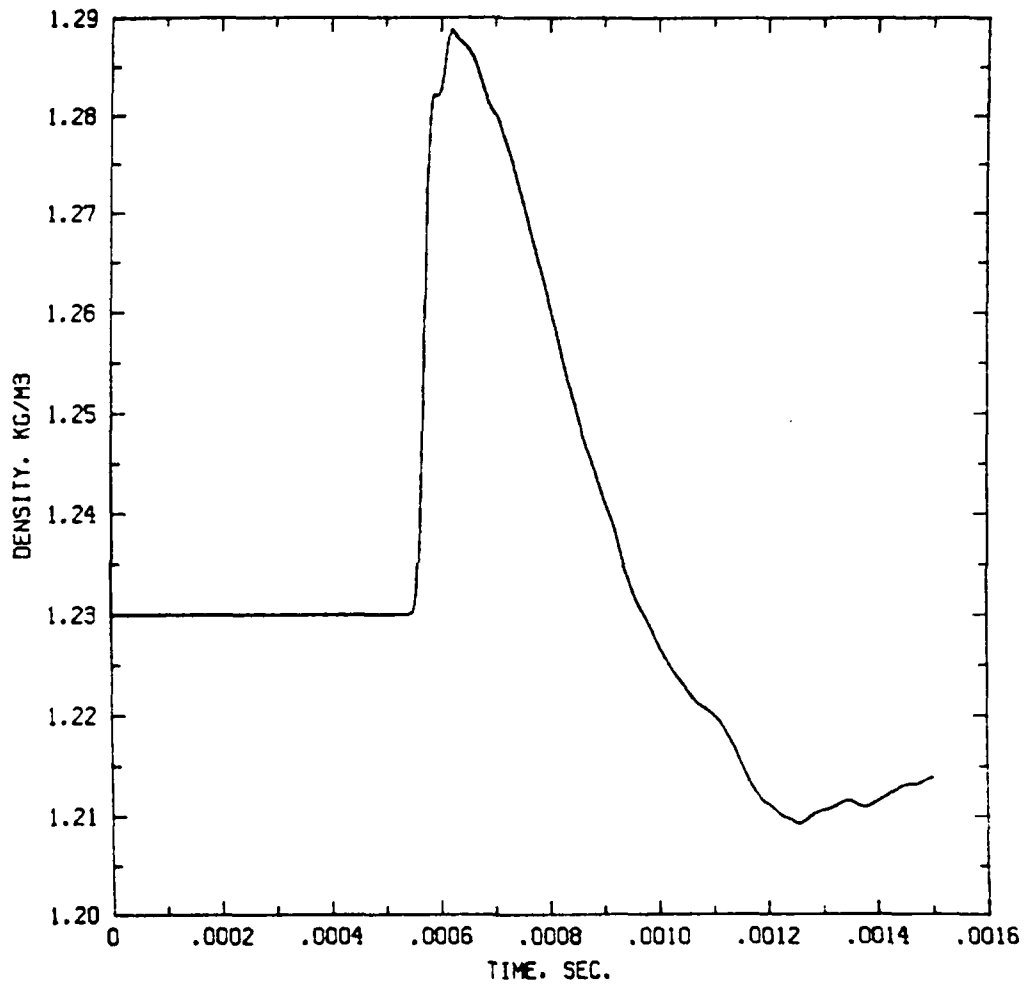


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBS0008

Figure 13a

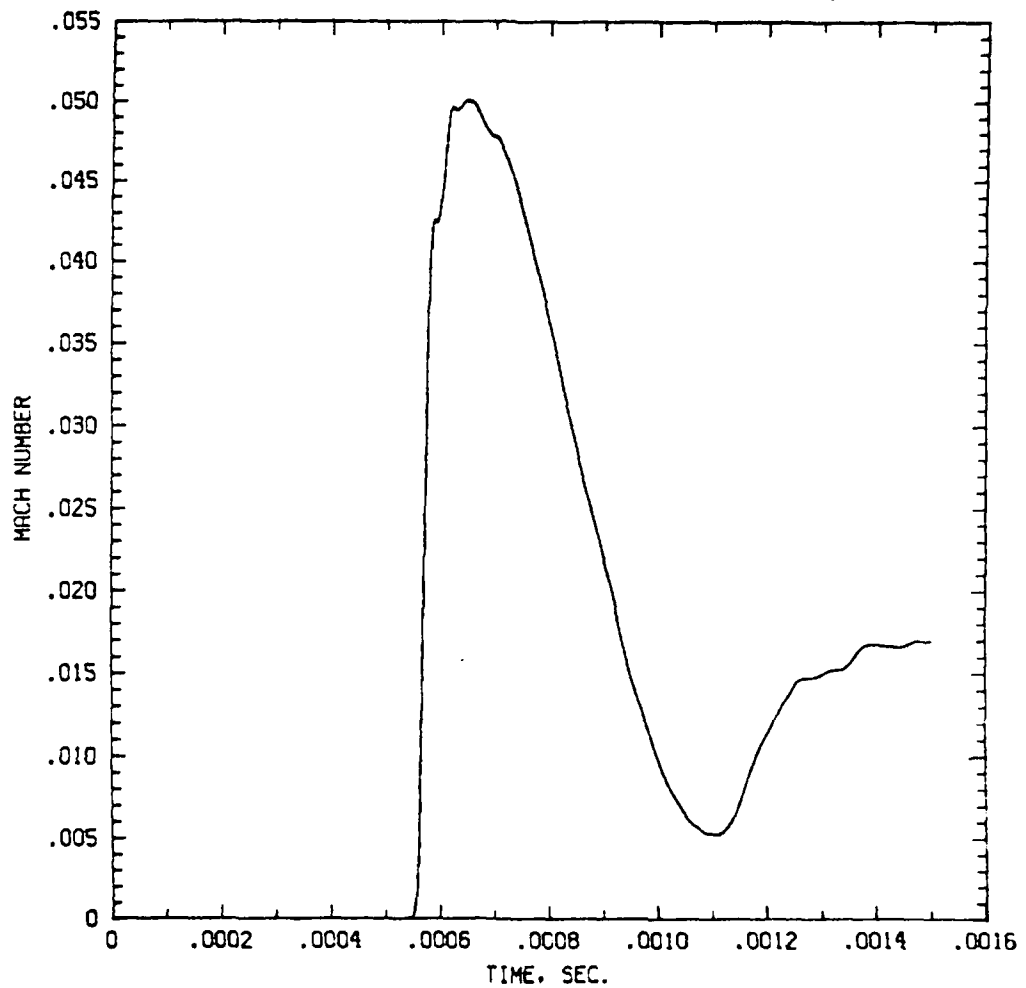
STATION 5. XS.YS= 0.197E+00 0.342E+00 M



BLAST DIFFRACTION FROM SHOCK TUBE  
7 DUMPS. LAST DUMP IS TUB00000

Figure 13b

STATION 5. XS,YS= 0.197E+00 0.342E+00 M

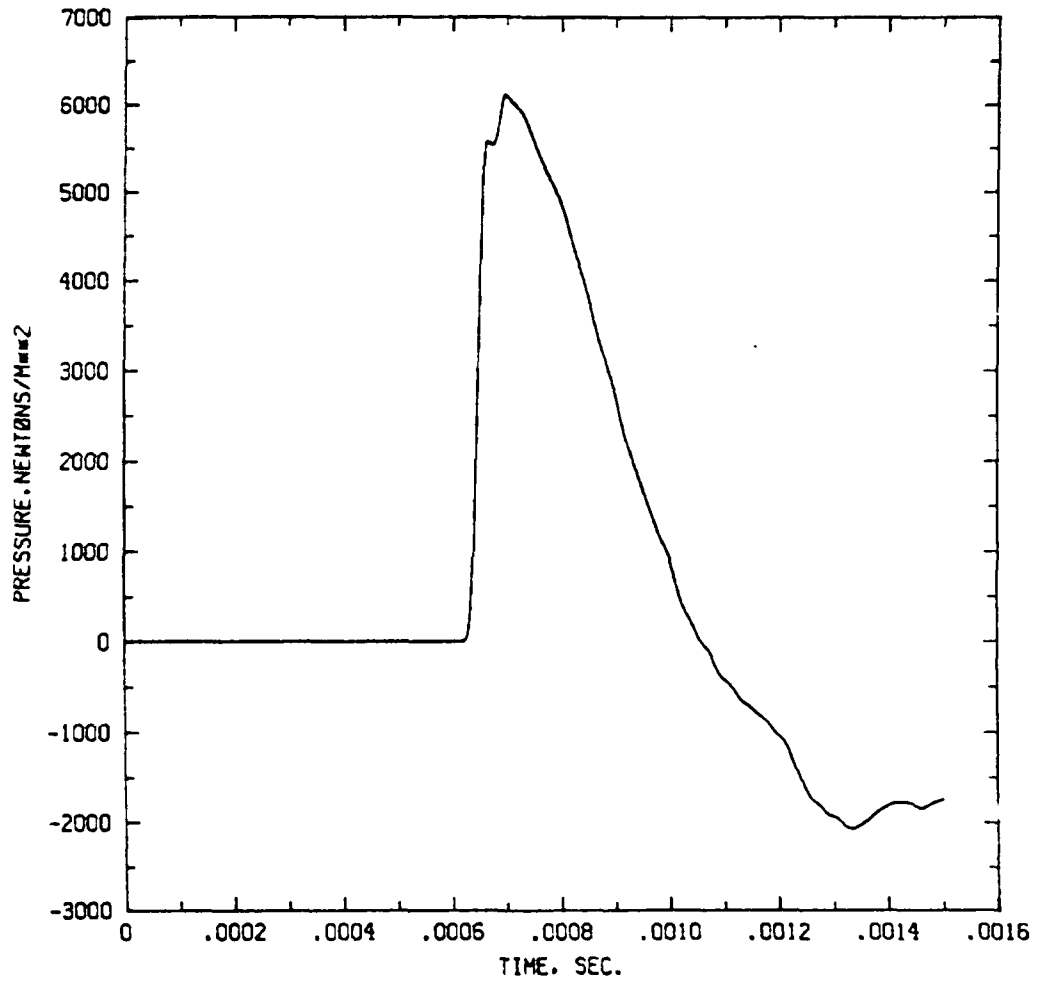


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB30008

Figure 13c

STATION 6. XS,YS= 0.175E+00 0.309E+00 M

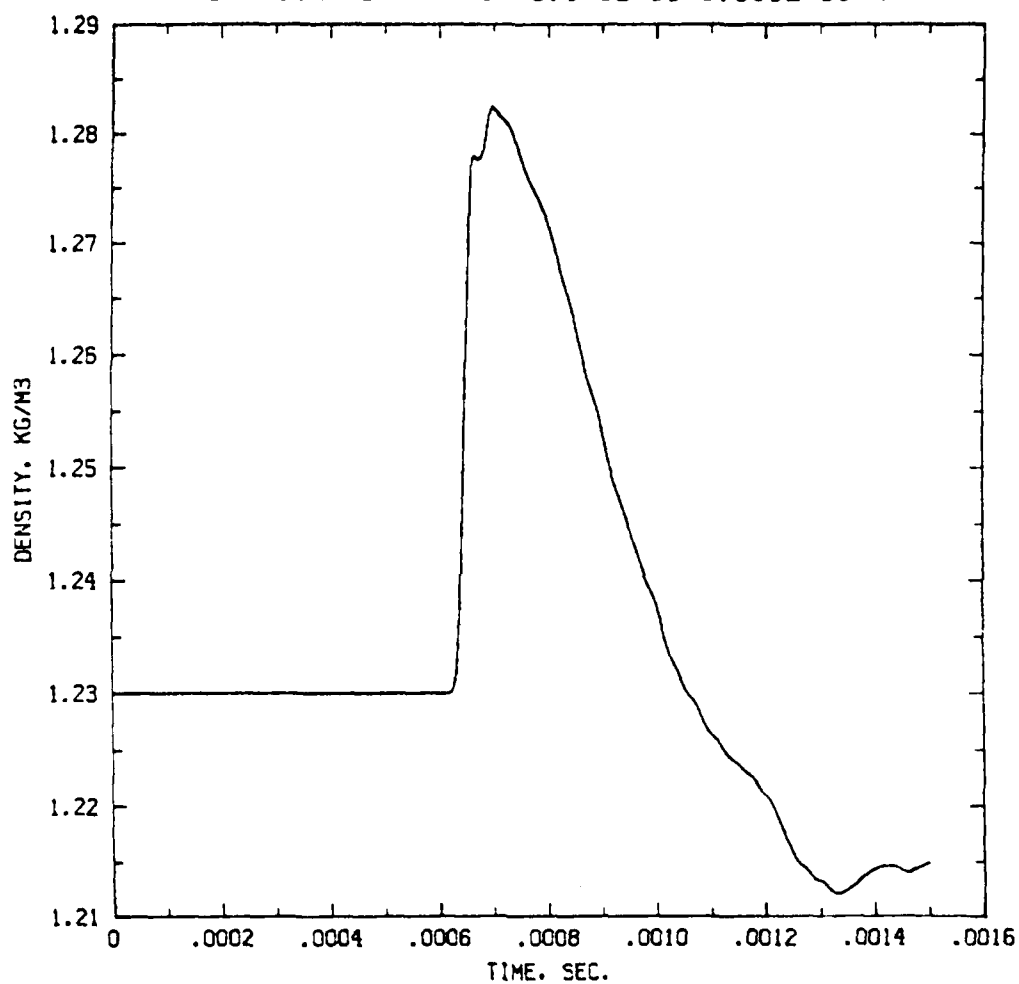


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB00008

Figure 14a

STATION 6. XS.YS= 0.175E+00 0.309E+00 M

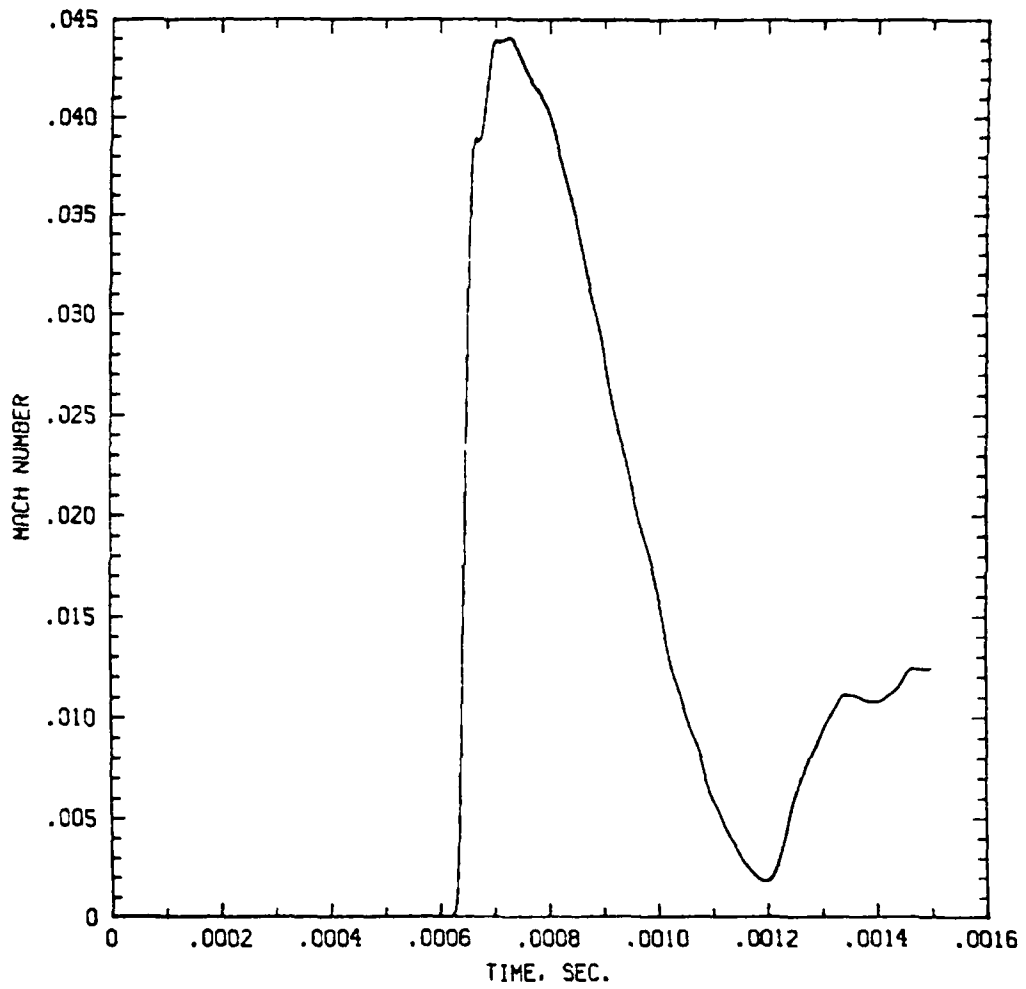


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TLAB0008

Figure 14b

STATION 6. XS.YS= 0.175E+00 0.309E+00 M

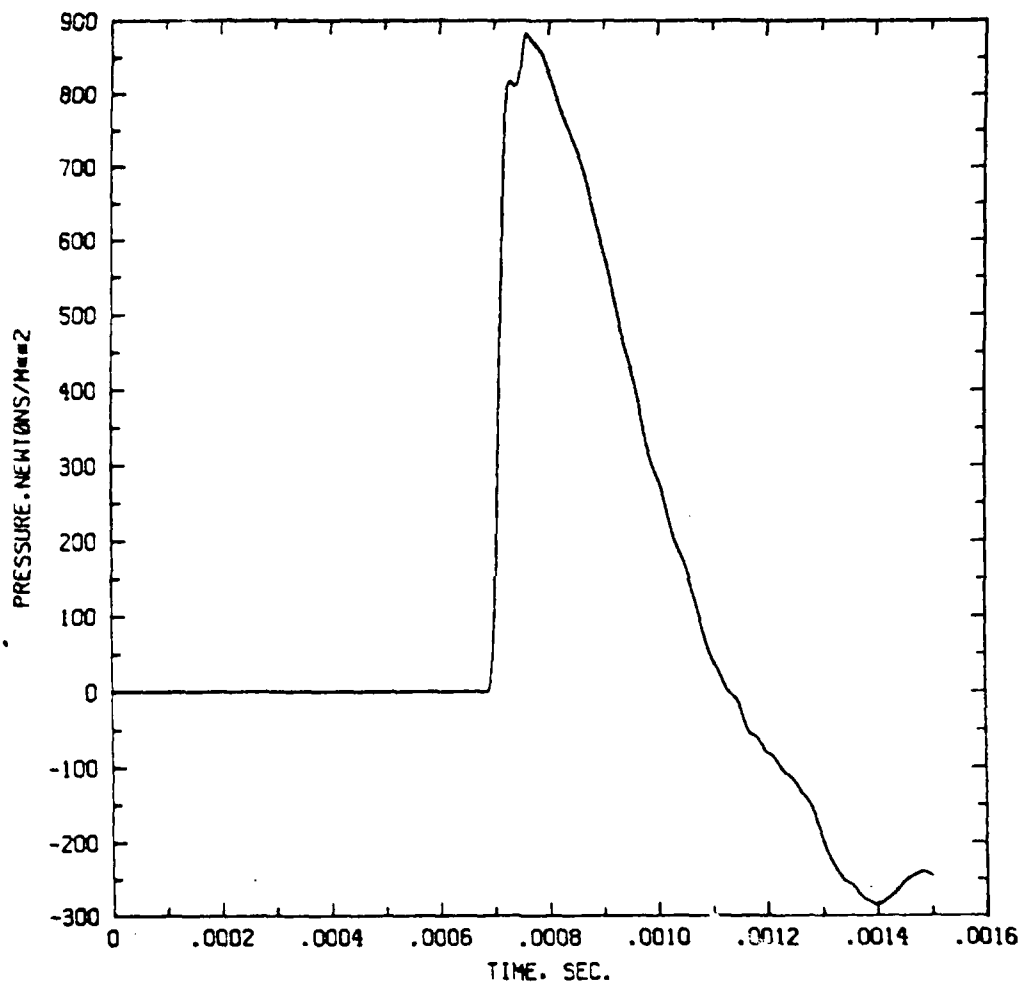


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB80008

Figure 14c

STATION 7. XS,YS= 0.152E+00 0.286E+00 M

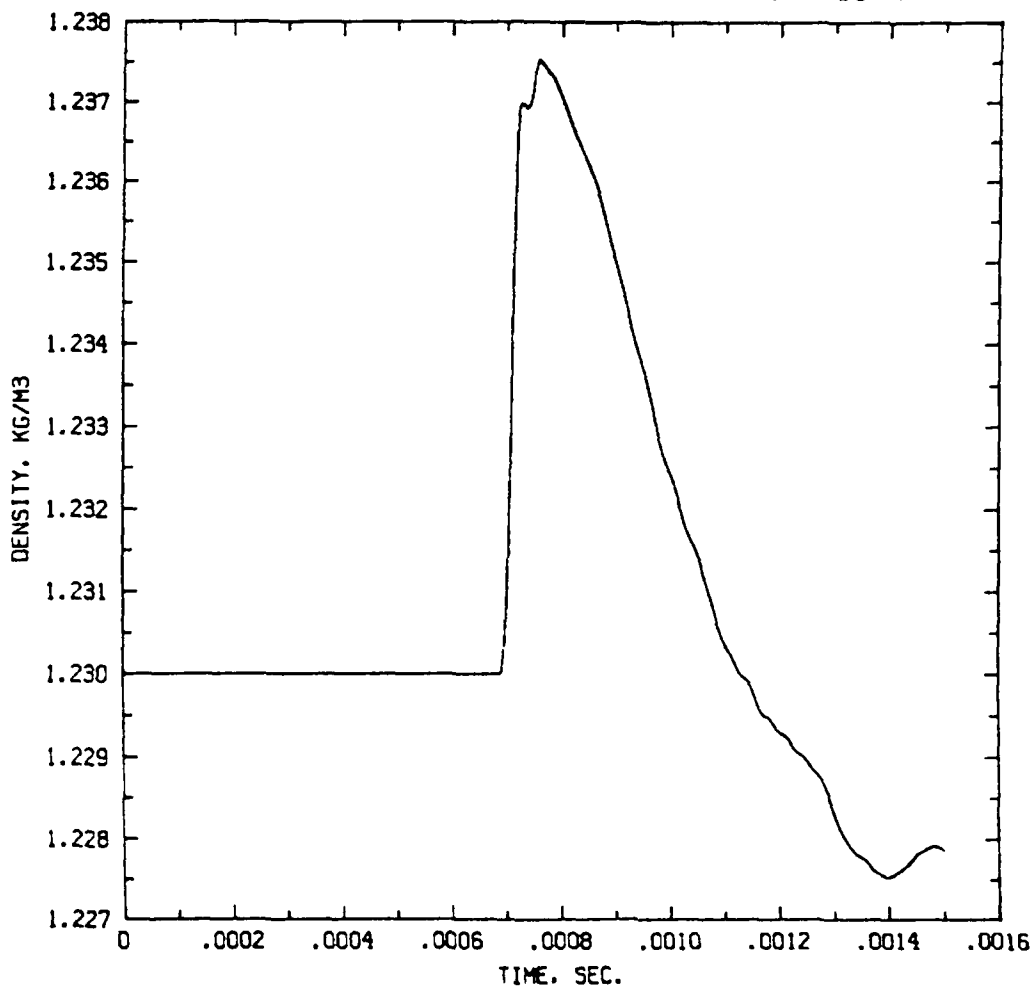


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUBS0008

Figure 15a

STATION 7. XS,YS= 0.152E+00 0.286E+00 M

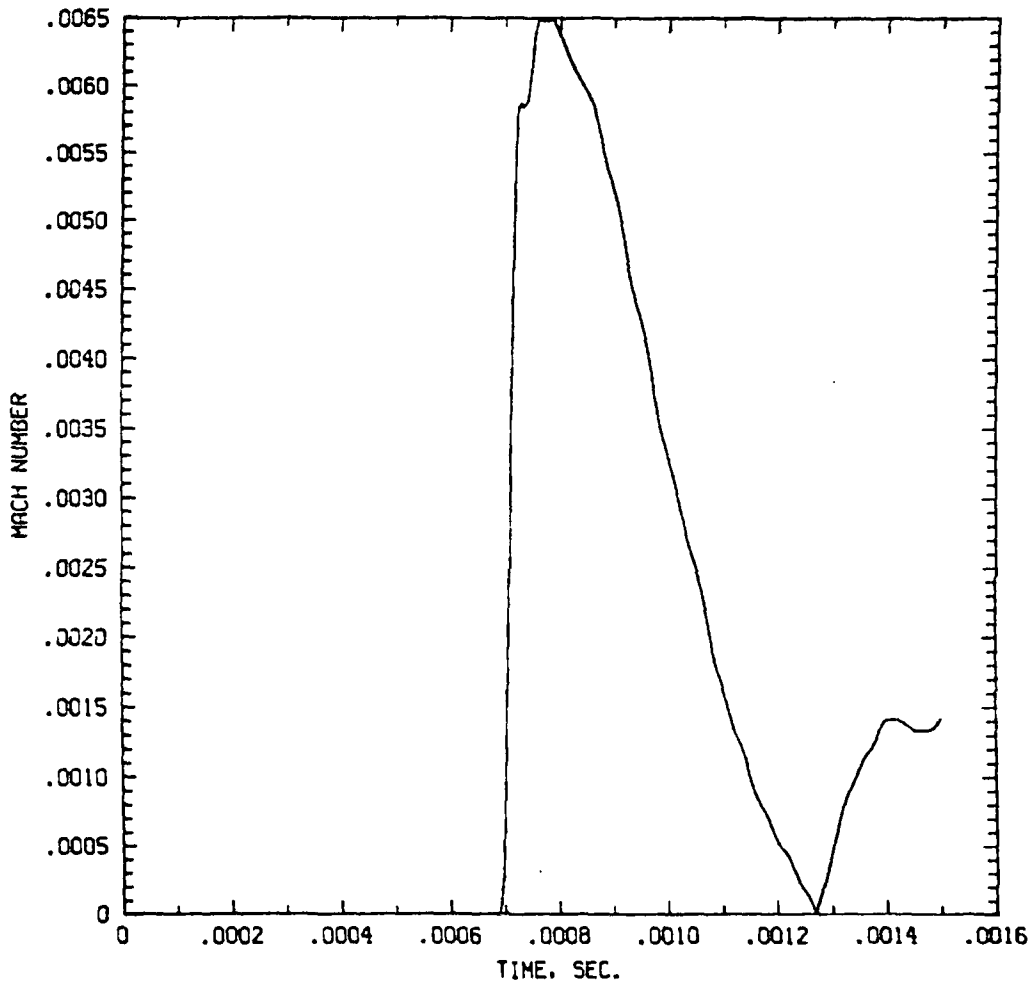


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUBS0008

Figure 15b

STATION 7, XS,YS= 0.152E+00 0.286E+00 M

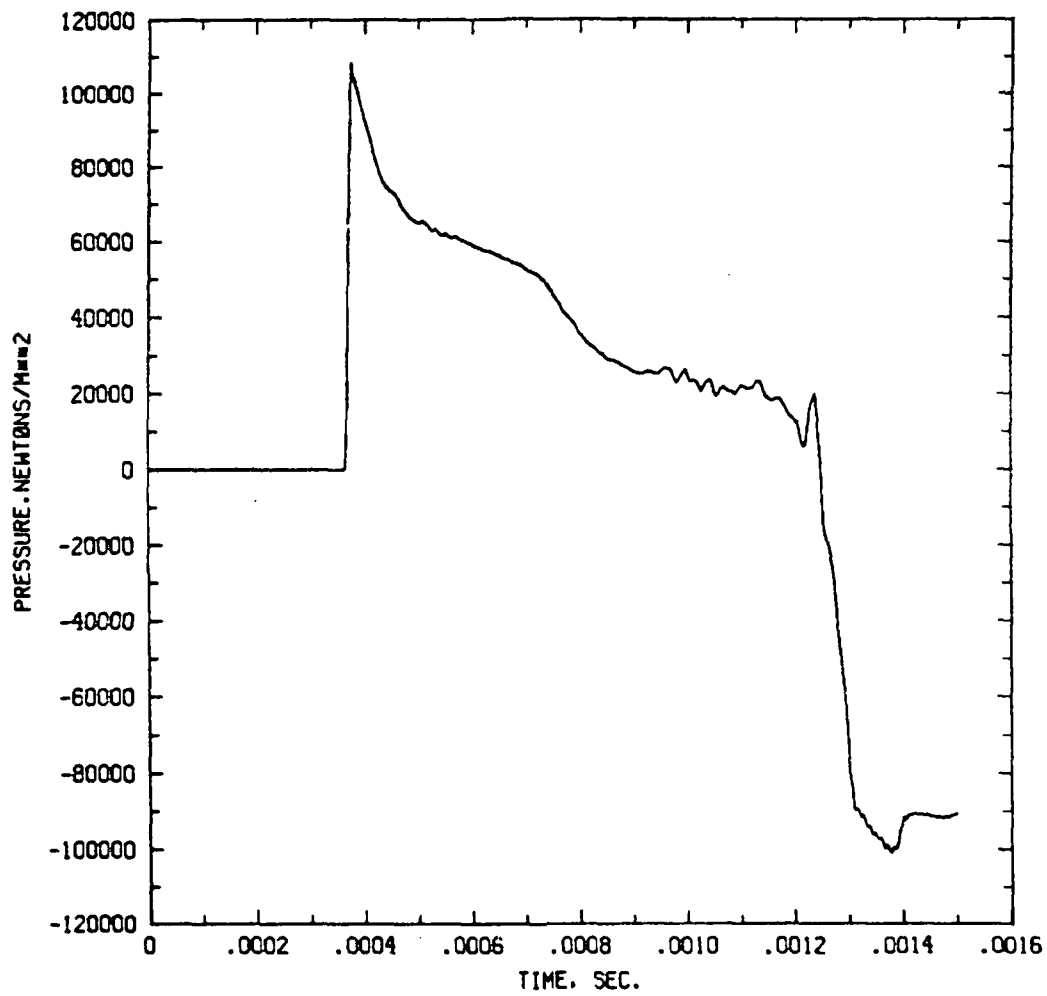


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB00008

Figure 15c

STATION 10, XS,YS= 0.115E-02 0.667E+00 M

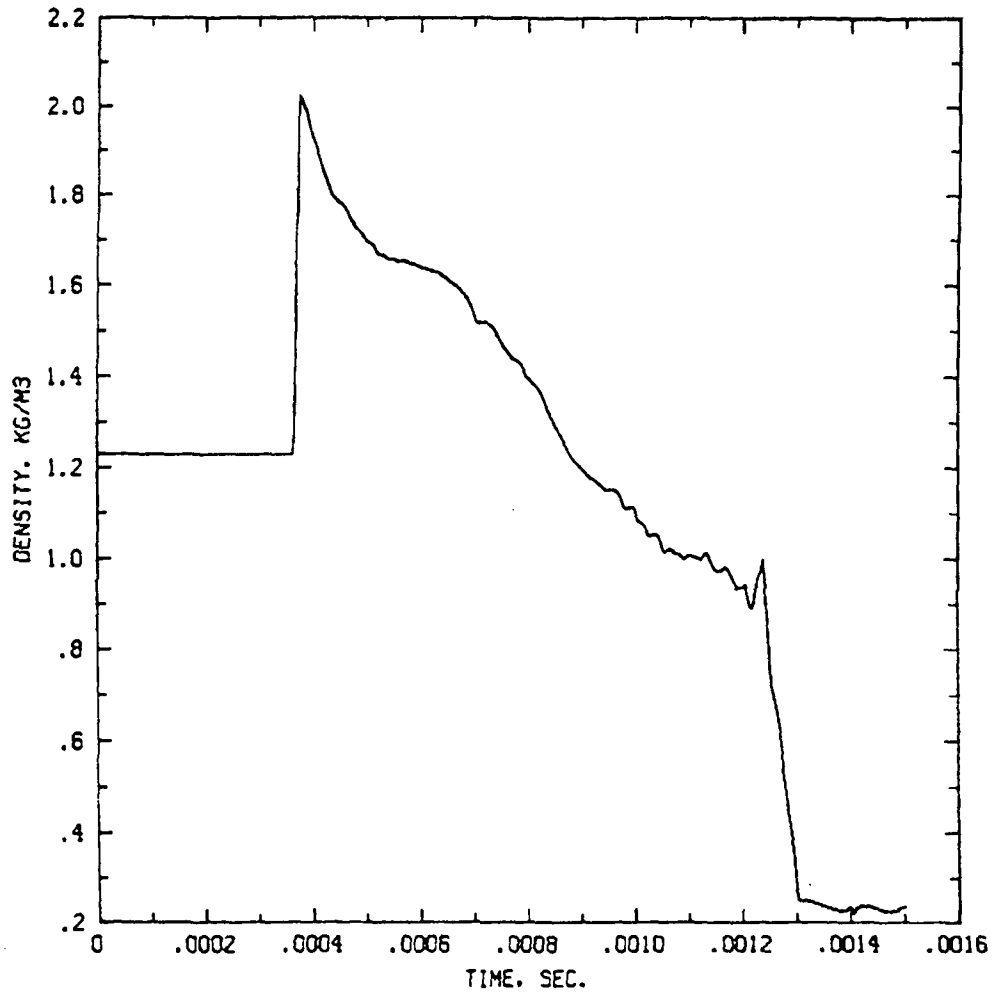


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB30008

Figure 16a

STATION 10, XS.YS= 0.115E-02 0.667E+00 M

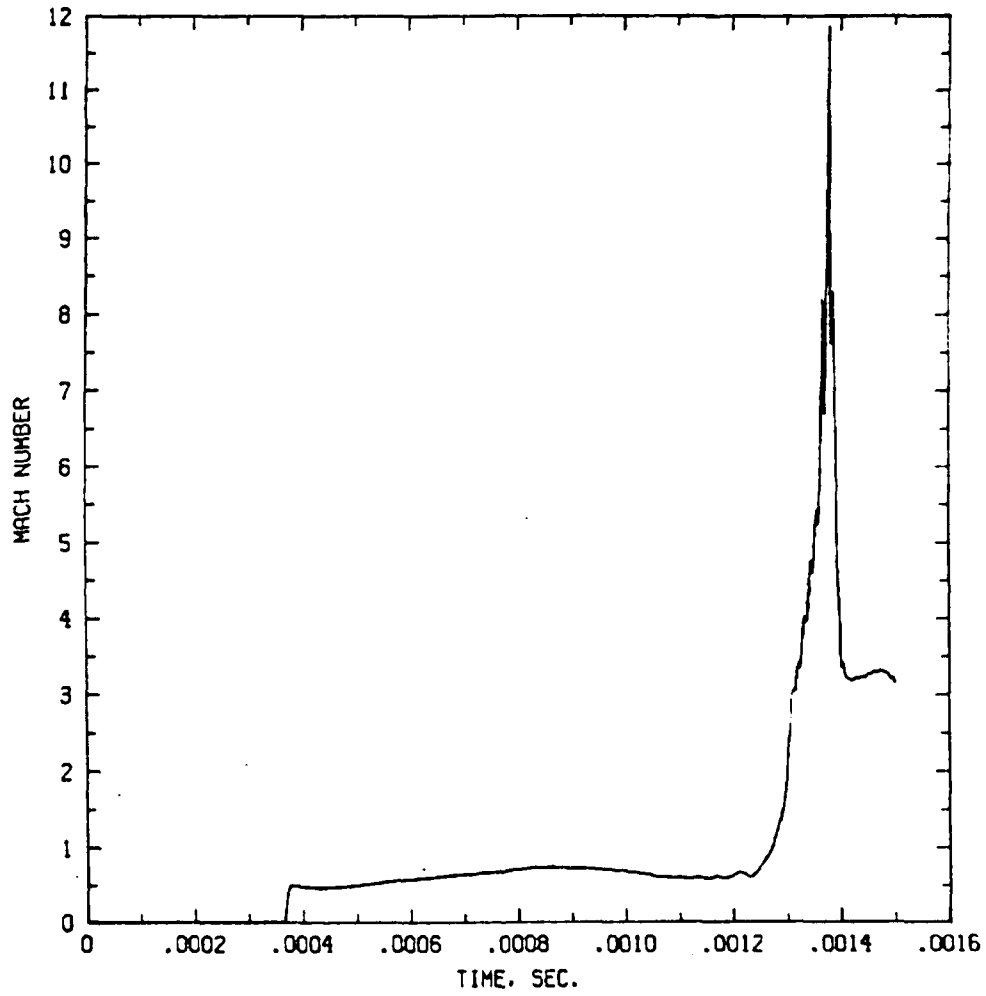


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB80008

Figure 16b

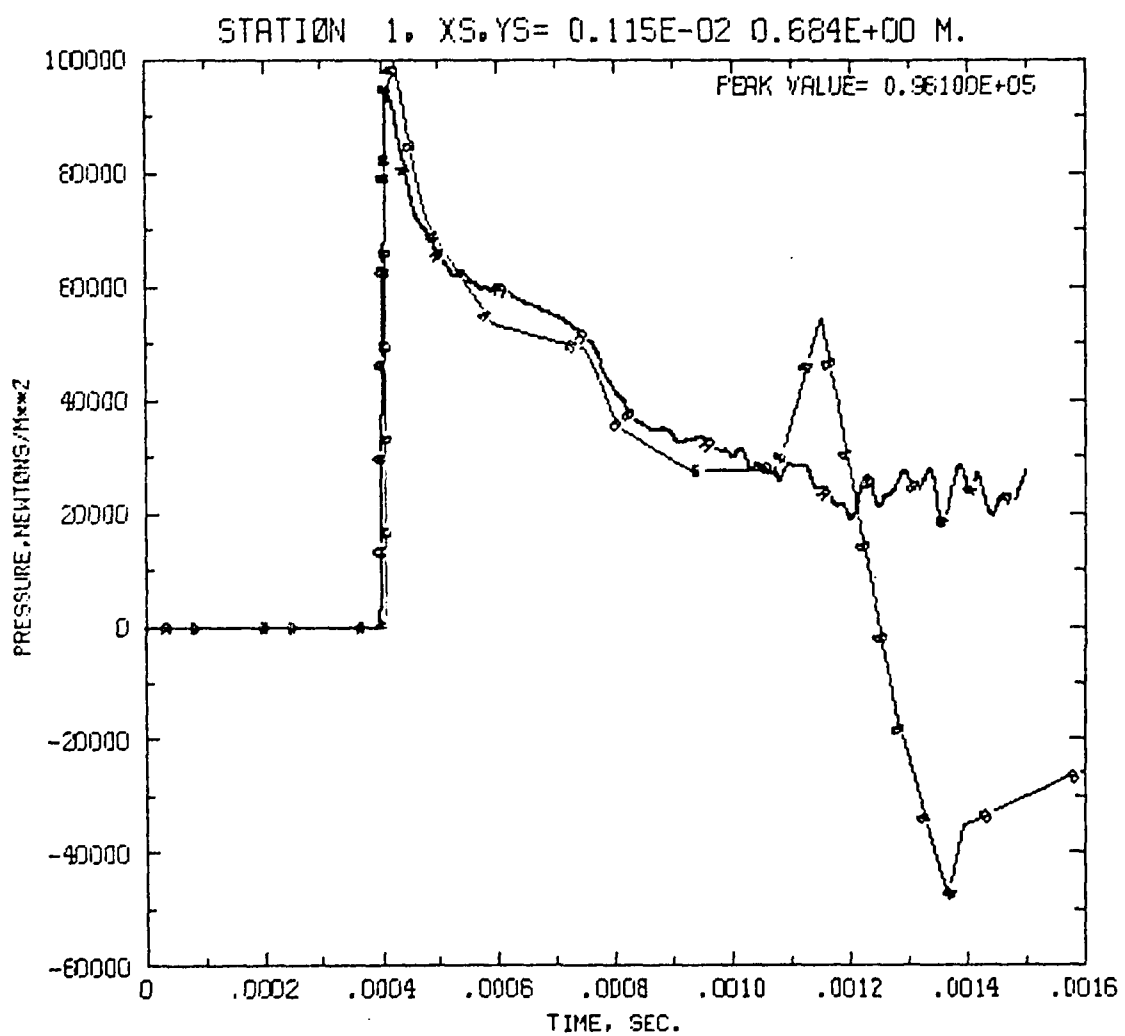
STATION 10, XS,YS= 0.115E-02 0.667E+00 M



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS. LAST DUMP IS TUB80008

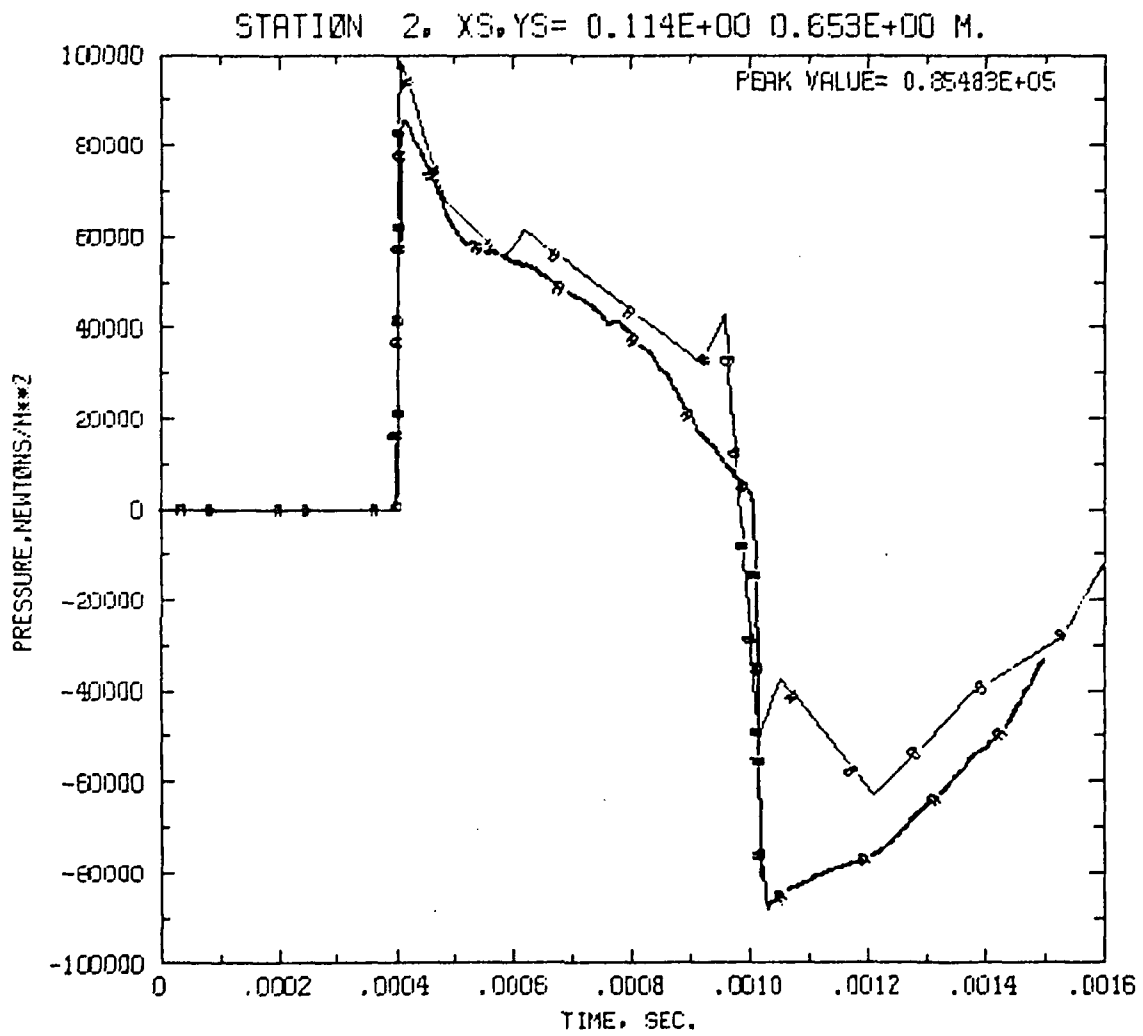
Figure 16c



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBB0008

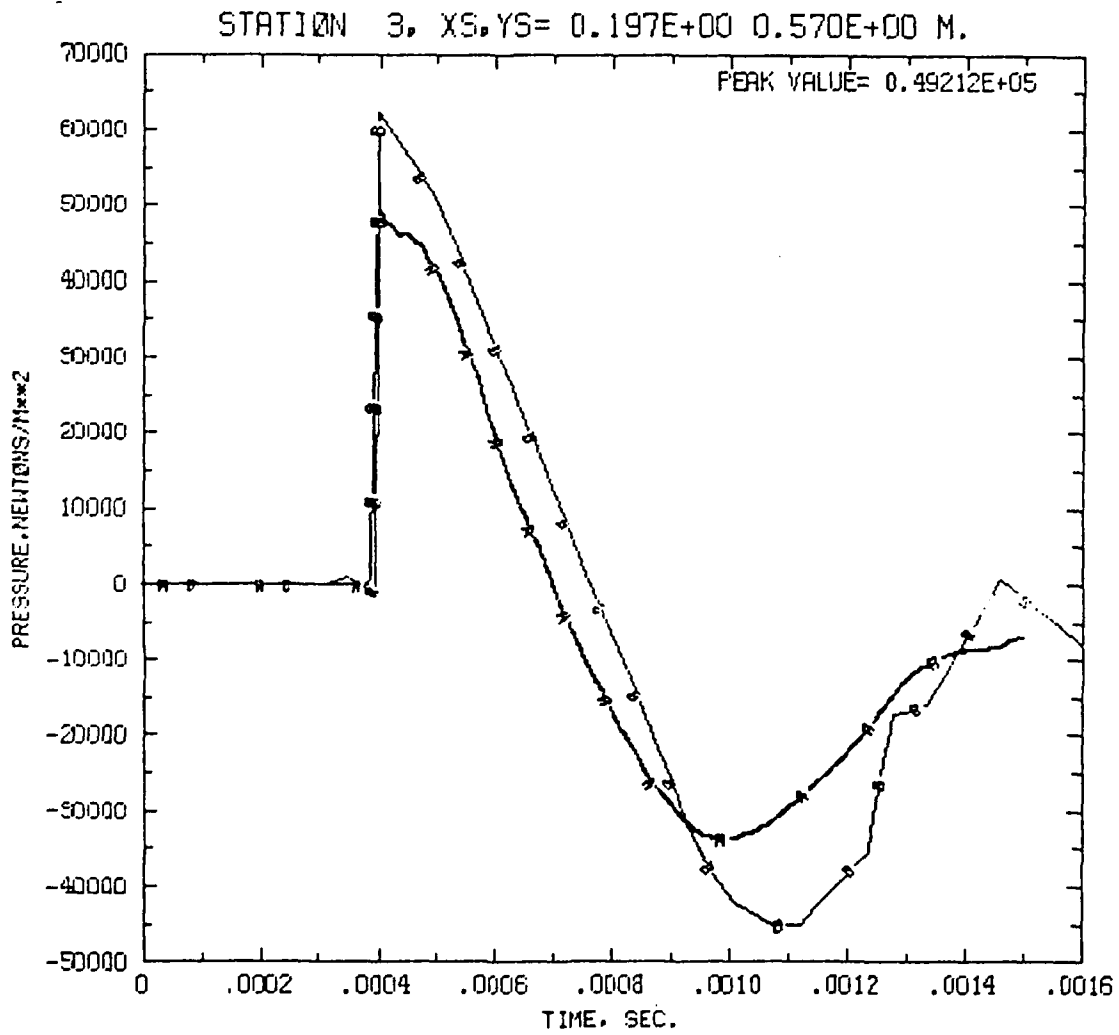
Figure 17



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBB0008

Figure 18

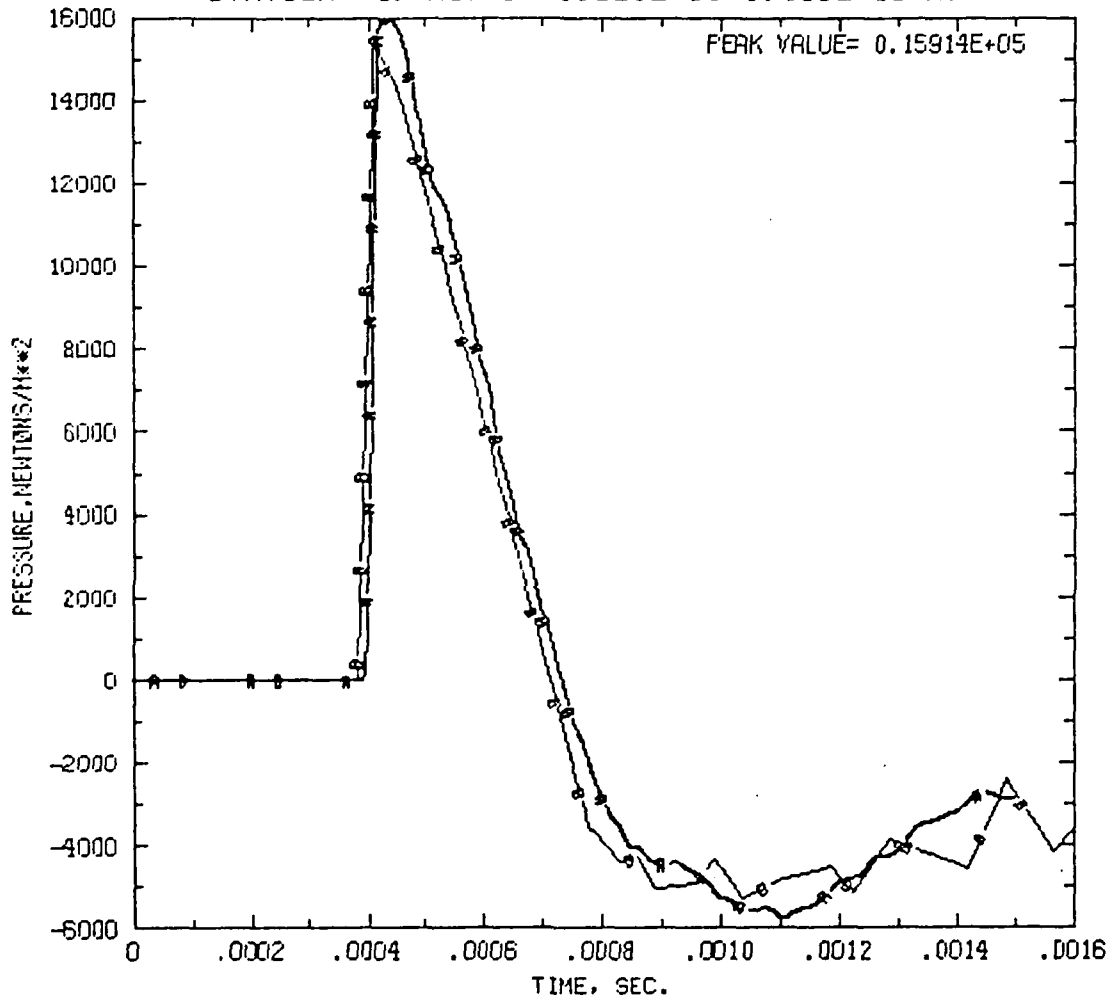


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUB00008

Figure 19

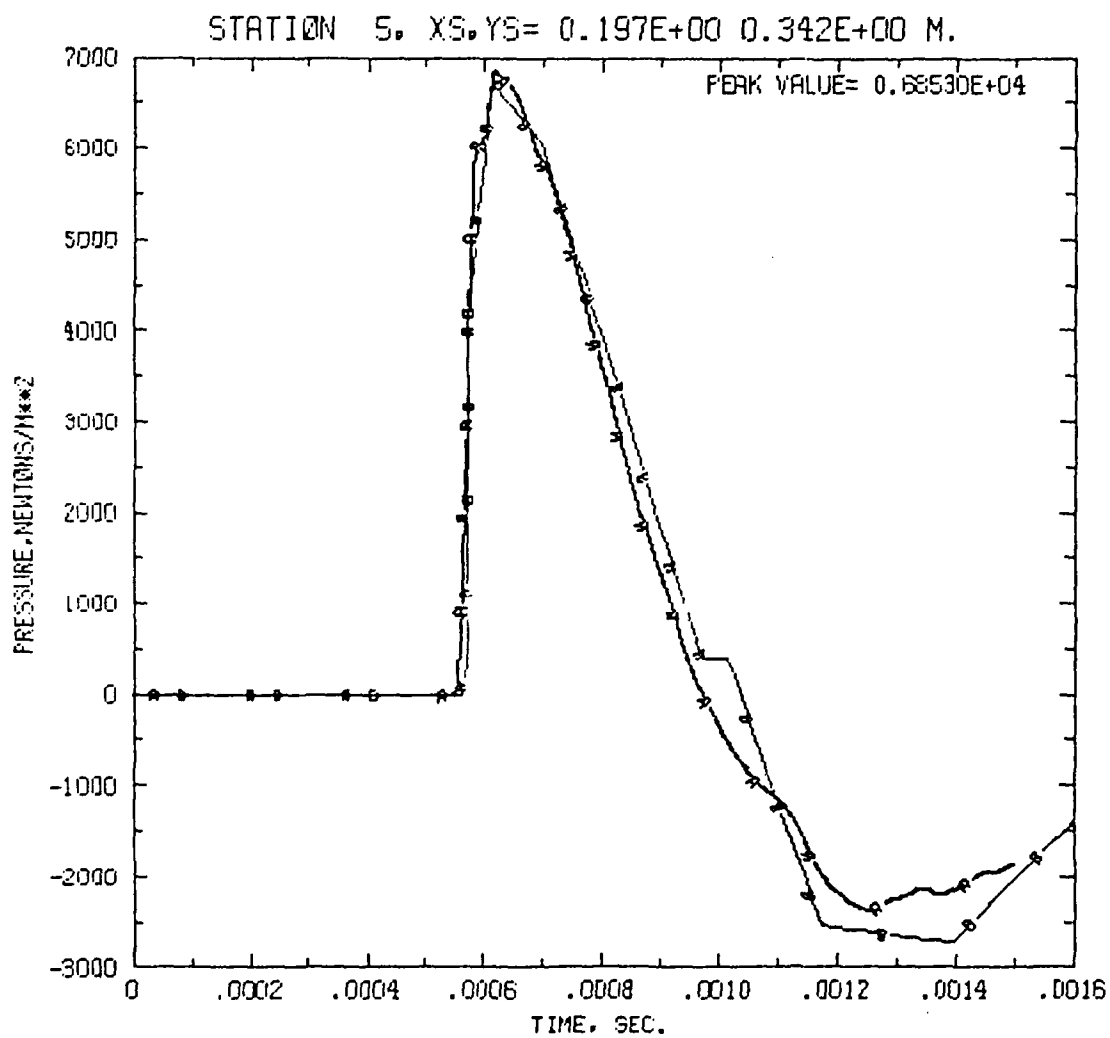
STATION 4. XS,YS= 0.228E+00 0.456E+00 M.



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBE0008

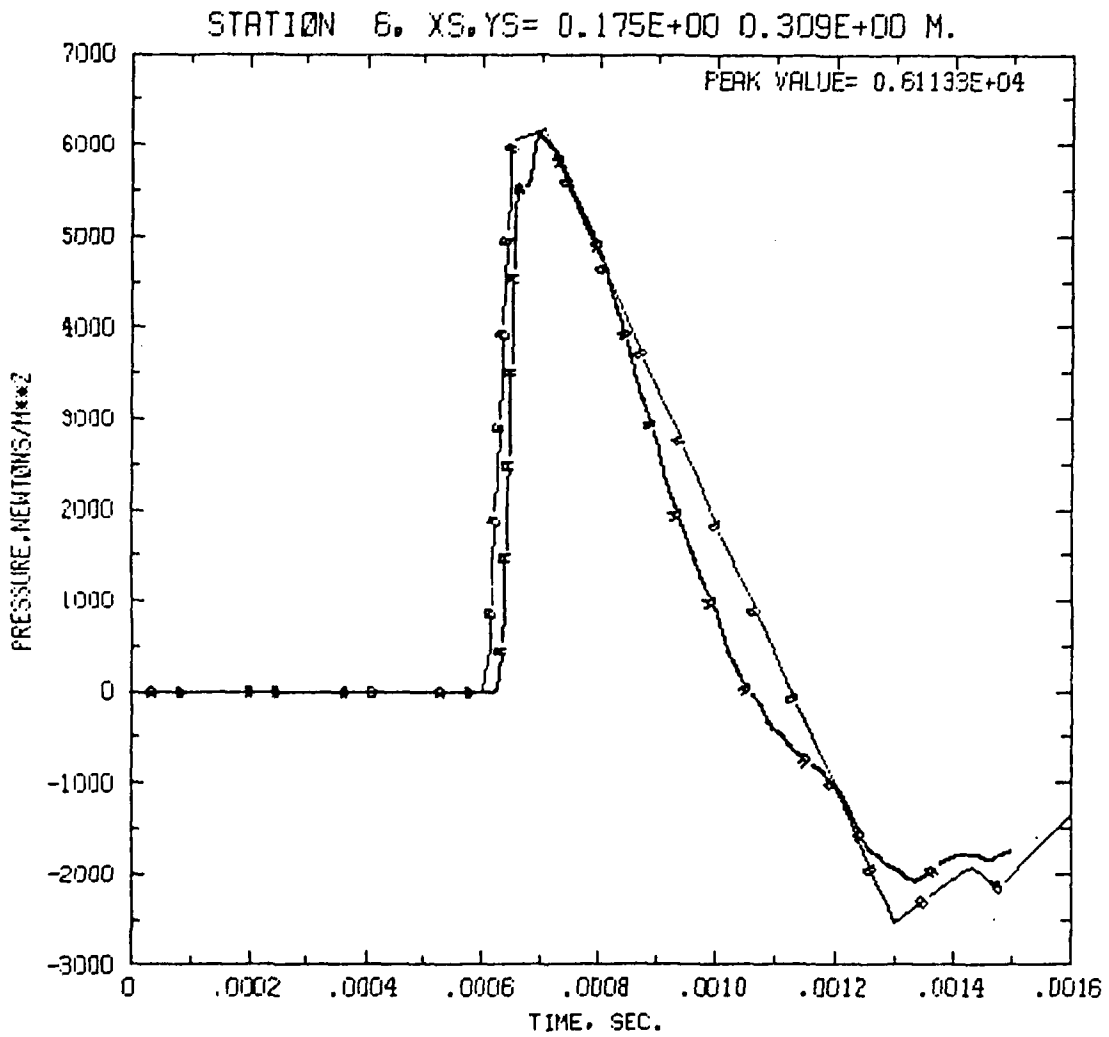
Figure 20



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP 13 TUBEC008

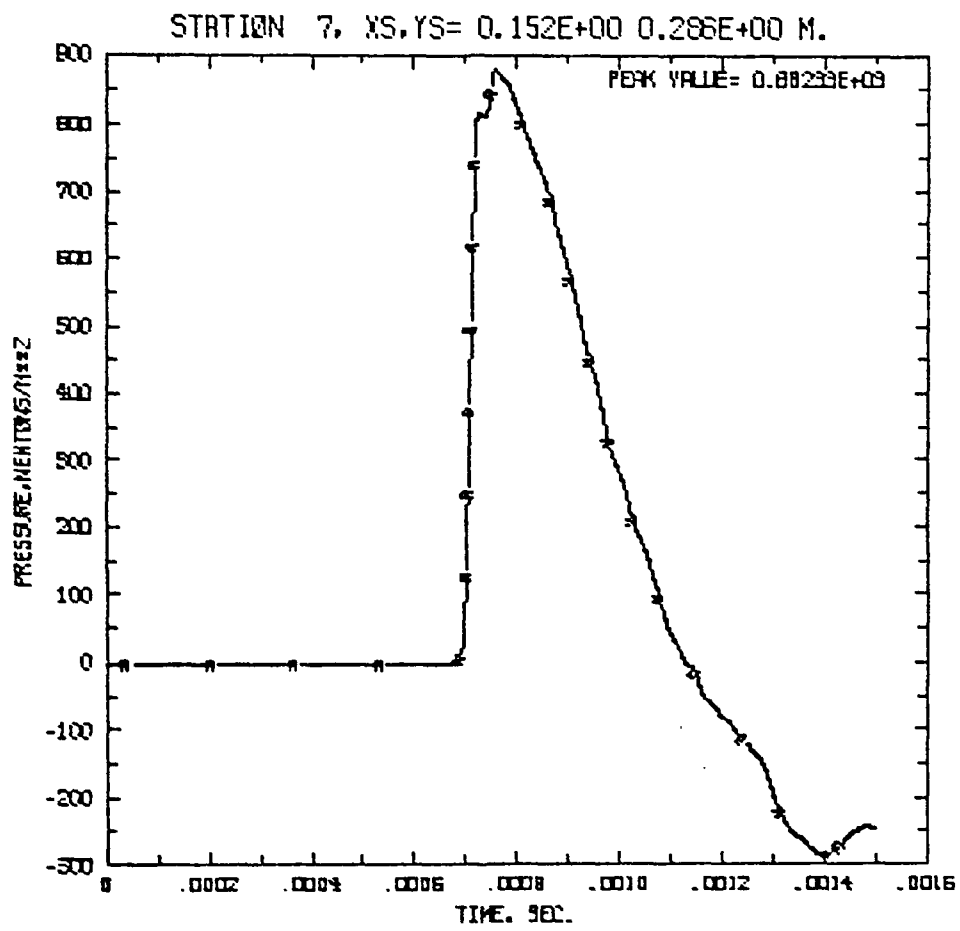
Figure 21



BLAST DIFFRACTION FROM SHOCK TUBE

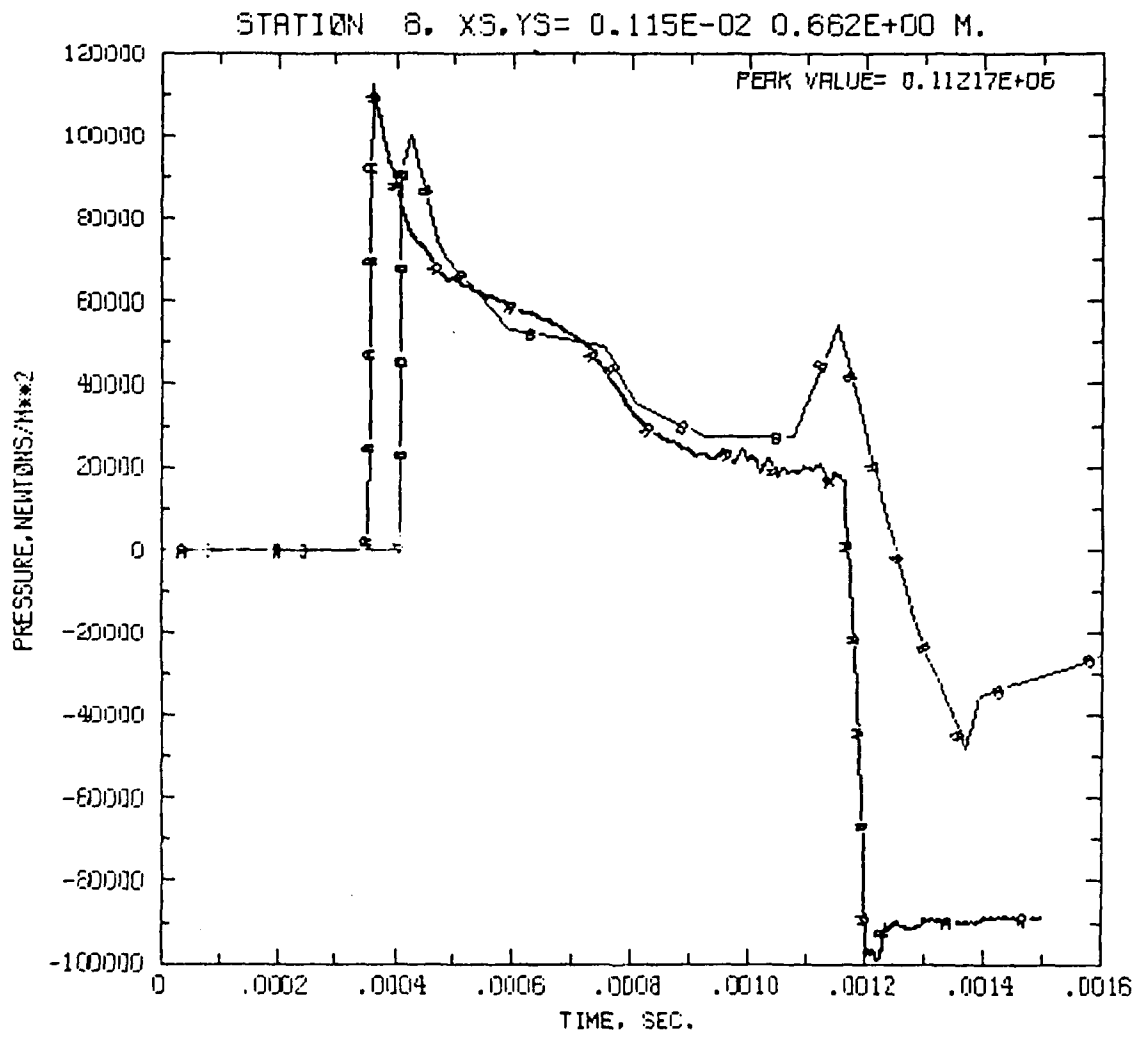
7 DUMPS, LAST DUMP IS TUBB0003

Figure 22

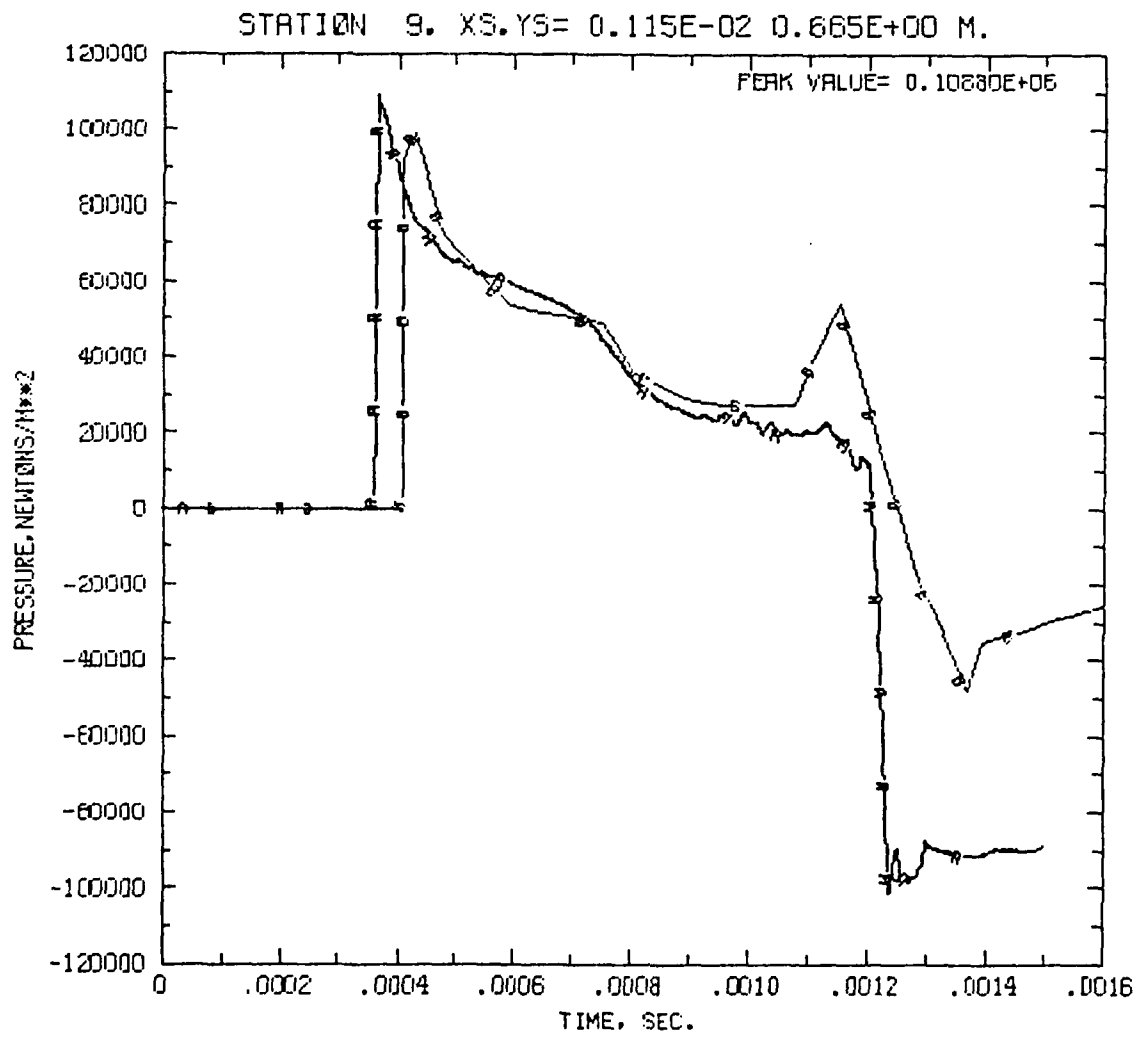


BLAST DIFFRACTION FROM SHOCK TUBE  
 7 DUMPS. LAST DUMP IS TUB00000

Figure 23



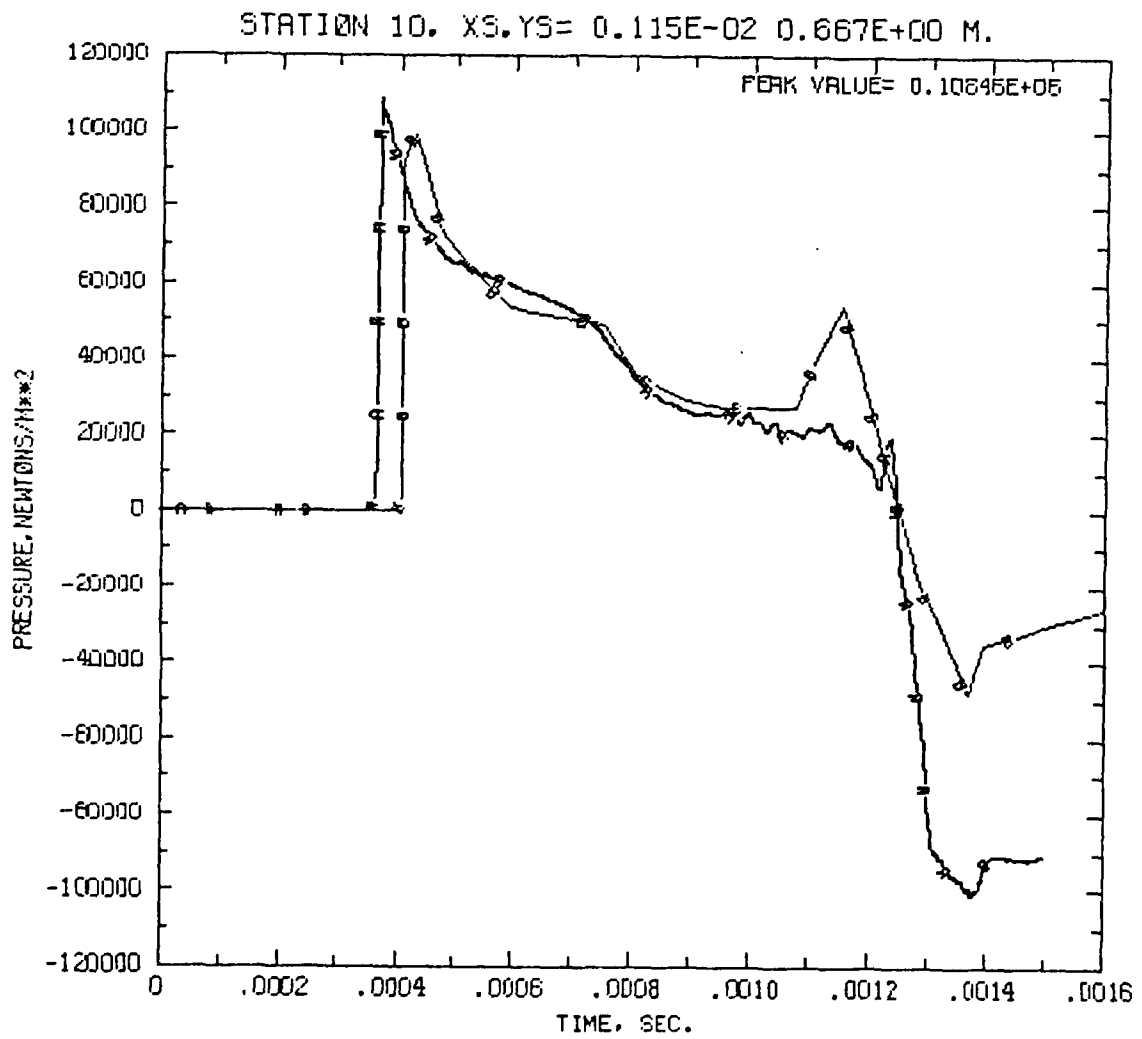
BLAST DIFFRACTION FROM SHOCK TUBE  
 7 DUMPS, LAST DUMP IS TUBE0003  
 Figure 24



ELAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBEG008

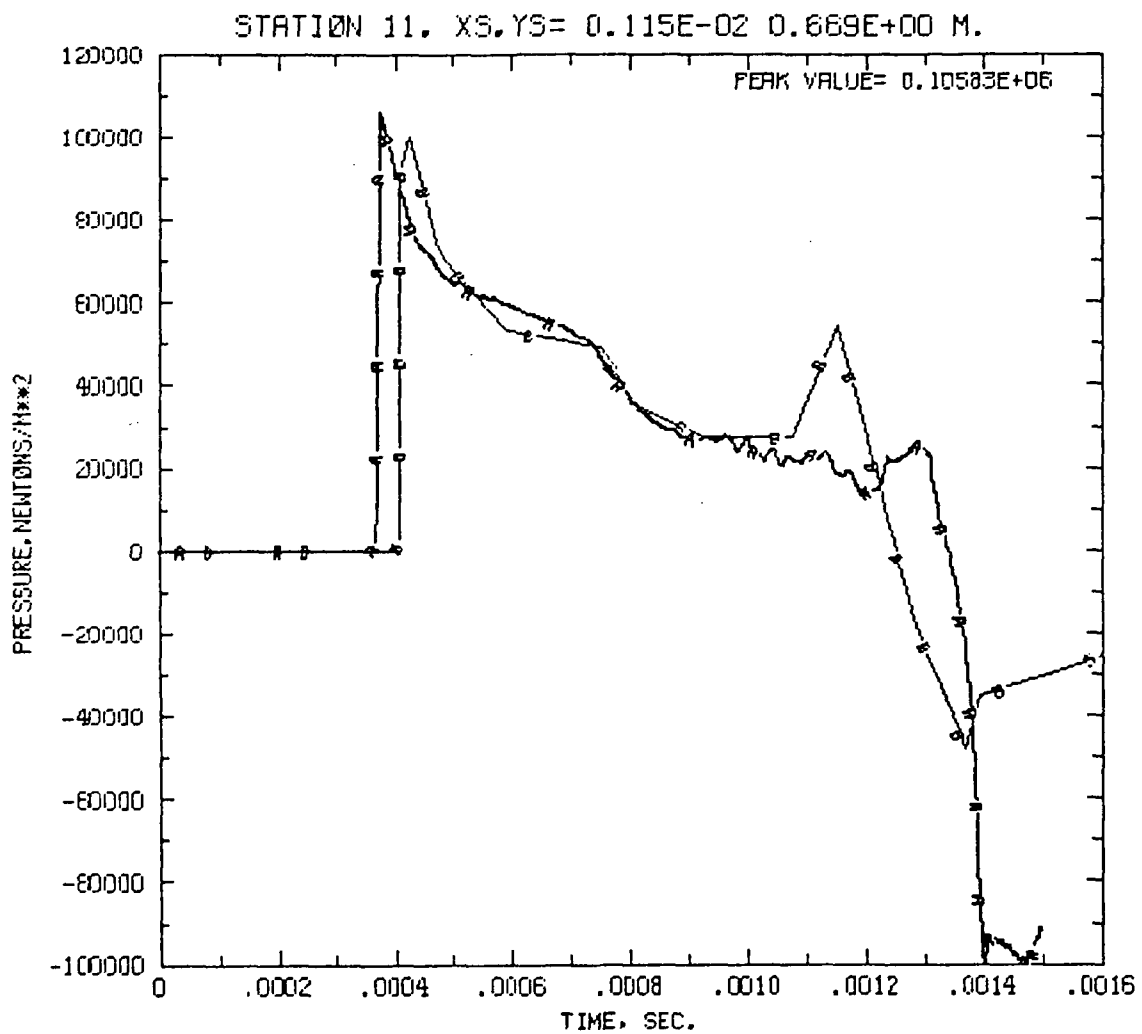
Figure 25



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBE0003

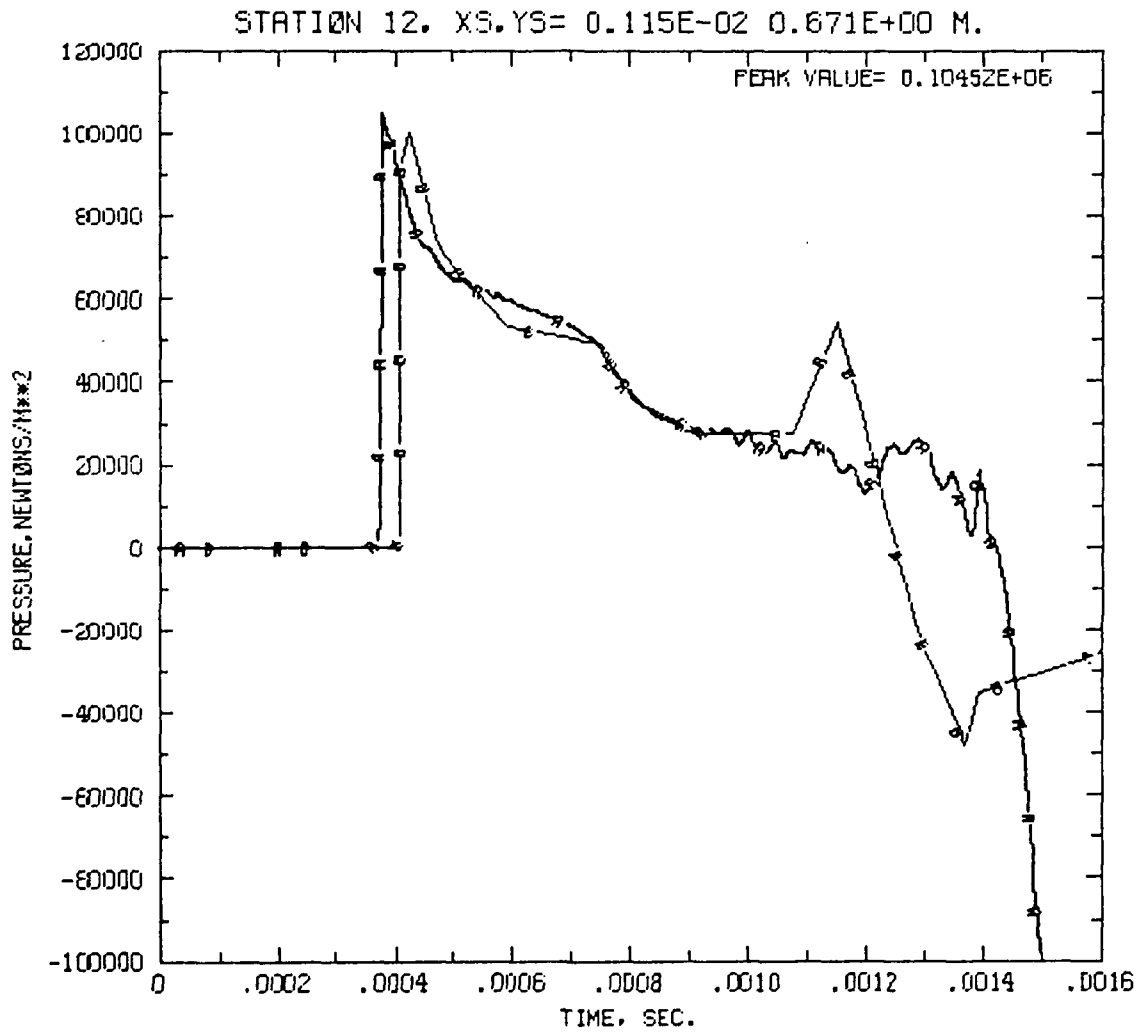
Figure 26



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBB0008

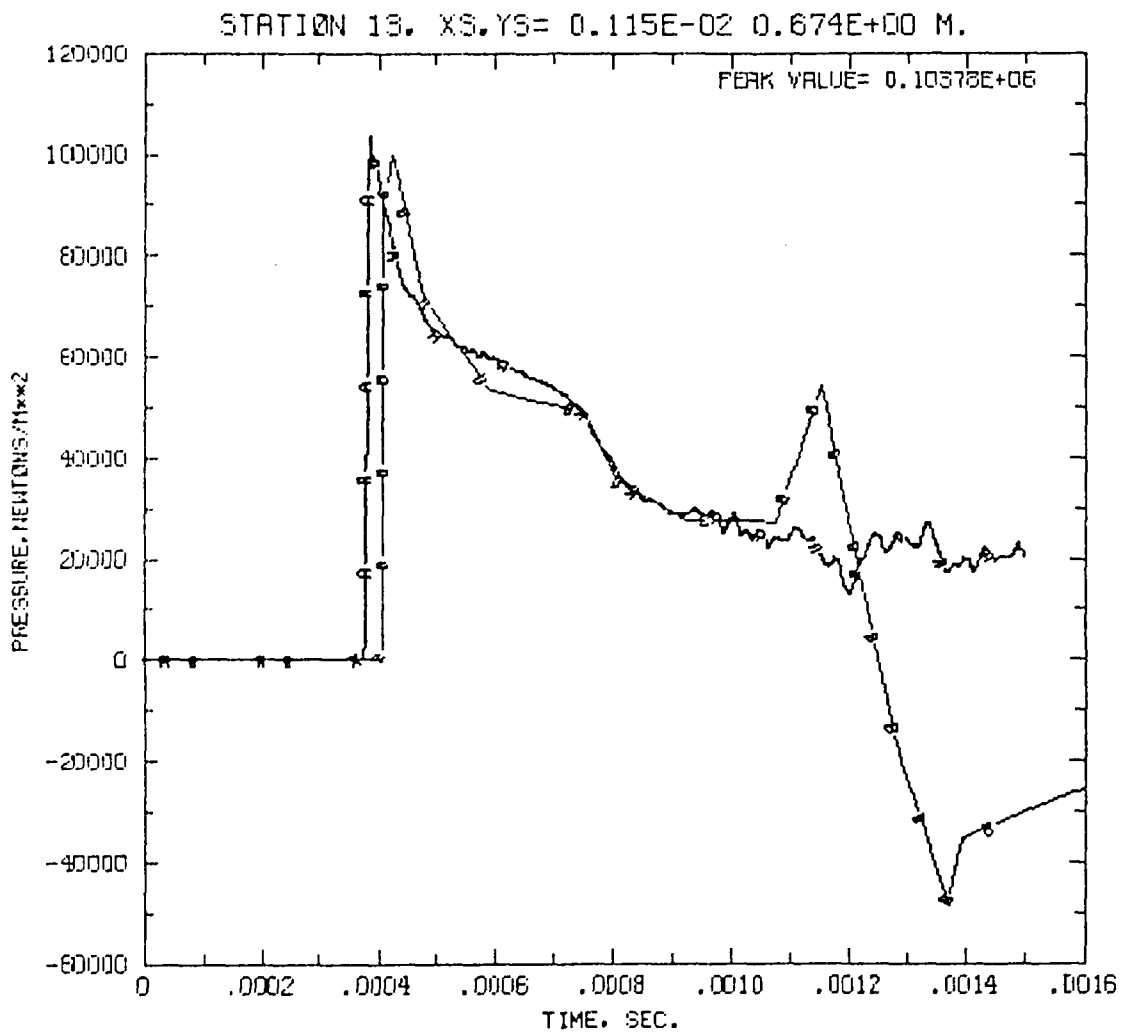
Figure 27



BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBE0008

Figure 28

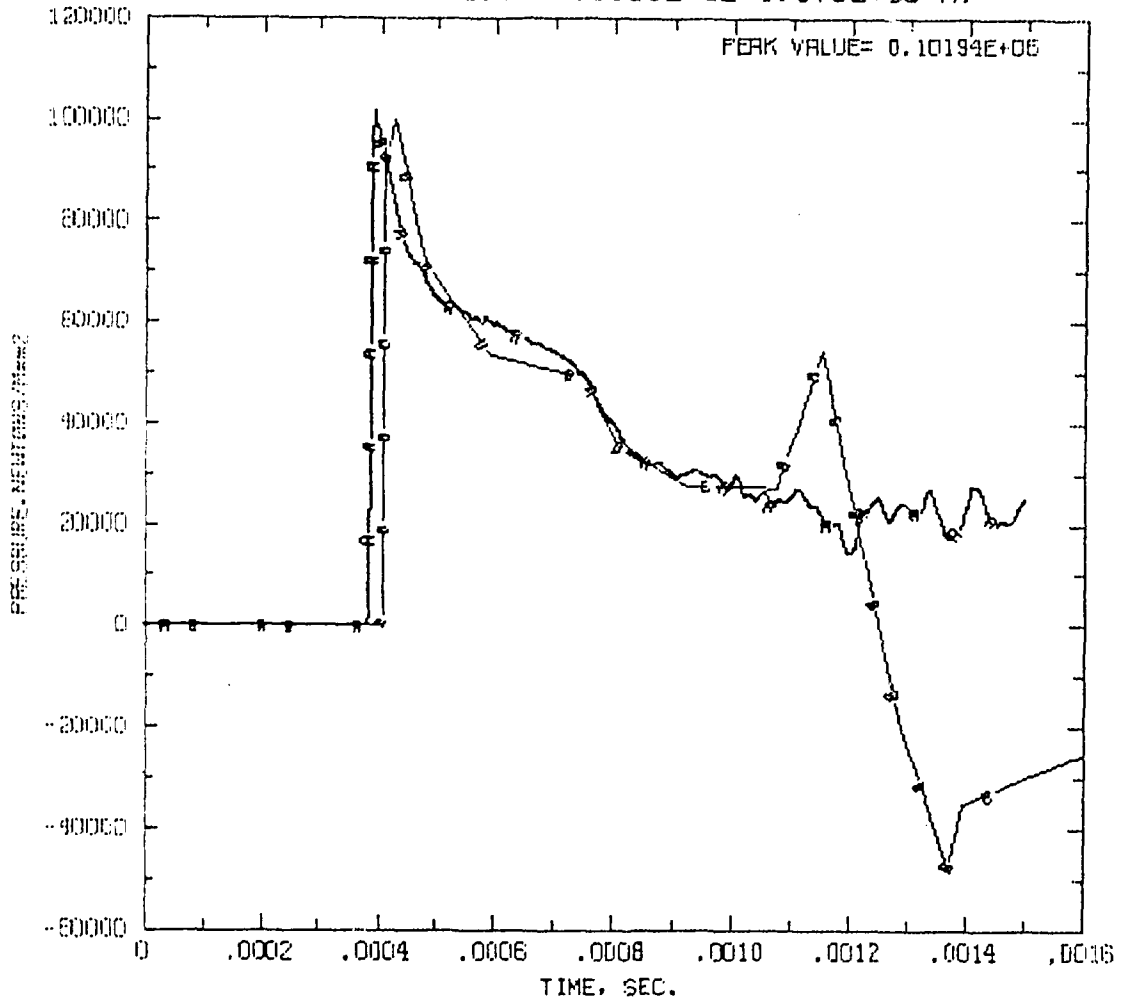


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBE0008

Figure 29

STATION 14, XS,YS= 0.115E-02 0.676E+00 M.

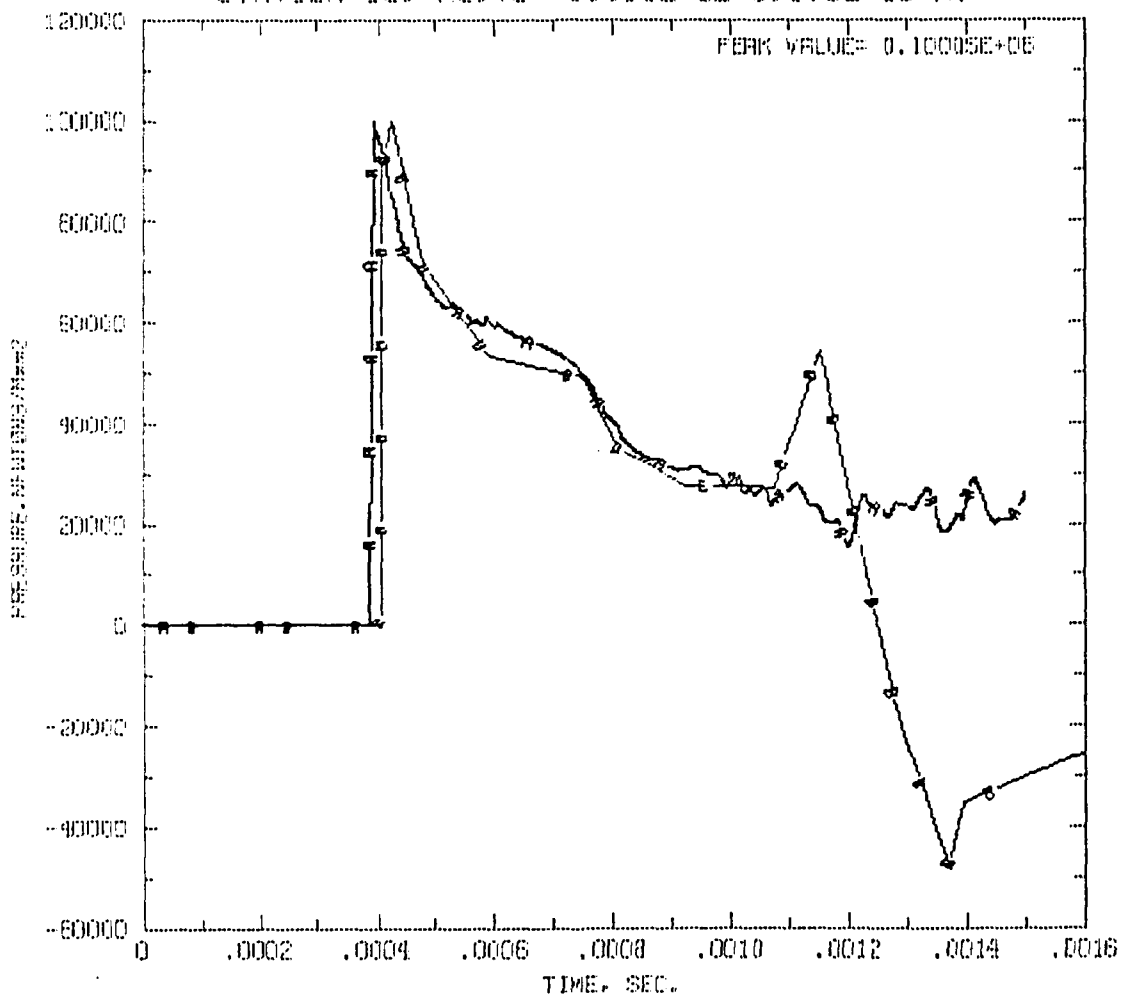


BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBB0003

Figure 30

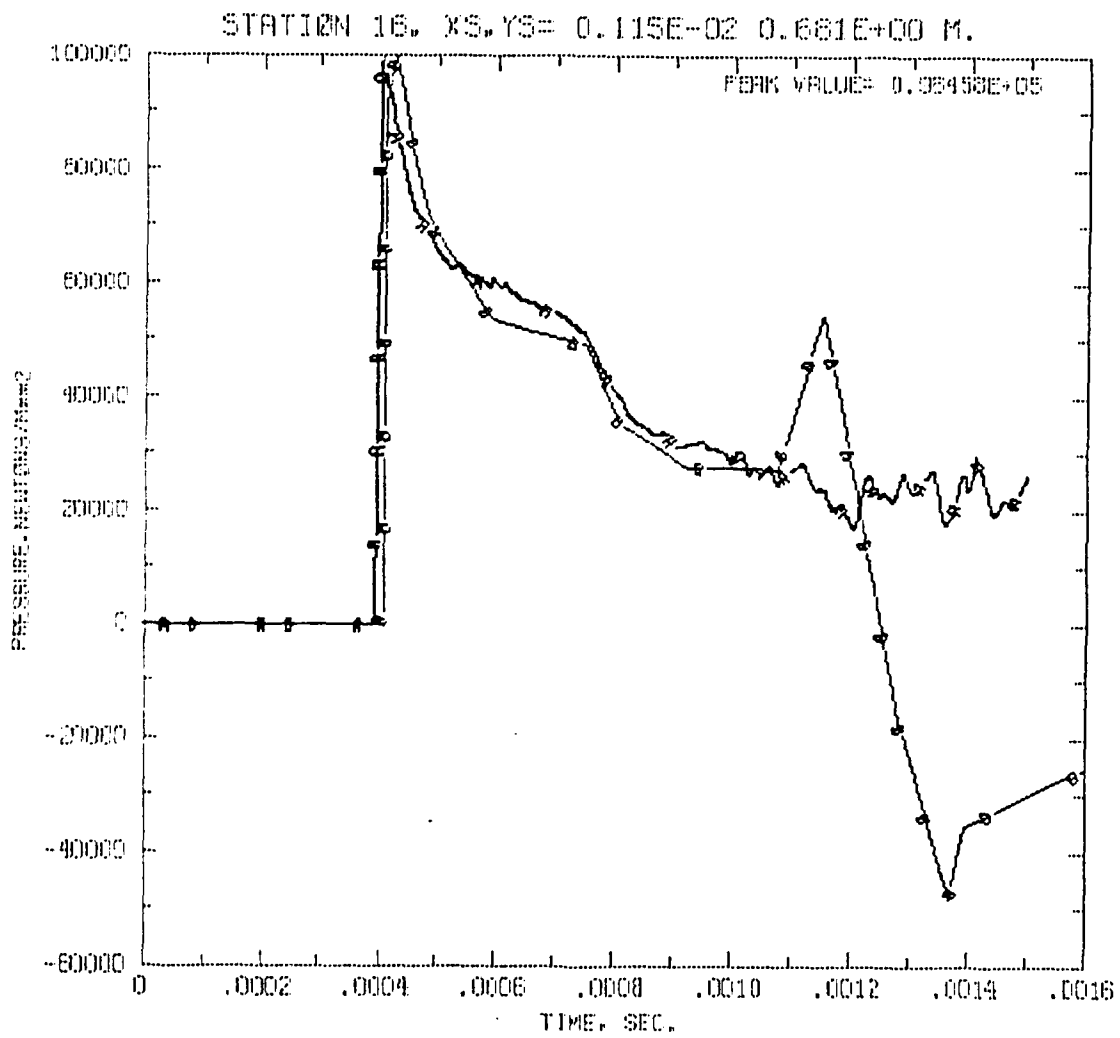
STATION 15. XS,YS= 0.115E-02 0.678E+00 M.



ELAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBB0008

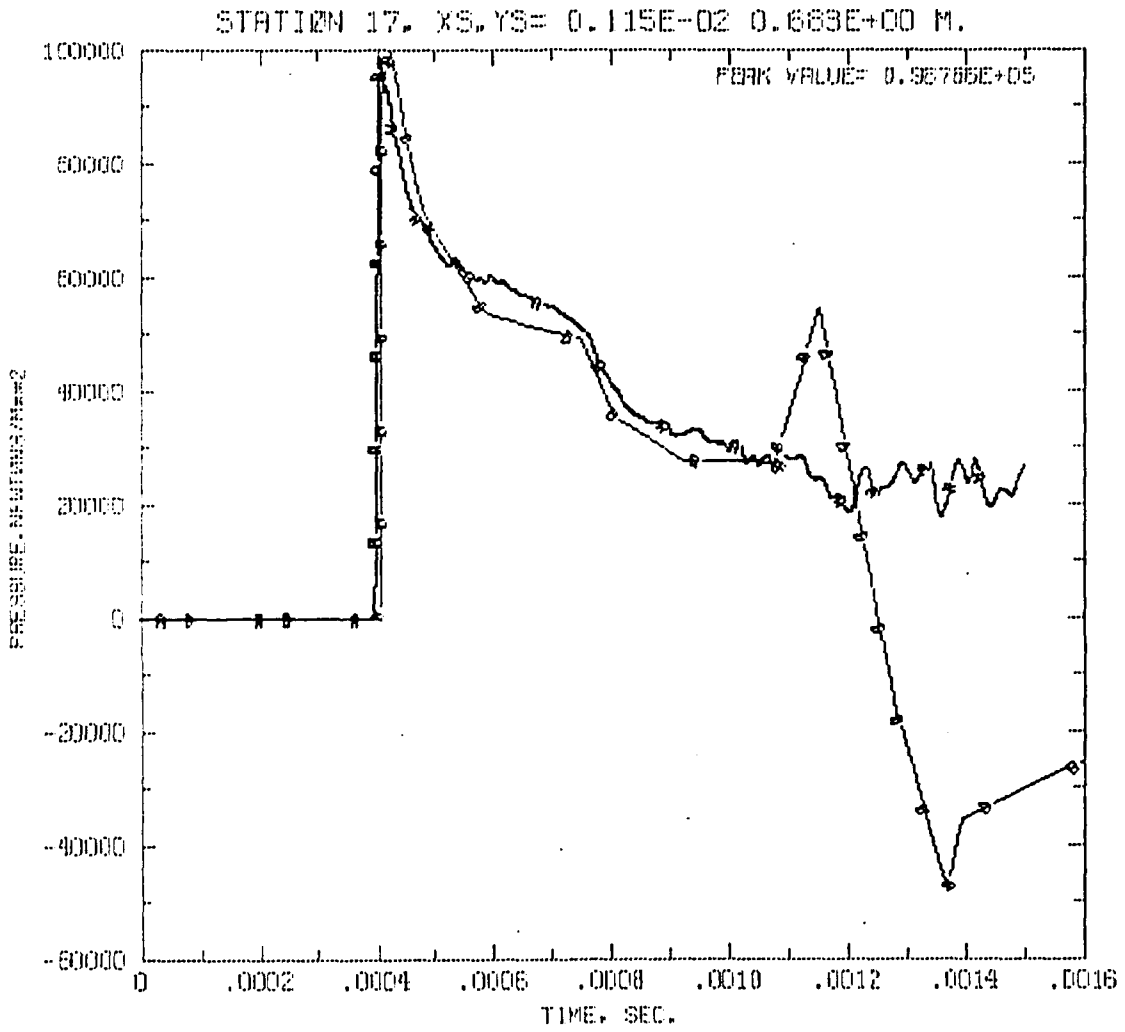
Figure 31



ELAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBE0008

Figure 32



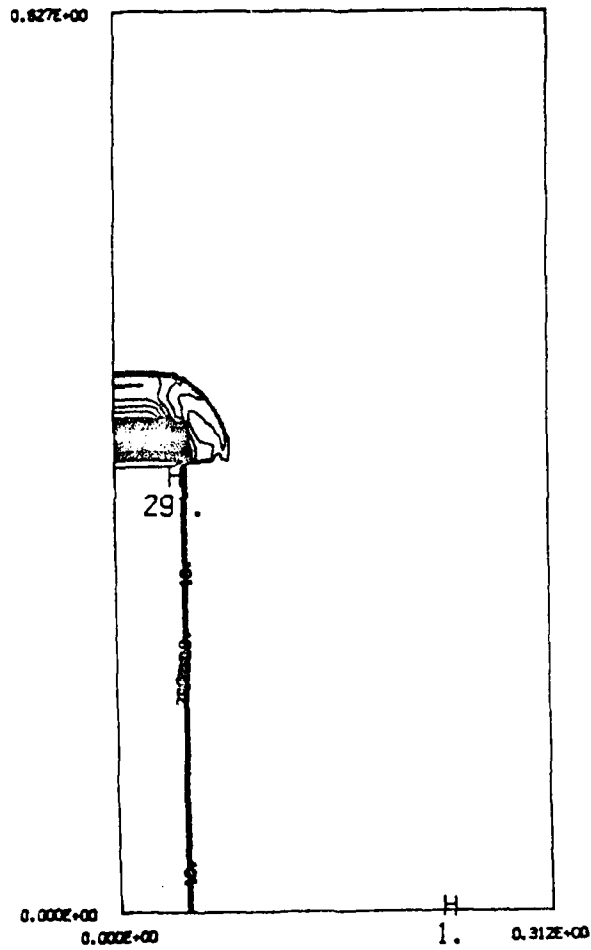
BLAST DIFFRACTION FROM SHOCK TUBE

7 DUMPS, LAST DUMP IS TUBB0000

Figure 33

105 MM HOWITZER MUZZLE FLOW

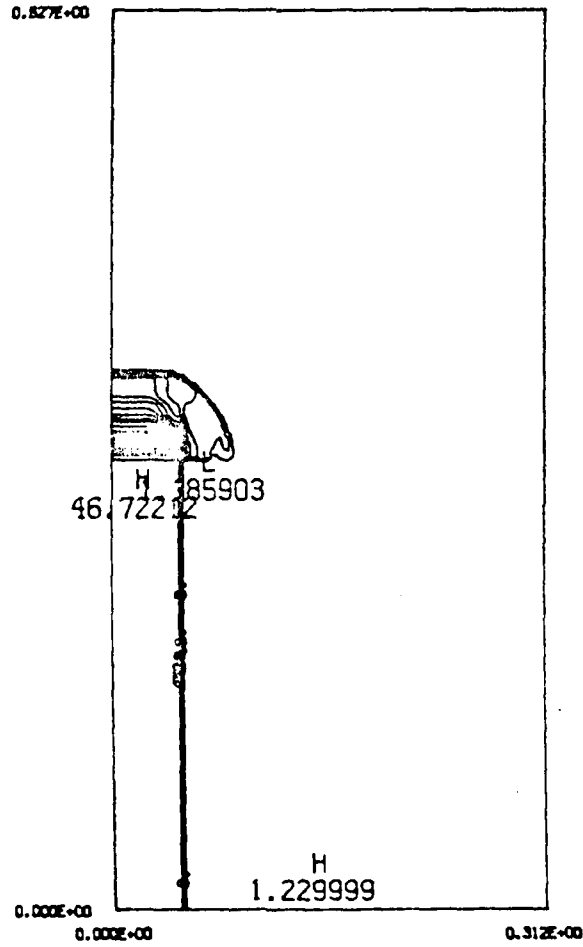
TIME= 0.25352E-04 SEC., STEP 89, DUMP HOWZ0001 PRESSURE NEWTONS/M<sup>2</sup>



CENTERS FROM 0.00000 TS 0.28000E-08 CENTERS INTERVAL SP 0.10000E-07 PT (1.0, 51) 0.28100E-08 LABELS SCALED BY 0.10000E-08

Figure 34a

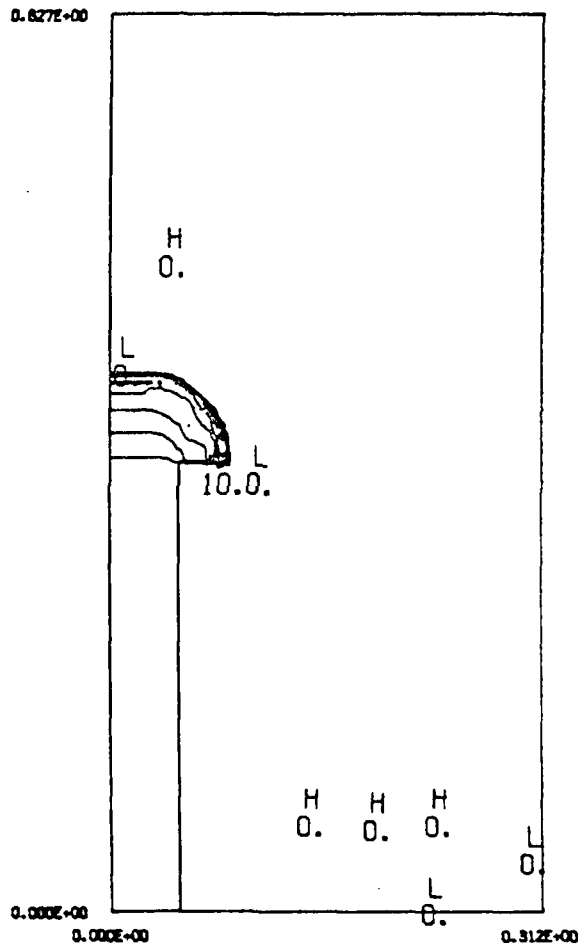
105 MM HOWITZER MUZZLE FLOW  
 TIME= 0.25352E-04 SEC.. STEP 89. DUMP H0NZ0001 DENSITY 1. KG/M3



CENTUR FROM 0.0000 TO 46.000 CENTUR INTERVAL OF 2.0000 PT(3-3) = 46.722

Figure 34b

105 MM HOWITZER MUZZLE FLOW  
 TIME= 0.25352E-04 SEC., STEP 89. DUMP HOWZ0001 MACH NUMBER



CENTRAL PRESS 0.00000 TS 0.0000 CENTRAL INTERVAL OF 0.00000 PT(0.01) = 1.1296

Figure 34c

105 MM HOWITZER MUZZLE FLOW  
TIME= 0.25352E-04 SEC.. STEP 69. DUMP HOW20001 VELOCITY. M/SEC

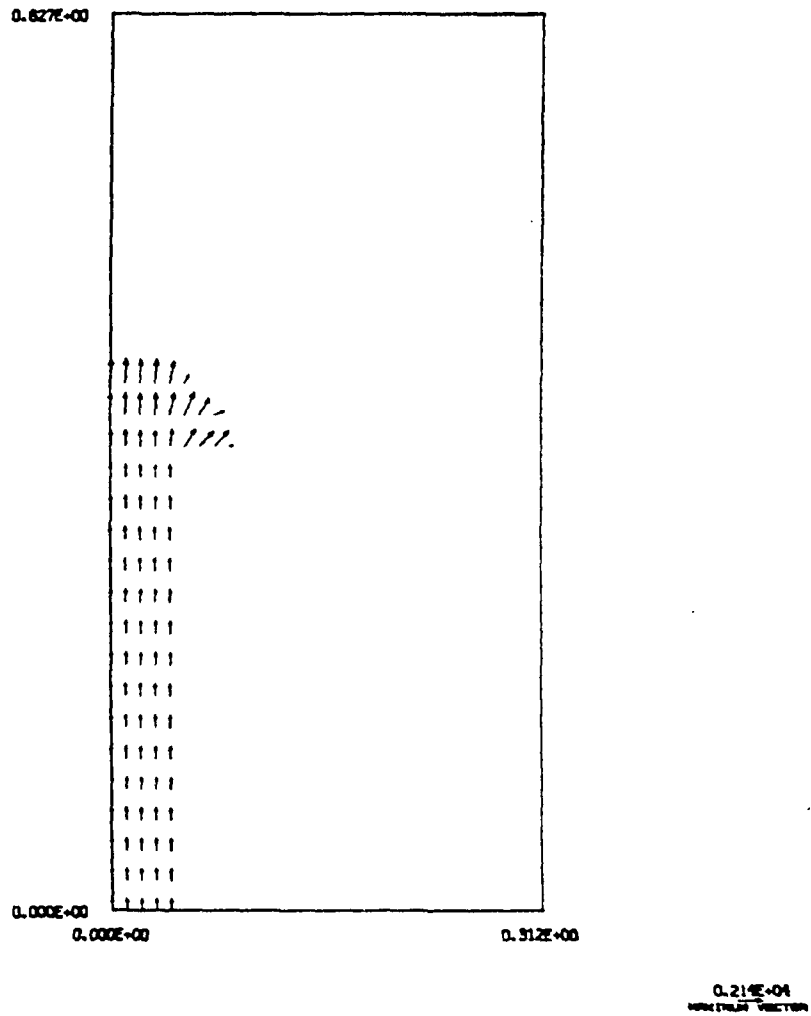
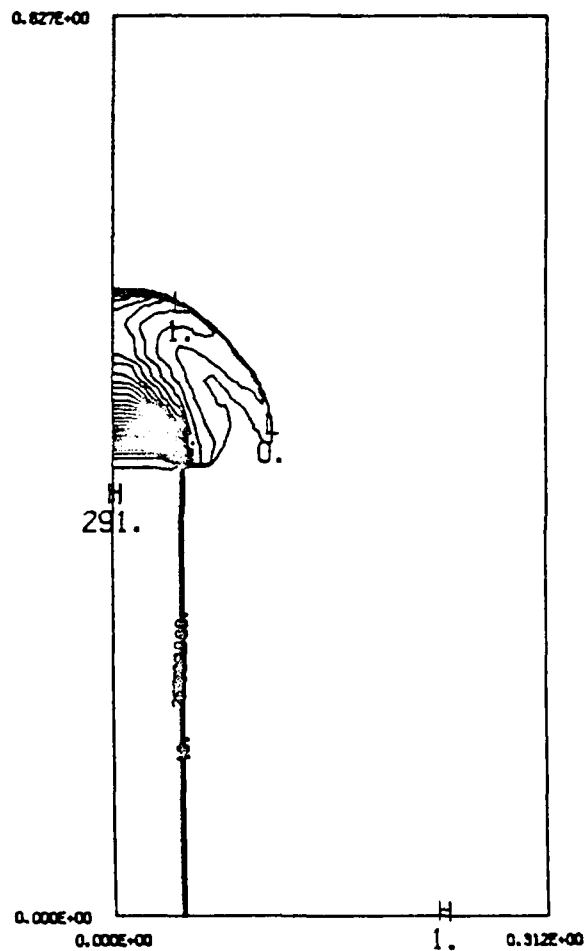


Figure 34d

105 MM HOWITZER MUZZLE FLOW  
TIME= 0.50452E-04 SEC.. STEP 143. DUMP HOWZ0002 PRESSURE, NEWTONS/M<sup>2</sup>

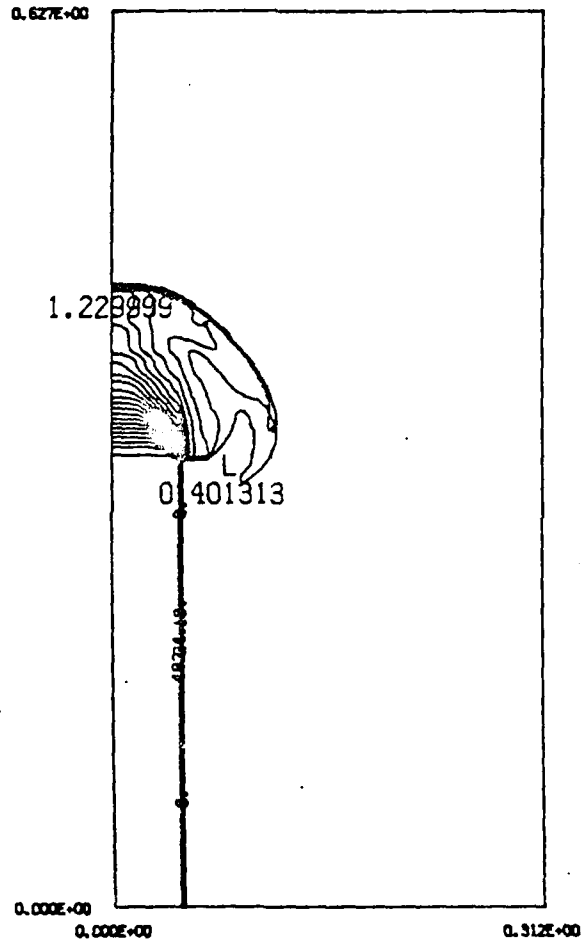


CONTOUR FROM 0.00000 TO 0.28000E+08 CONTOUR INTERVAL BY 0.10000E+07 PT(1,2)= 0.29100E+08 LABELS SCALED BY 0.10000E+04

Figure 35a

105 MM HOWITZER MUZZLE FLOW

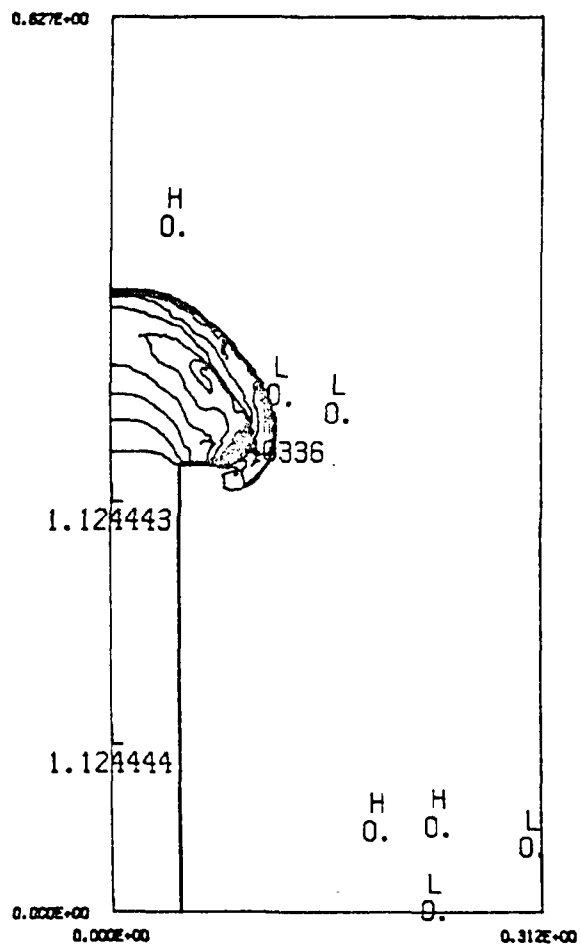
TIME= 0.50452E-04 SEC., STEP 143, DUMP HOWZ0002 DENSITY 1. KG/M3



CENTERS FROM 0.00000 TS 00.000 CENTERS INTERVAL OF 2.000 PT (S. 31) 00.722

Figure 35b

105 MM HOWITZER MUZZLE FLOW  
 TIME= 0.50452E-04 SEC., STEP 143. DUMP HOWZ0002 MACH NUMBER

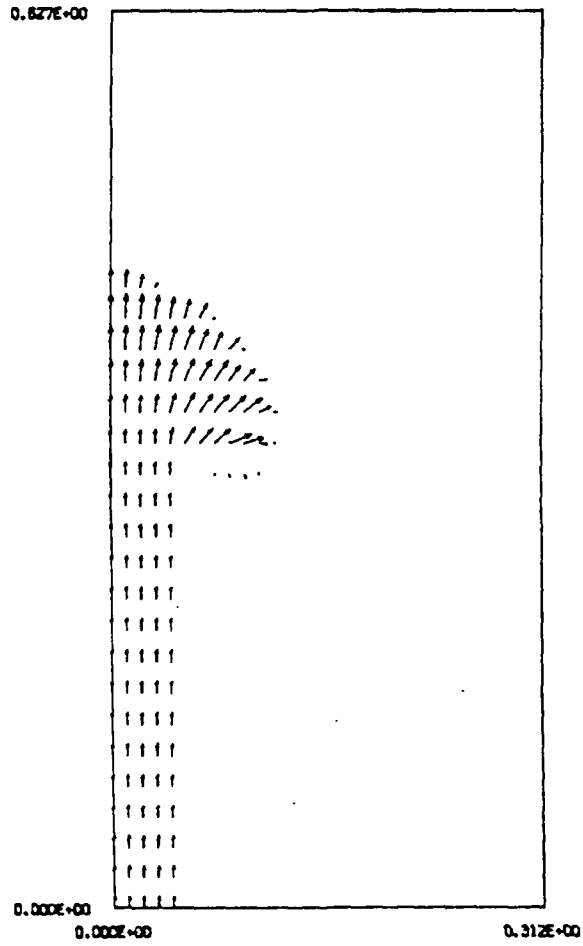


CONTOUR FROM 0.00000 TO 7.2000 CONTOUR INTERVAL OF 0.40000 PT (A, B) 1.1244

Figure 35c

105 MM HOWITZER MUZZLE FLOW

TIME= 0.50452E-04 SEC., STEP 143. DUMP HOWZ0002 VELOCITY, M/SEC

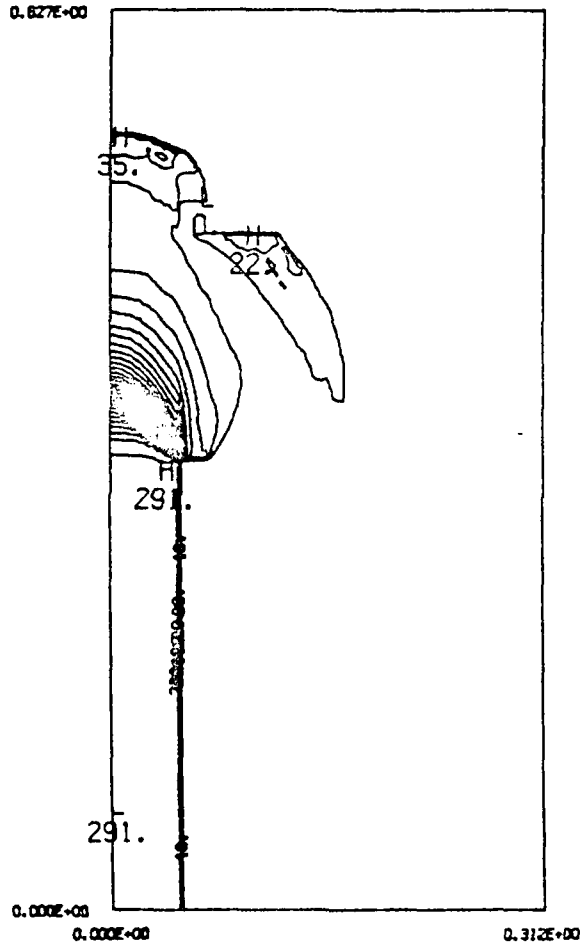


0.217E-04  
MAGNITUDE VECTOR

Figure 35d

105 MM HOWITZER MUZZLE FLOW

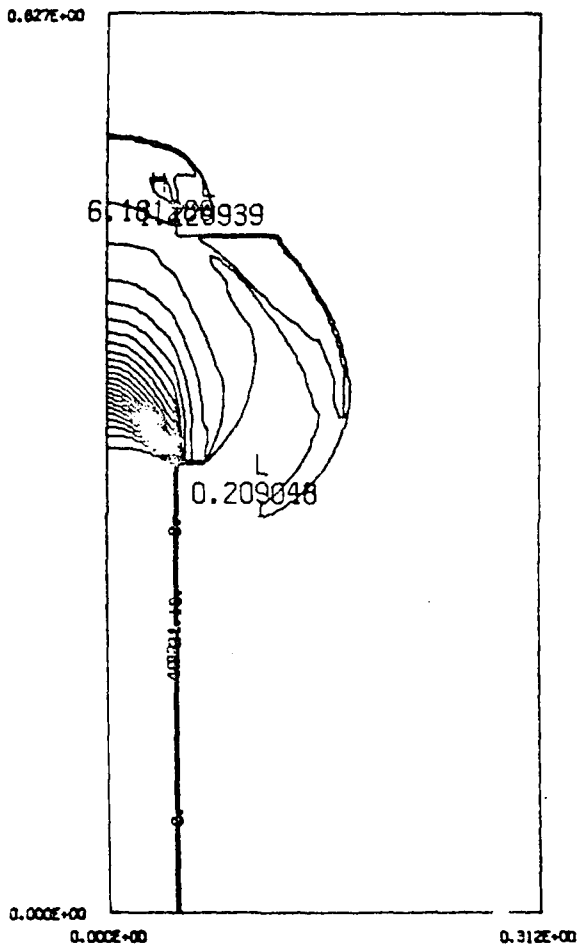
TIME= 0.10006E-03 SEC., STEP 253. DUMP HOWZ0003 PRESSURE, NEWTONS/M\*\*2



CENTUR FROM 0.00000 TO 0.28000E+00 CENTUR INTERVAL OF 0.10000E+07 PT(S) 0.0 0.28100E+00 LABELS SCALED BY 0.10000E+04

Figure 36a

105 MM HOWITZER MUZZLE FLOW  
 TIME= 0.10006E-03 SEC., STEP 253, DUMP H04Z0003 DENSITY 1. KG/M3



CONTOUR FROM 0.00000 TR 46.000 CONTOUR INTERVAL OF 2.0000 PT(8-31) = 66.722

Figure 36b

AD-A163 332

APPLICATION OF FLUX-CORRECTED TRANSPORT TO TTCP JOINT  
LAUNCH BLAST COMPUTATIONAL EFFORT(U) NAVAL RESEARCH LAB  
WASHINGTON DC P S KAMATH ET AL. 31 DEC 85 NRL-MR-5781

2/2

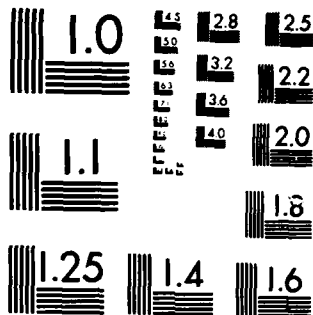
UNCLASSIFIED

F/G 19/4

NL

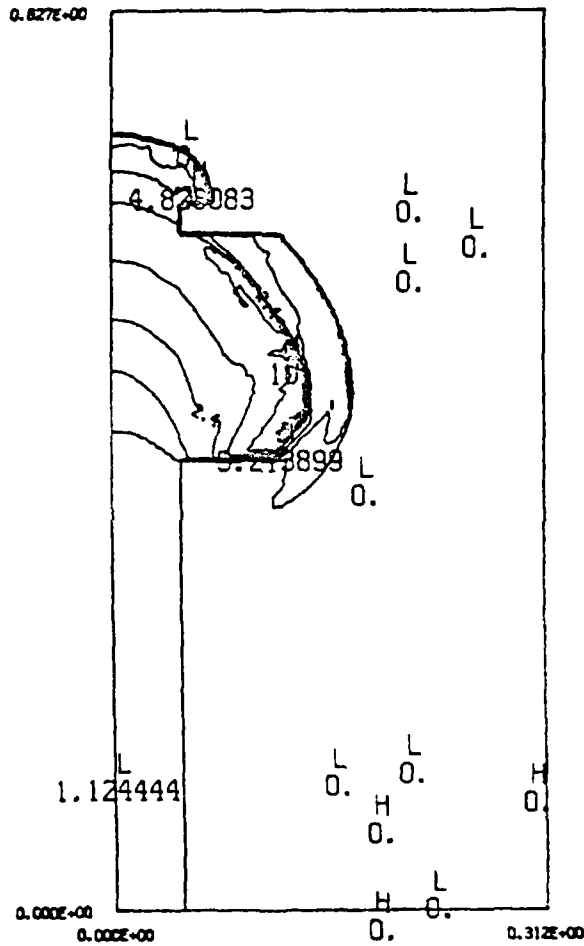
												END	

FILED  
IN  
GPO



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

105 MM HOWITZER MUZZLE FLOW  
 TIME= 0.10006E-03 SEC., STEP 253. DUMP HOWZ0003 MACH NUMBER



CENTUR FROM 0.0000 TO 0.3000 CENTUR INTERVAL OF 0.0000 PT(3,51) 1.1294

Figure 36c

105 MM HOWITZER MUZZLE FLOW  
TIME= 0.10006E-03 SEC., STEP 253, DUMP HOWZ0003 VELOCITY, M/SEC

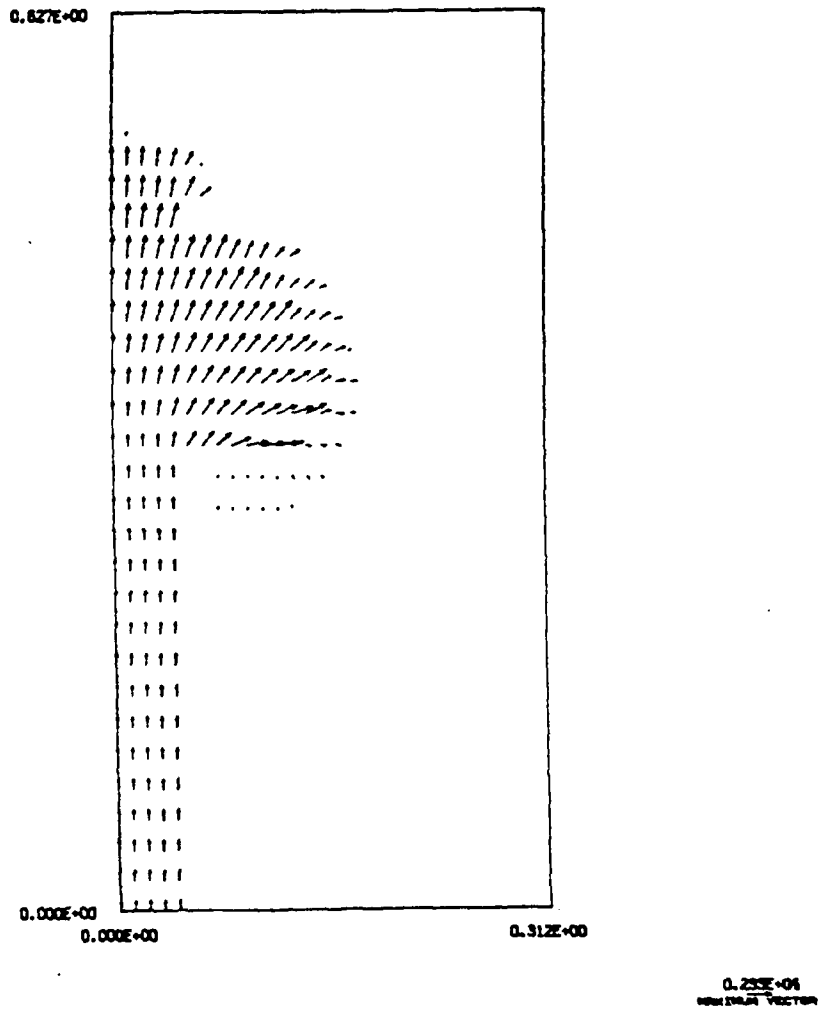
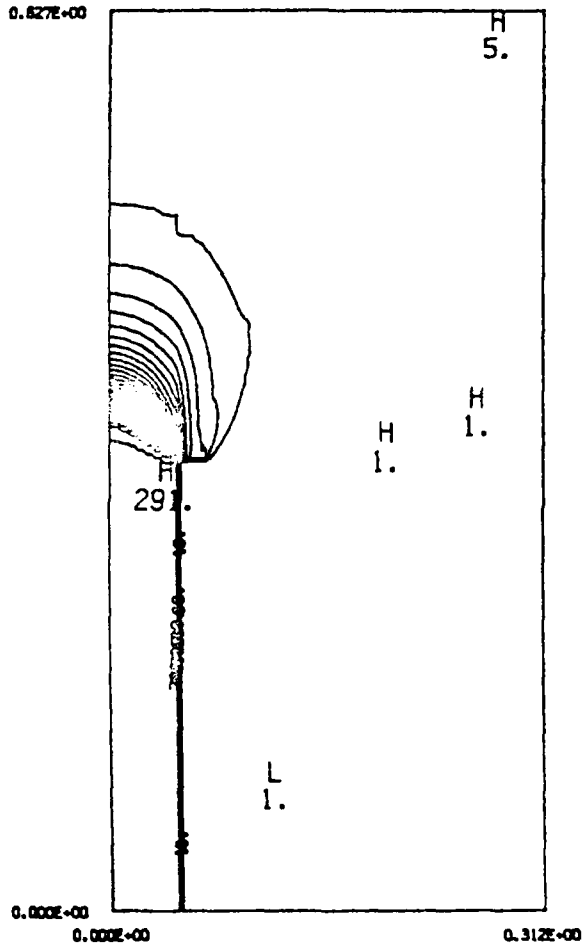


Figure 36d

105 MM HOWITZER MUZZLE FLOW

TIME= 0.50000E-03 SEC.. STEP 1433. DUMP H0WZ0005 PRESSURE, NEWTONS/M<sup>2</sup>



CONTOUR FROM 0.00000 TO 0.28000E+08 CONTOUR INTERVAL OF 0.10000E+07 P(18.91) 0.28100E+08 LABELS SCALED BY 0.10000E+04

Figure 37a

105 MM HOWITZER MUZZLE FLOW  
TIME= 0.50000E-03 SEC., STEP 1433, DUMP HOWZ0005 DENSITY 1. KG/M3

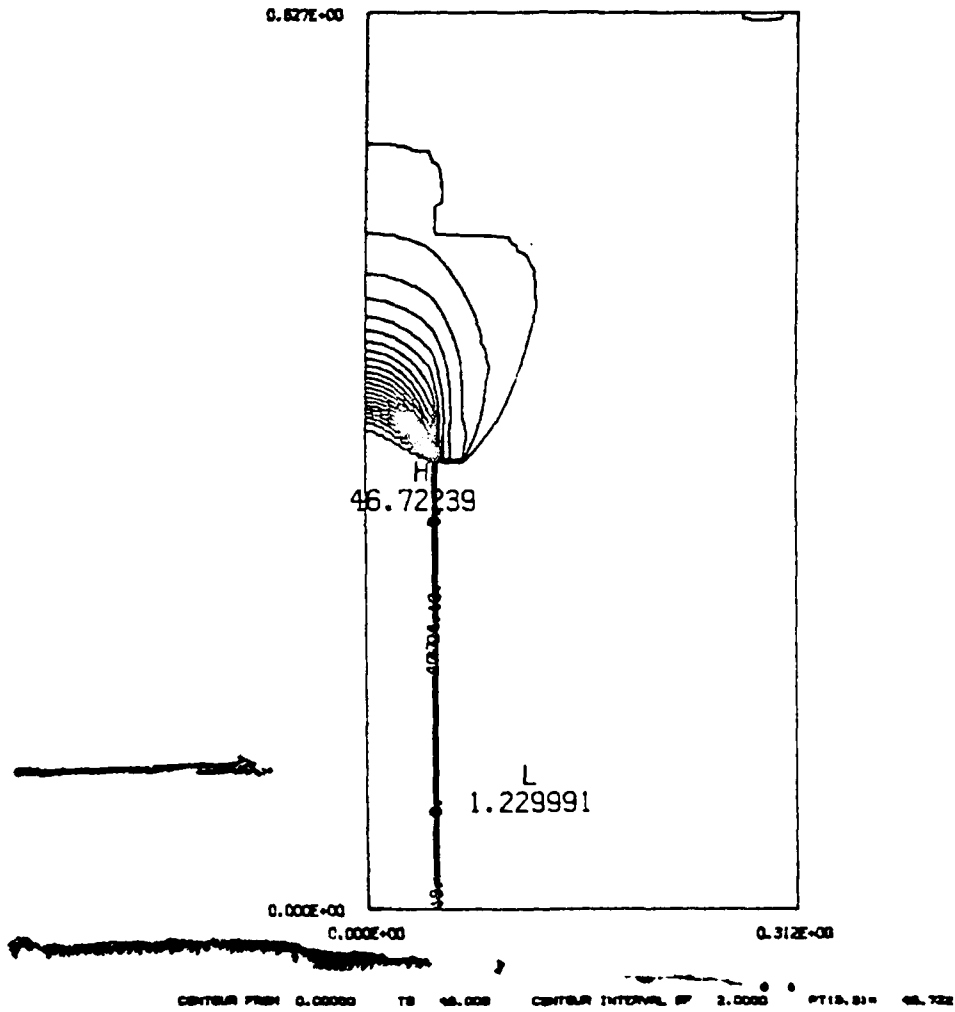
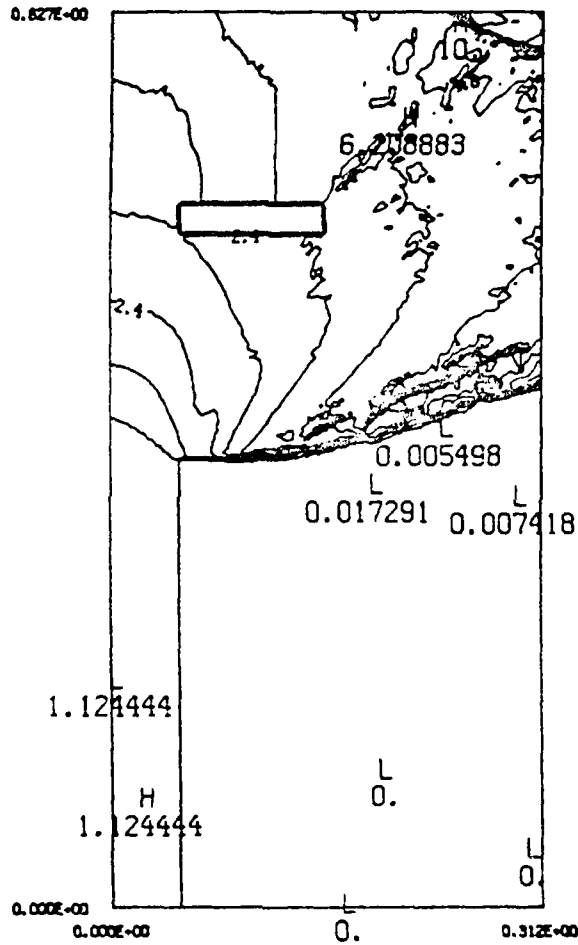


Figure 37b

105 MM HOWITZER MUZZLE FLOW

TIME= 0.50000E-03 SEC.. STEP 1433. DUMP HOWZ0005

MACH NUMBER



CENTUR FROM 0.0000 TO 0.0008 CENTER INTERVAL OF 0.0000 P1:0.514 1.1299

Figure 37c

105 MM HOWITZER MUZZLE FLOW  
TIME= 0.50000E-03 SEC., STEP 1433. DUMP HOWZ0005 VELOCITY, M/SEC

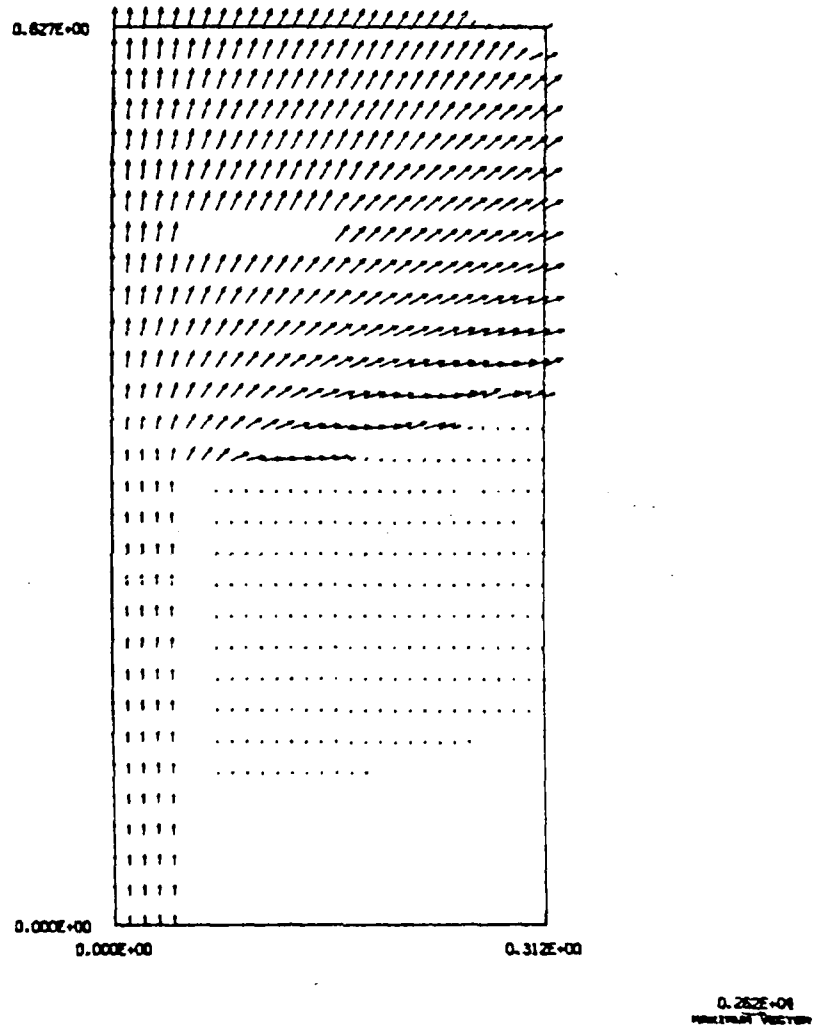
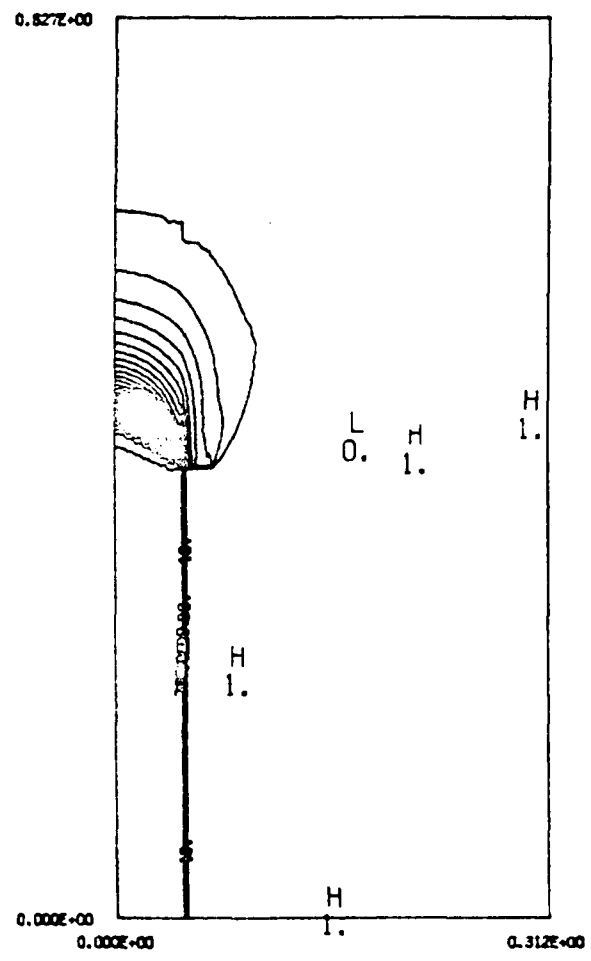


Figure 37d

105 MM HOWITZER MUZZLE FLOW  
 TIME= 0.10000E-02 SEC., STEP 2735. DUMP H0WZ0007 PRESSURE, NEWTONS/M\*\*2

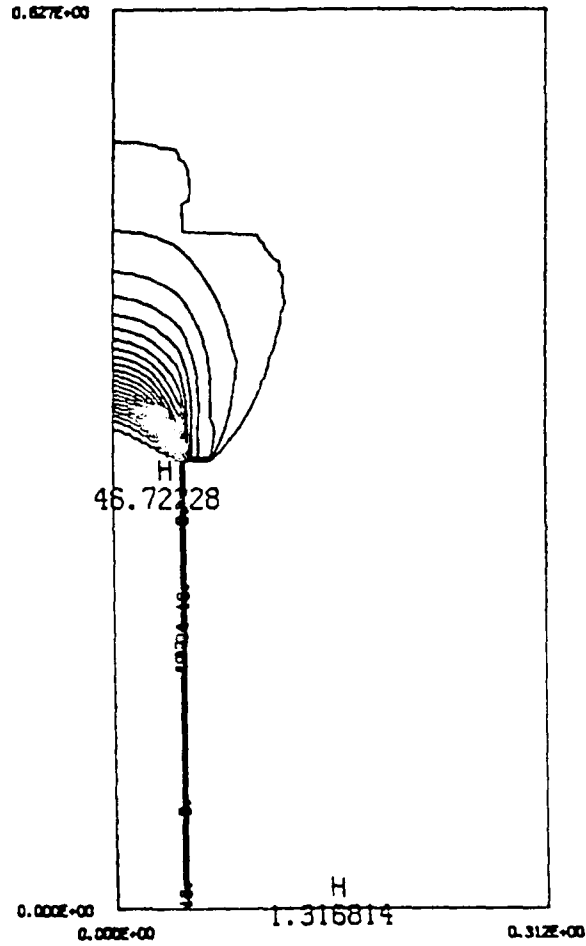


CENTERS FROM 0.0000 TS 0.20000E-08 CENTER INTERVAL OF 0.10000E-07 P(0.0)= 0.20100E-08 LABELS SCALED BY 0.10000E-04

Figure 38a

105 MM HOWITZER MUZZLE FLOW

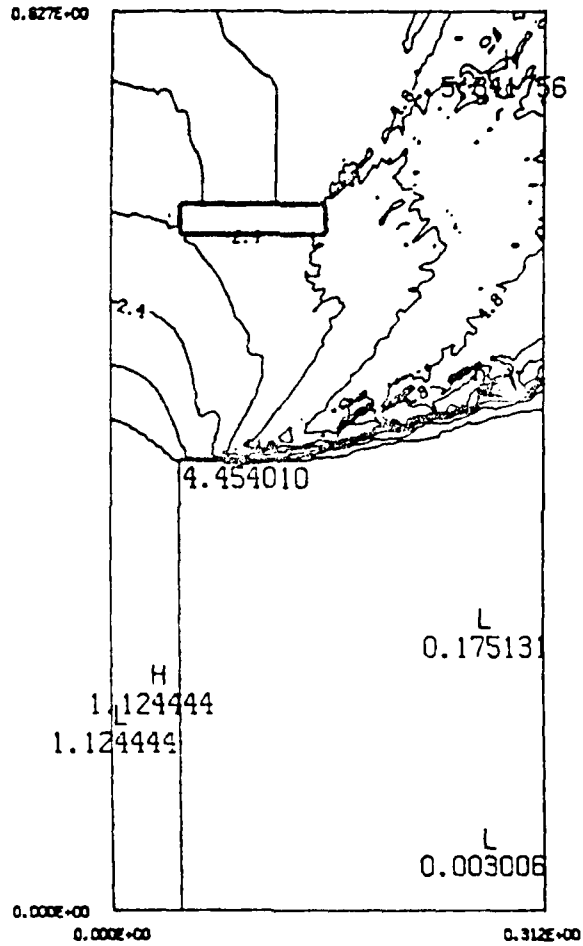
TIME= 0.10000E-02 SEC.. STEP 2735. DUMP HOWZ0007 DENSITY 1. KG/M3



CENTUR FROM 0.0000 TO 46.500 CENTUR INTERVAL OF 2.0000 PT(3, 3) = 46.722

Figure 38b

105 MM HOWITZER MUZZLE FLOW  
 TIME= 0.10000E-02 SEC., STEP 2735, DUMP HOWZ0007 MACH NUMBER



CENTRAL FROM 0.00000 TS 0.0000 CENTRAL INTERVAL OF 0.0000 PT(3-21) = 1.1294

Figure 38c

105 MM HOWITZER MUZZLE FLOW  
TIME= 0.75002E-03 SEC., STEP 2073. DUMP HOWZ0006 VELOCITY, M/SEC

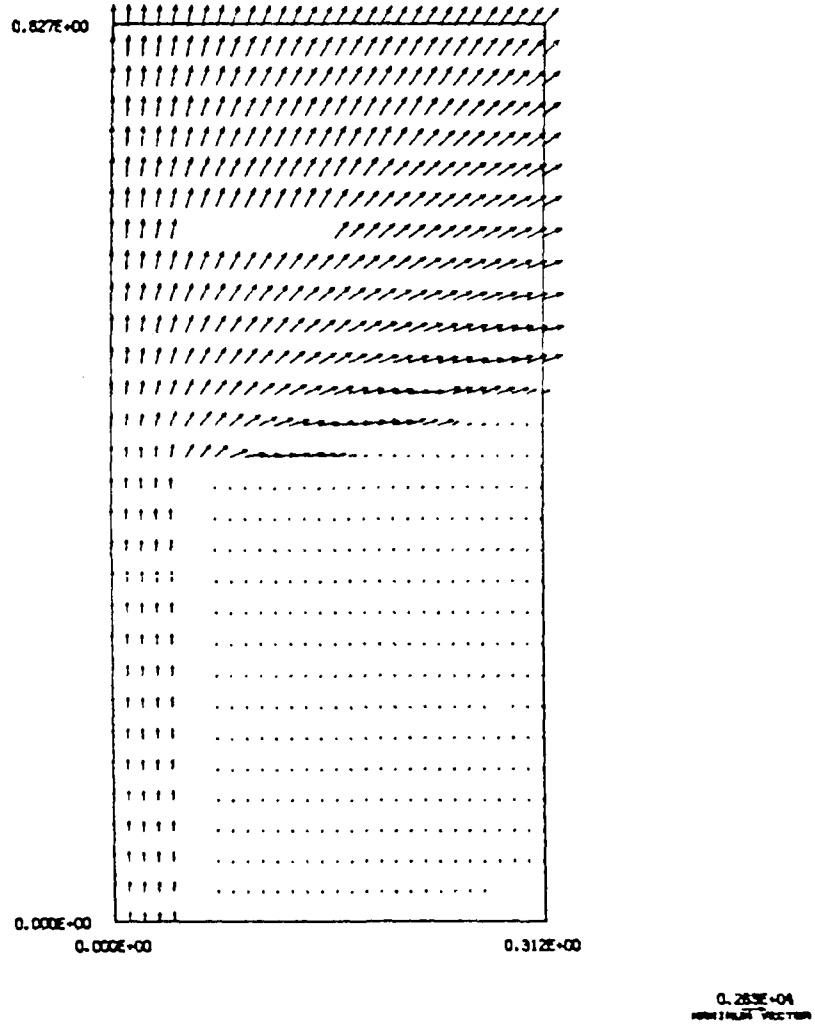
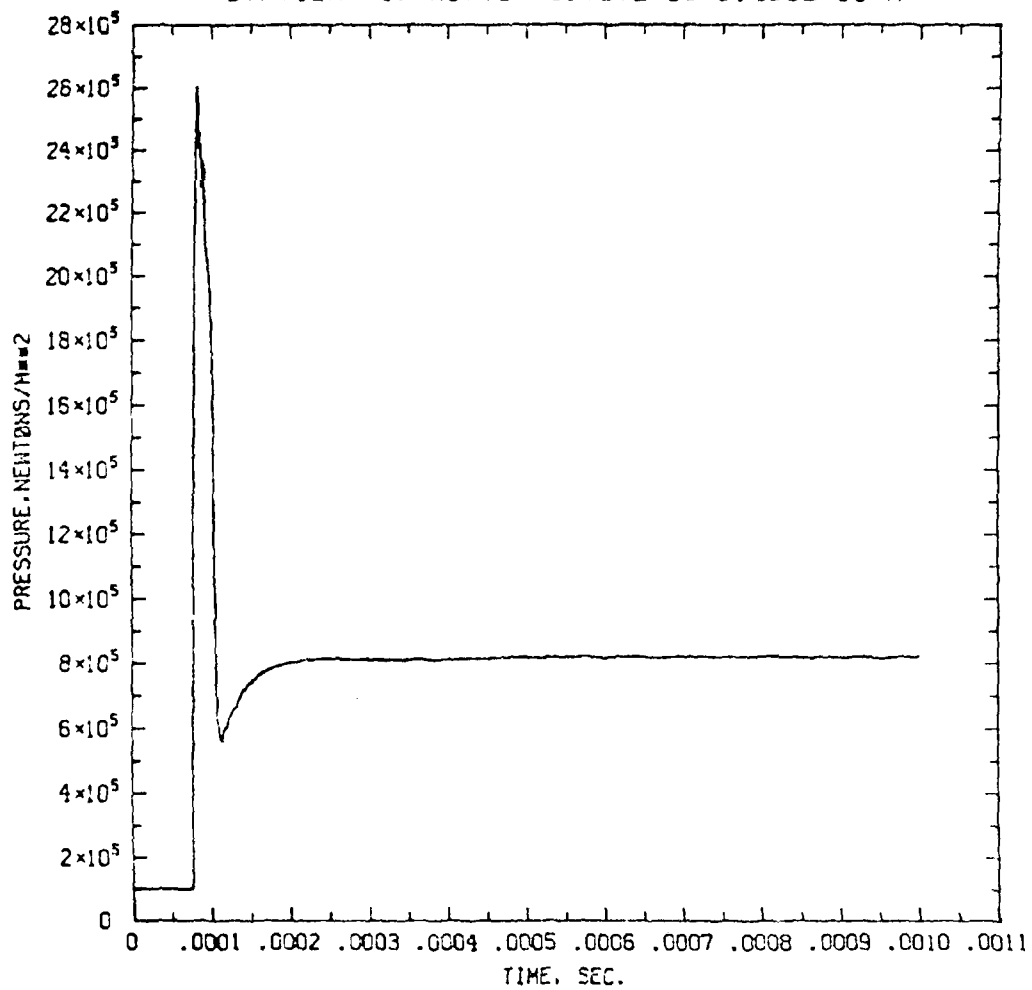


Figure 38d

STATION 1, XS,YS= 0.787E-01 0.466E+00 M

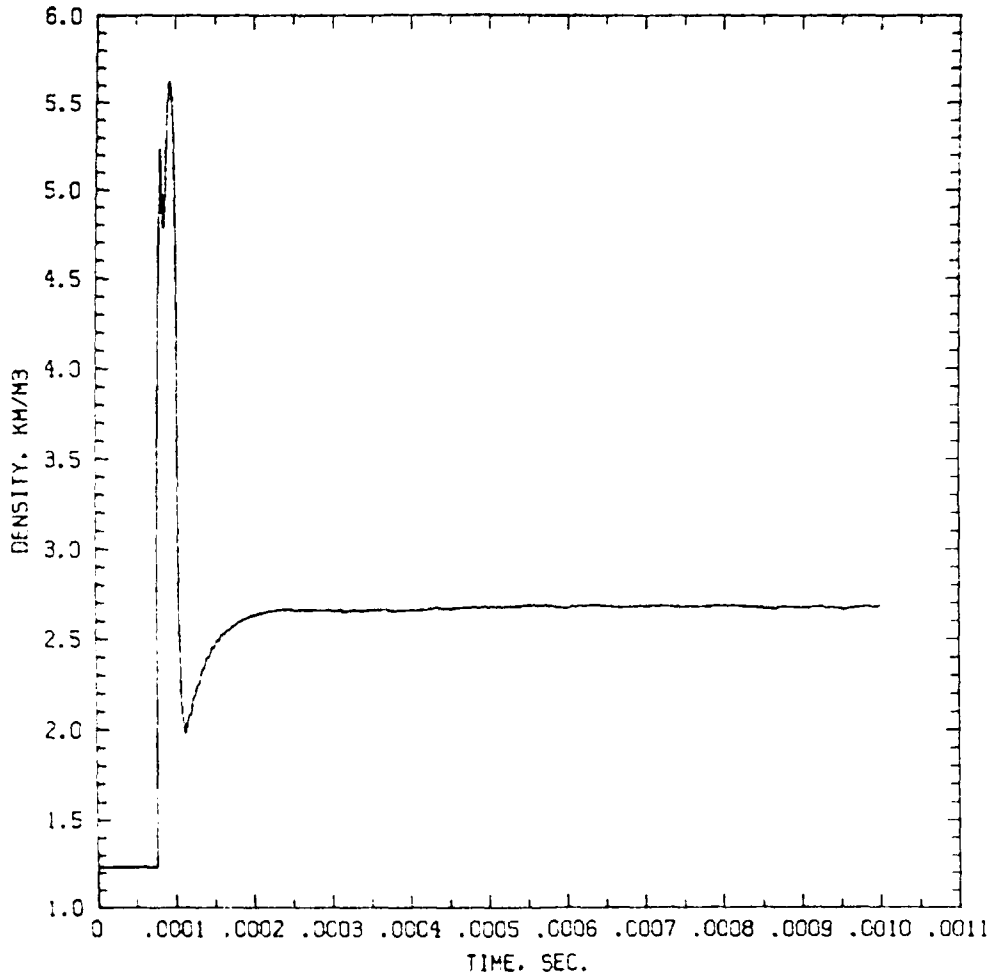


105 MM HOWITZER MUZZLE FLOW

9 DUMPS, LAST DUMP IS HORIZONTAL

Figure 39a

STATION 1, XS,YS= 0.787E-01 0.466E+00 M

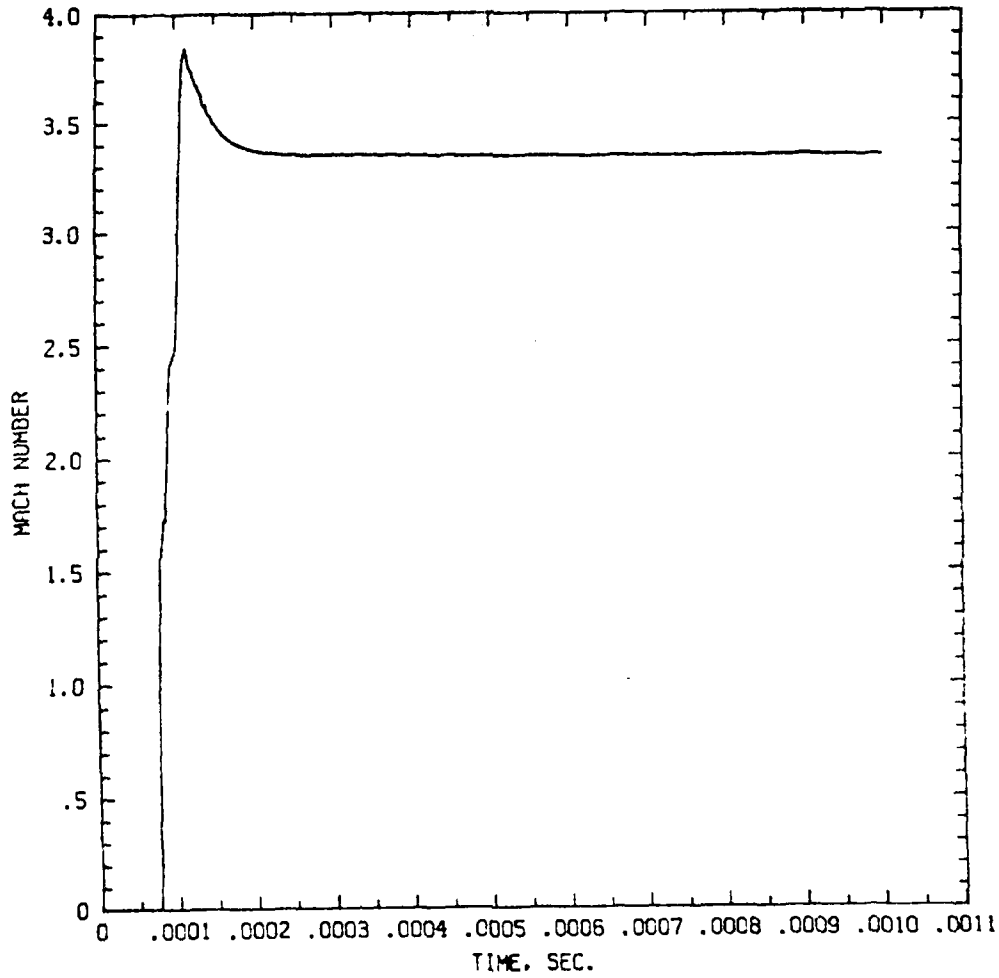


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HOWZOOO

Figure 39b

STATION 1. XS,YS= 0.787E-01 0.466E+00 M

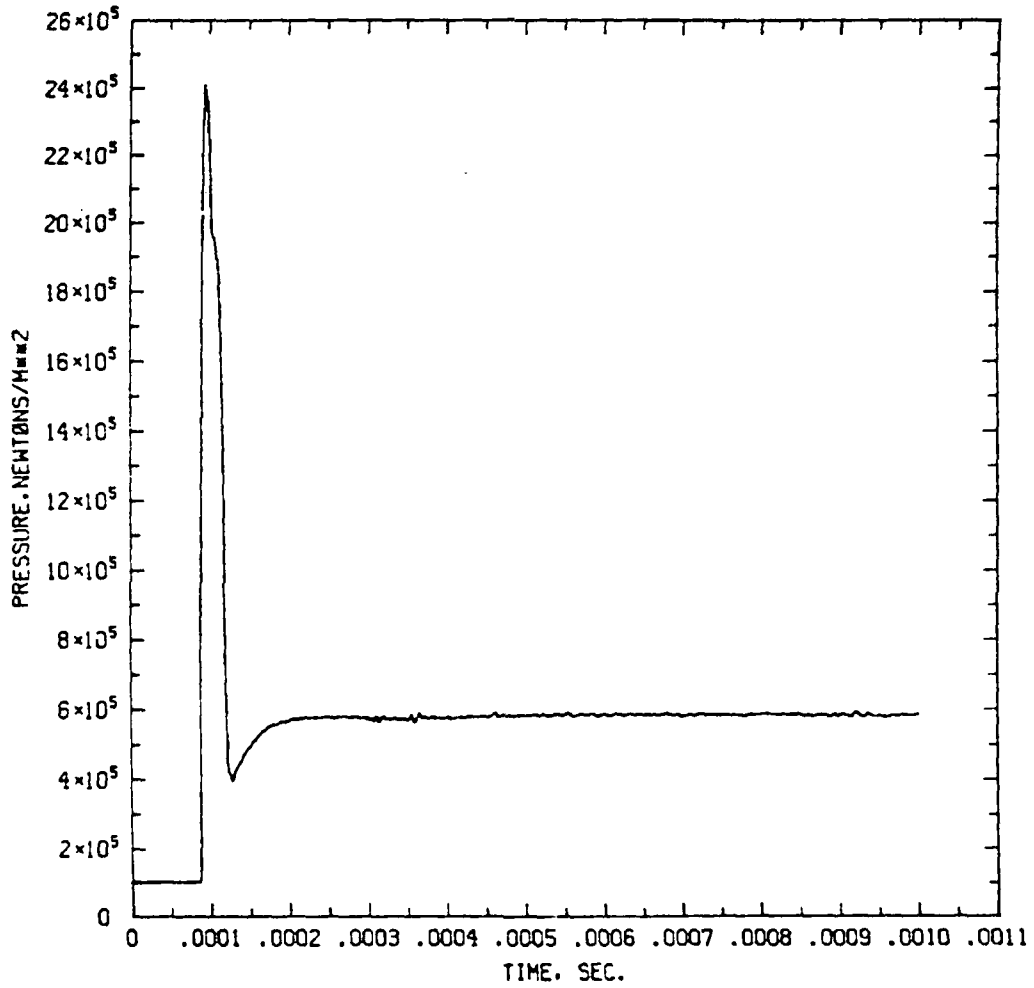


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS #2420009

Figure 39c

STATION 2, XS,YS= 0.105E+00 0.466E+00 M

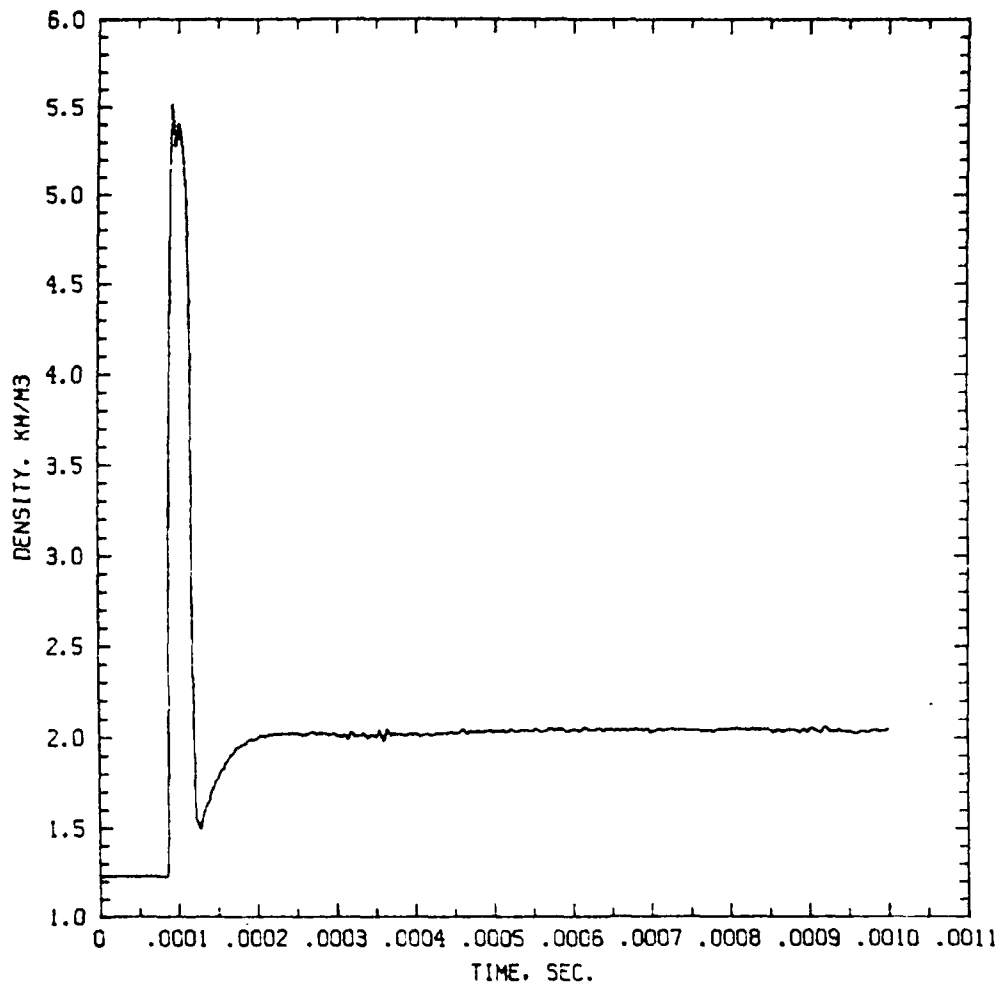


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS NEWZ0000

Figure 40a

STATION 2. XS,YS= 0.105E+00 0.466E+00 M

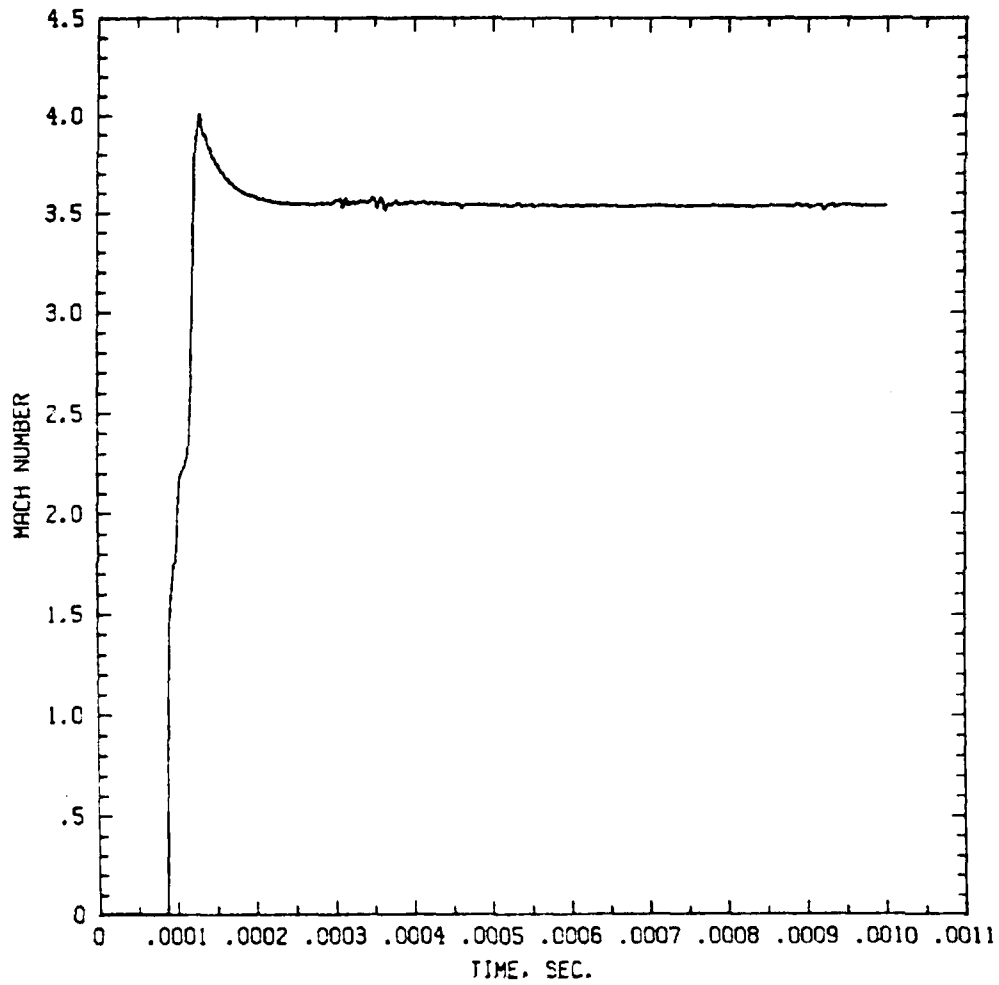


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HOWZ0009

Figure 40b

STATION 2. XS.YS= 0.105E+00 0.466E+00 M

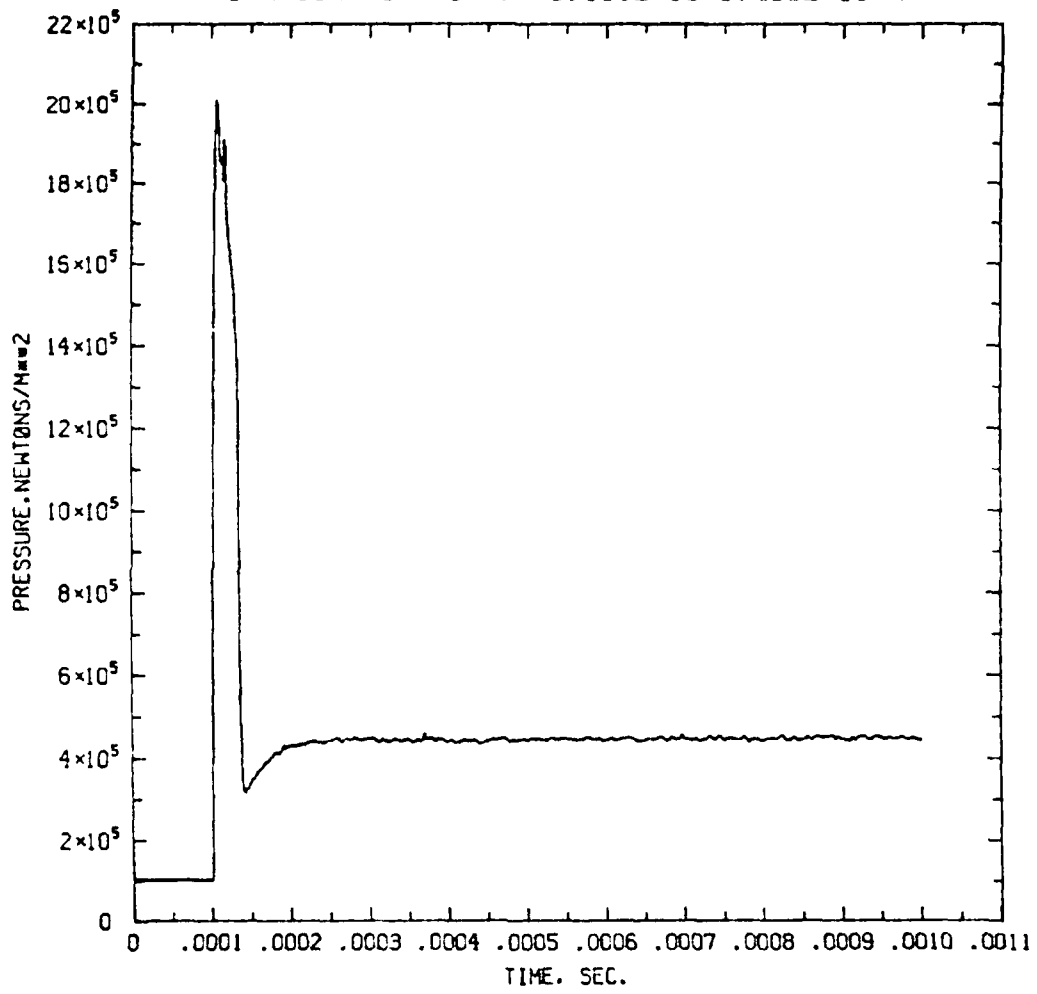


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HORIZONTAL

Figure 40c

STATION 3. XS.YS= 0.131E+00 0.466E+00 M

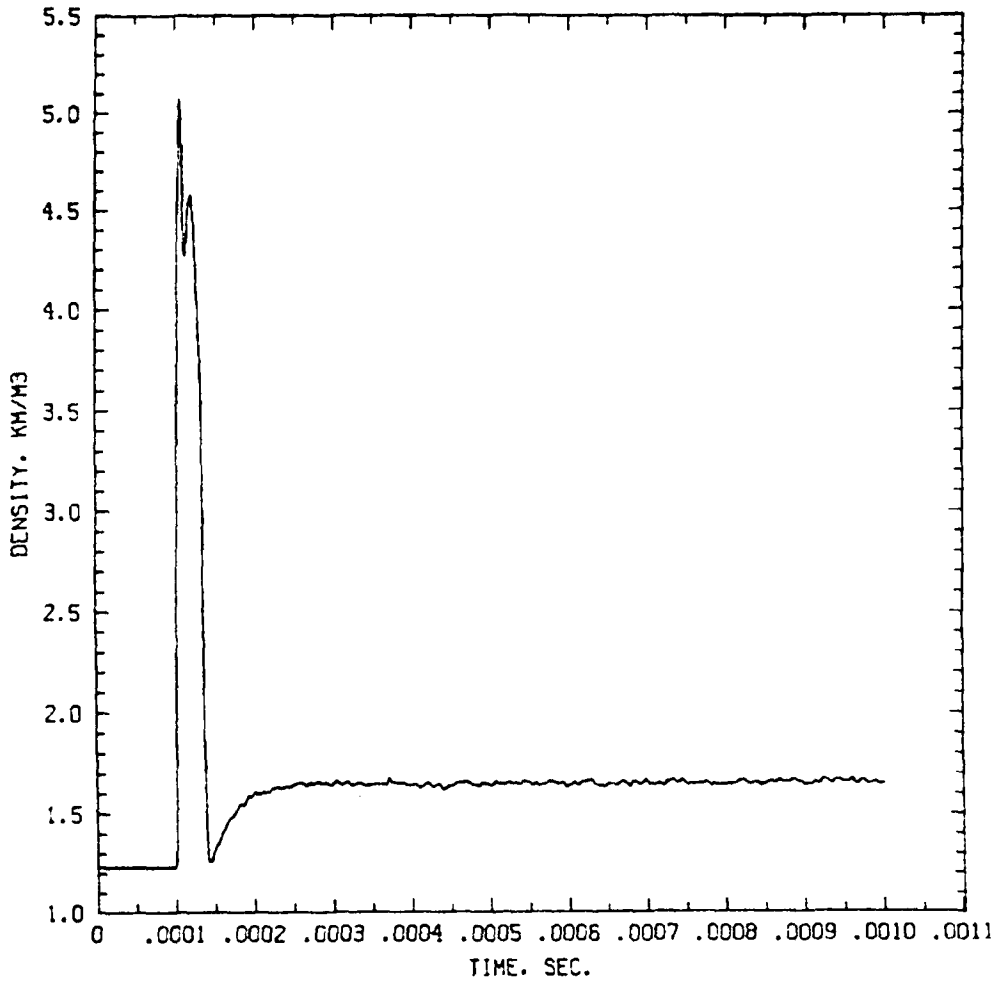


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS HSNZ0009

Figure 41a

STATION 3. XS,YS= 0.131E+00 0.466E+00 M

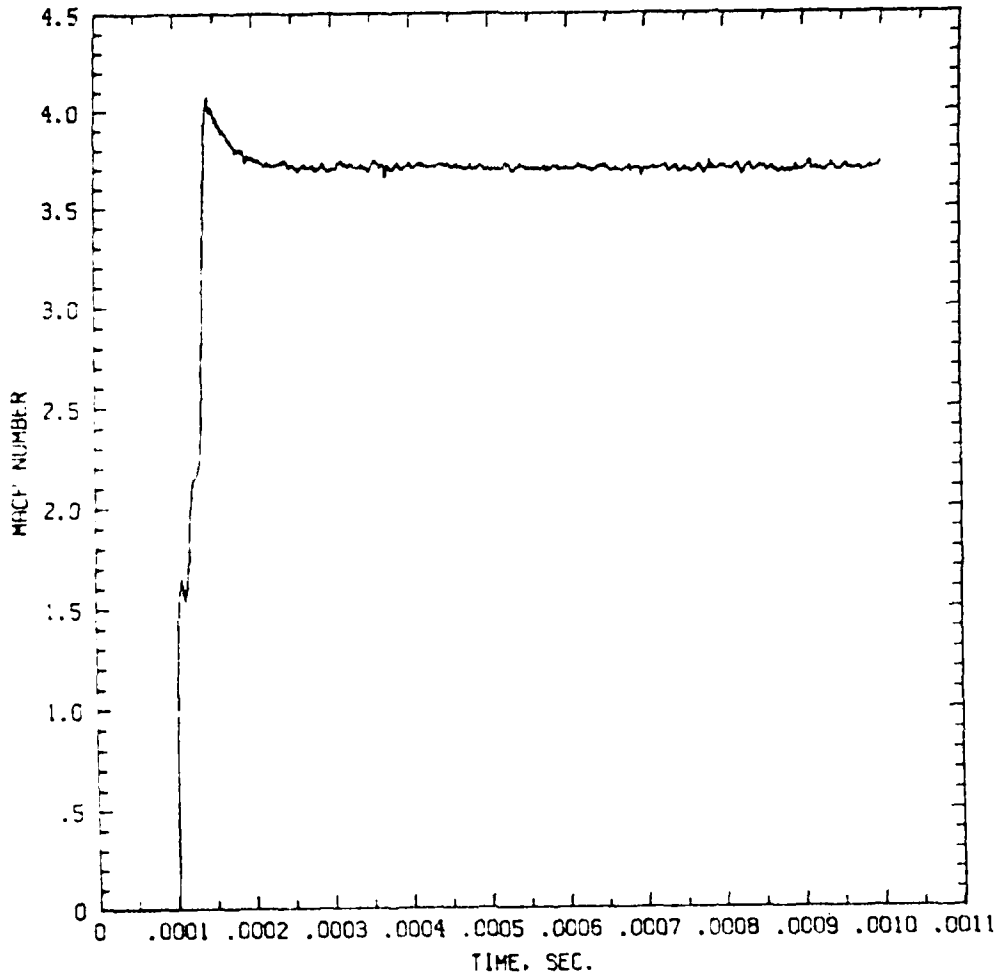


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HOWZ0009

Figure 41b

STATION 3. XS.YS= 0.131E+00 0.466E+00 M

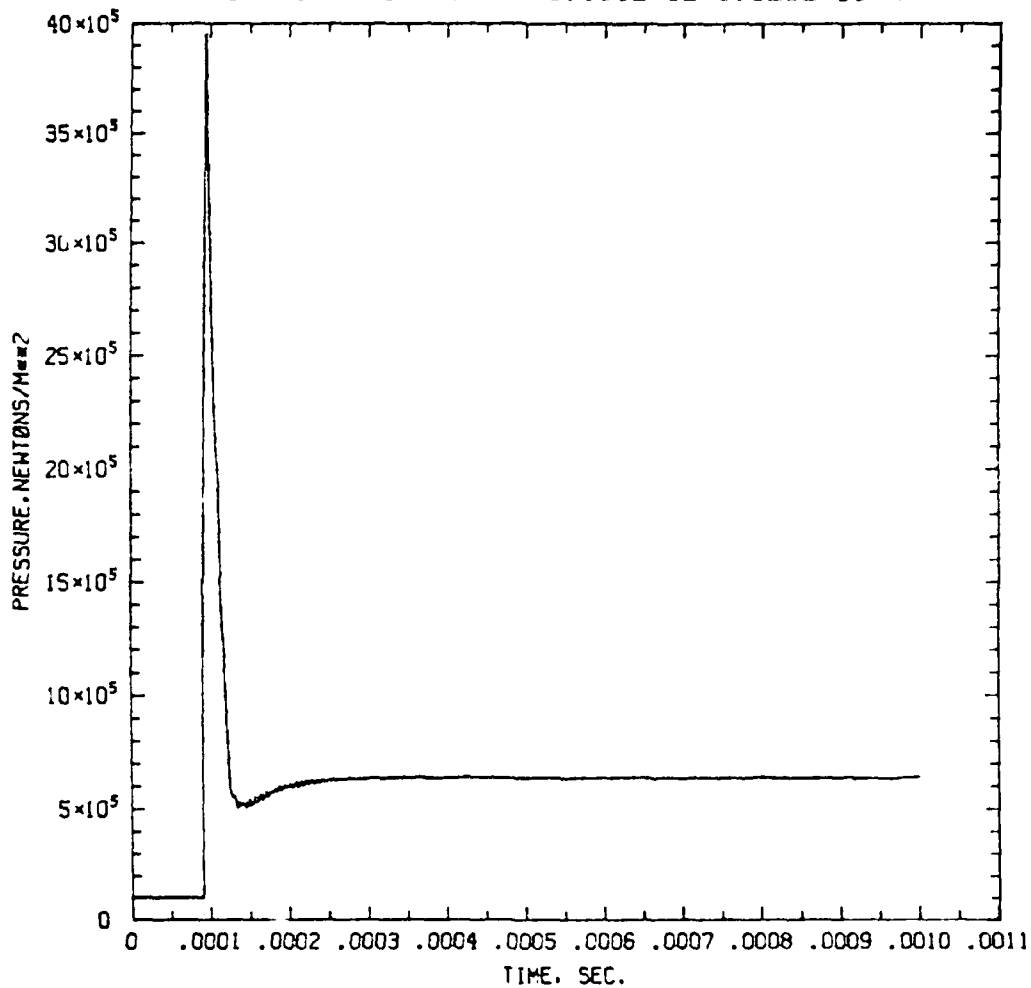


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HOWZ0009

Figure 41c

STATION 4. XS,YS= 0.151E-02 0.525E+00 M

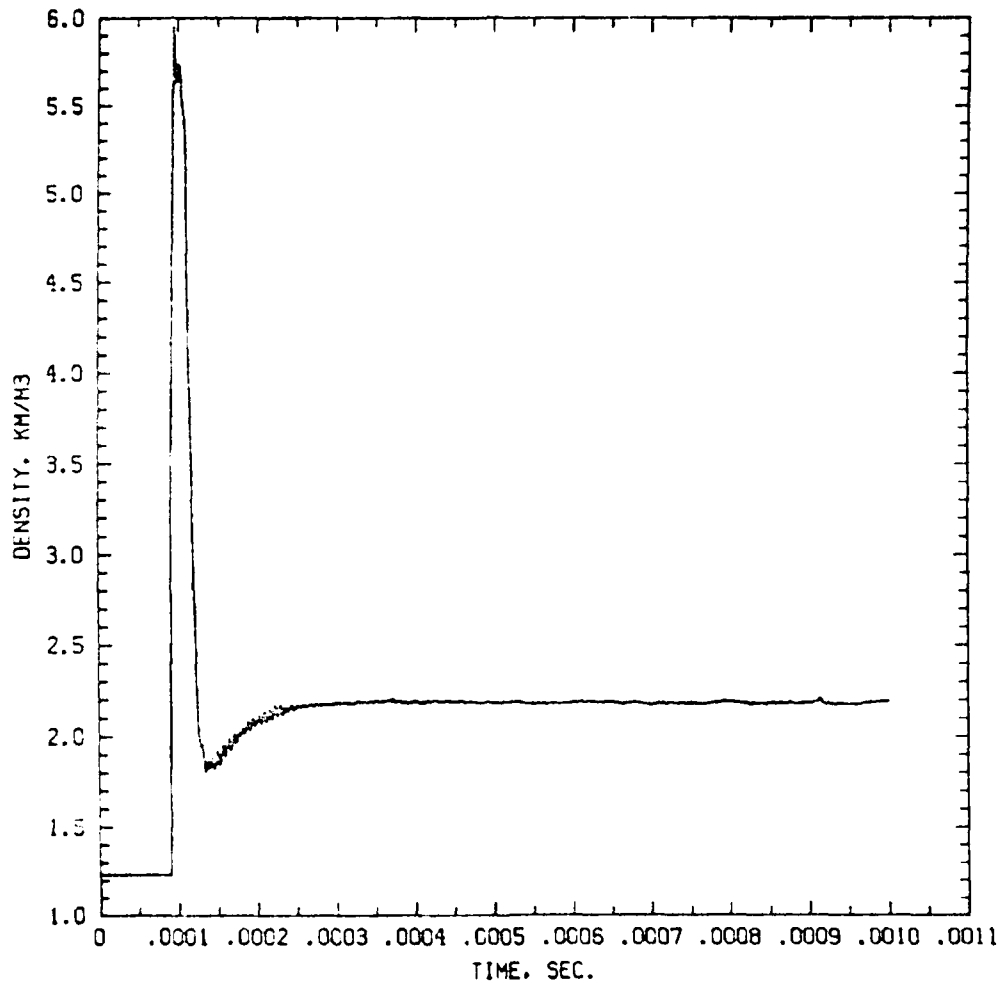


105 MM HOWITZER MUZZLE FLOW

0 DUMPS. LAST DUMP IS HOWZ0009

Figure 42a

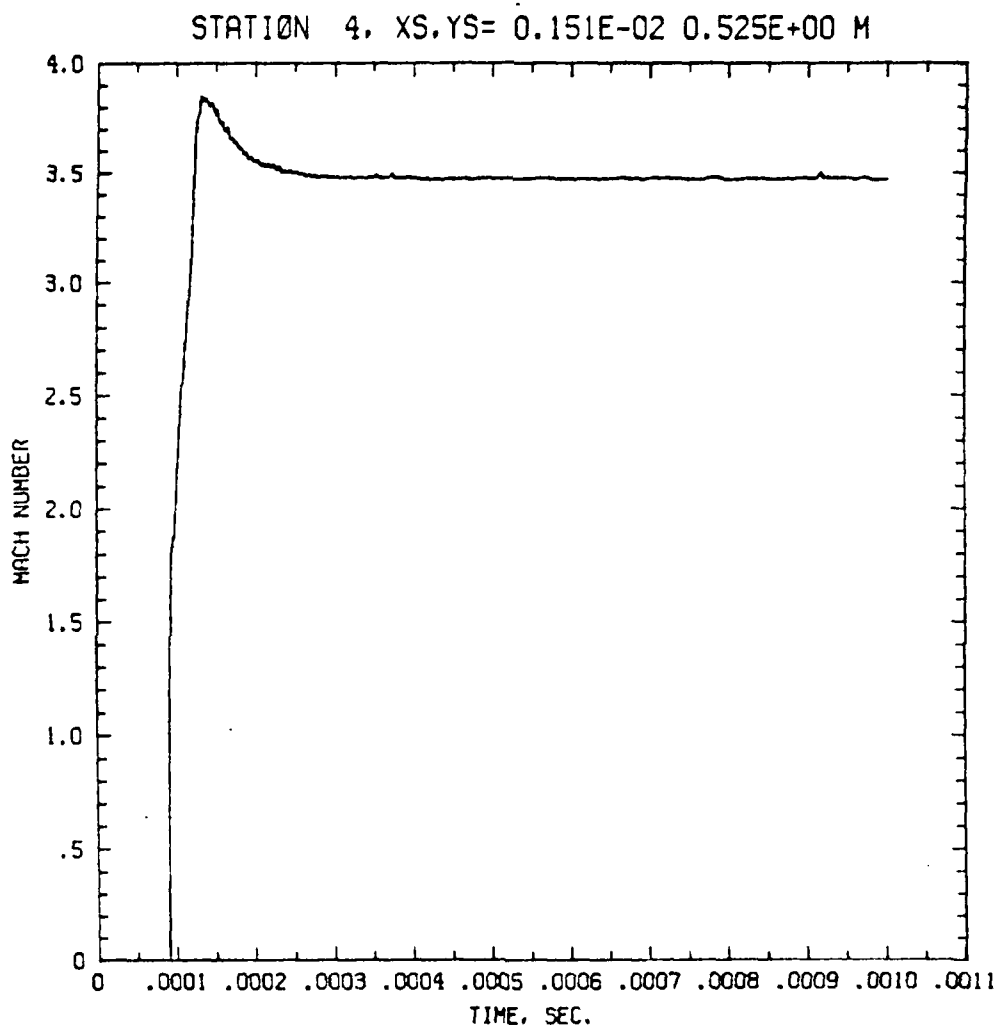
STATION 4, XS.YS= 0.151E-02 0.525E+00 M



105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HSNZ0009

Figure 42b

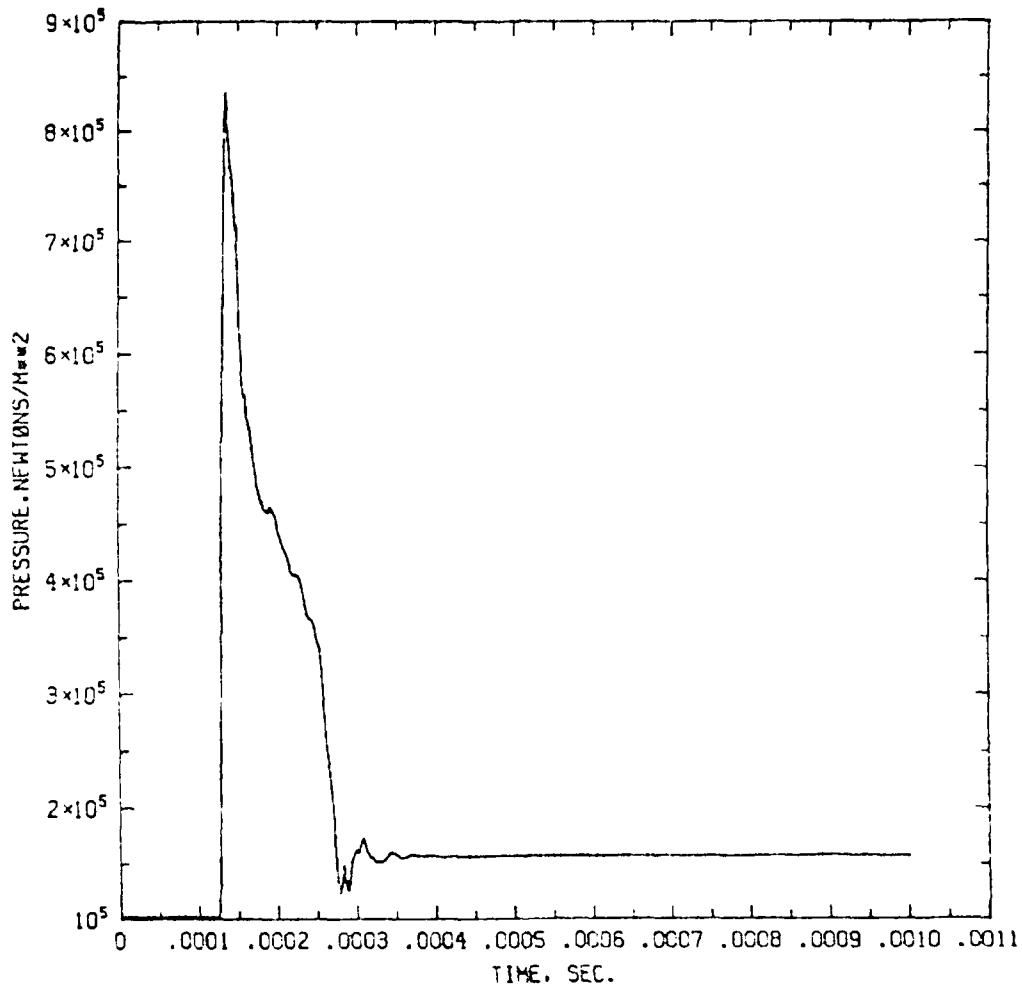


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HORIZONTAL

Figure 42c

STATION 5. XS.YS= 0.105E+00 0.497E+00 M

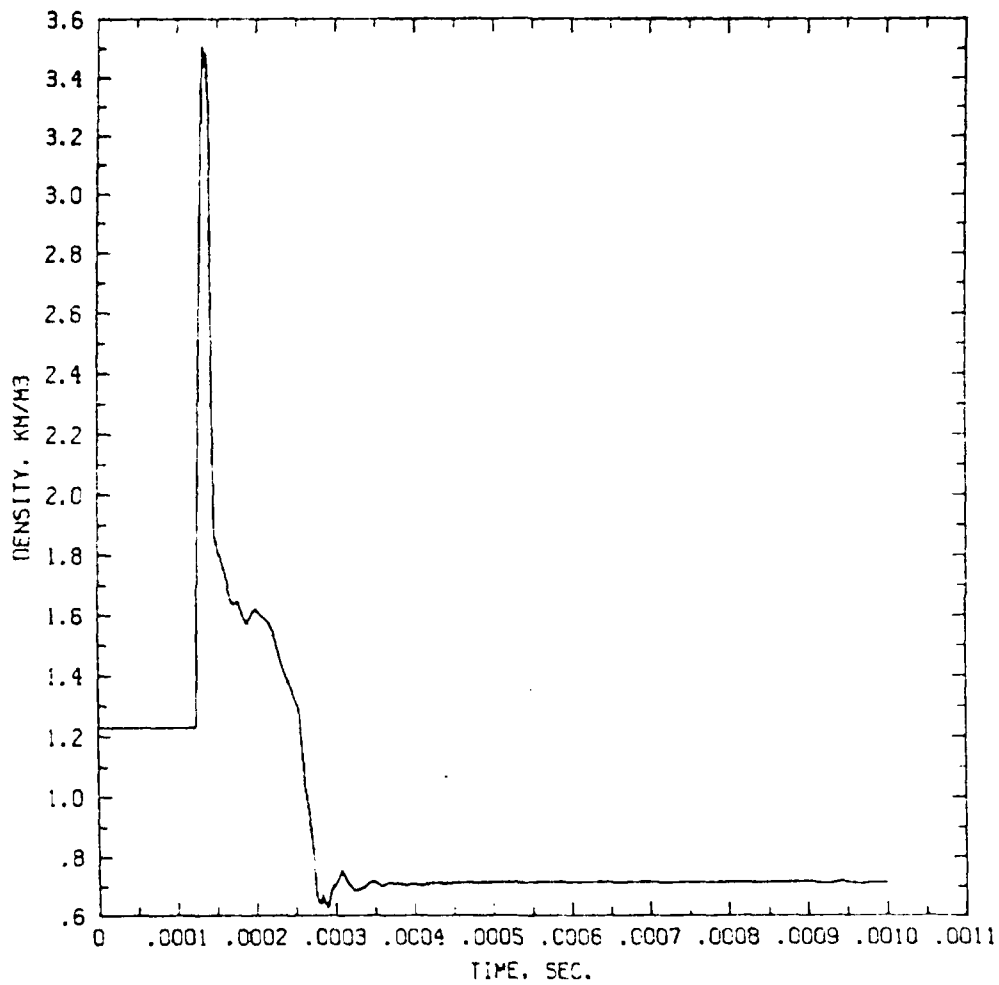


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS REMIDOGS

Figure 43a

STATION 5. XS.YS= 0.105E+00 0.497E+00 M

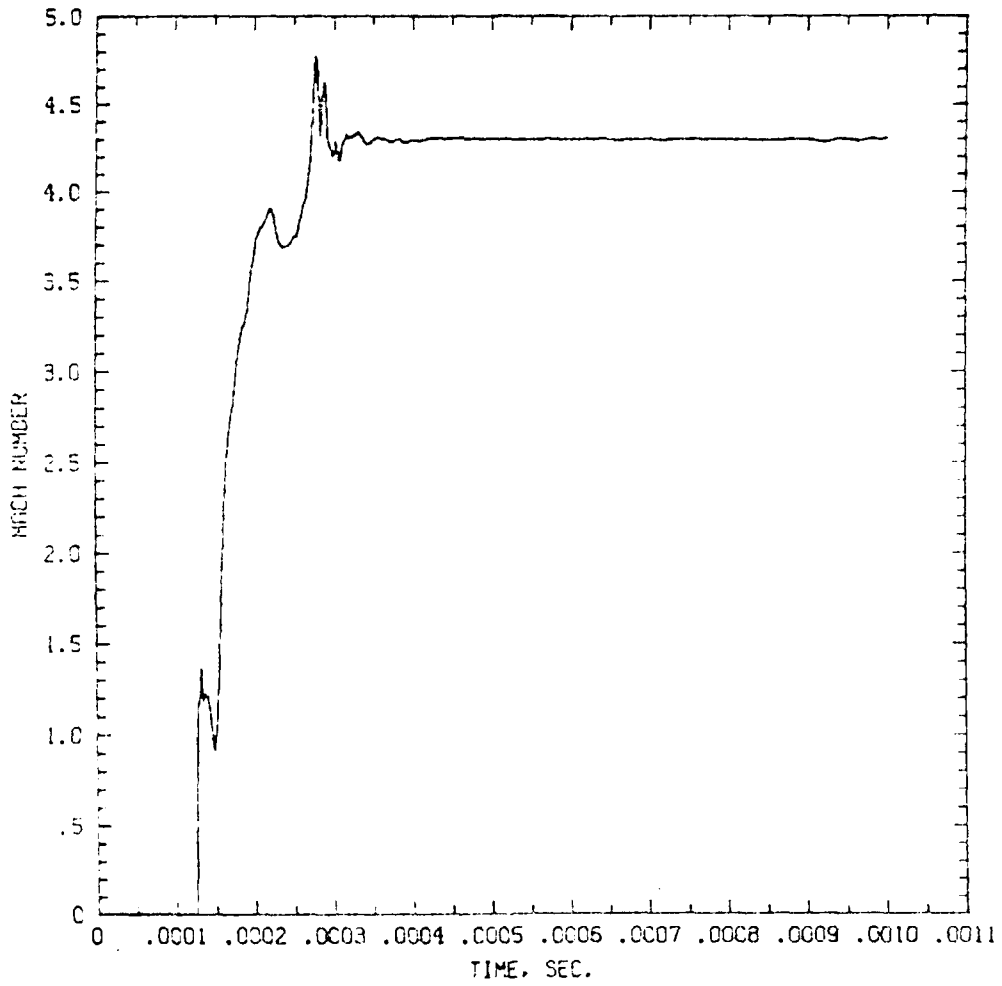


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HOWZ0009

Figure 43b

STATION 5. XS.YS= 0.105E+00 0.497E+00 M

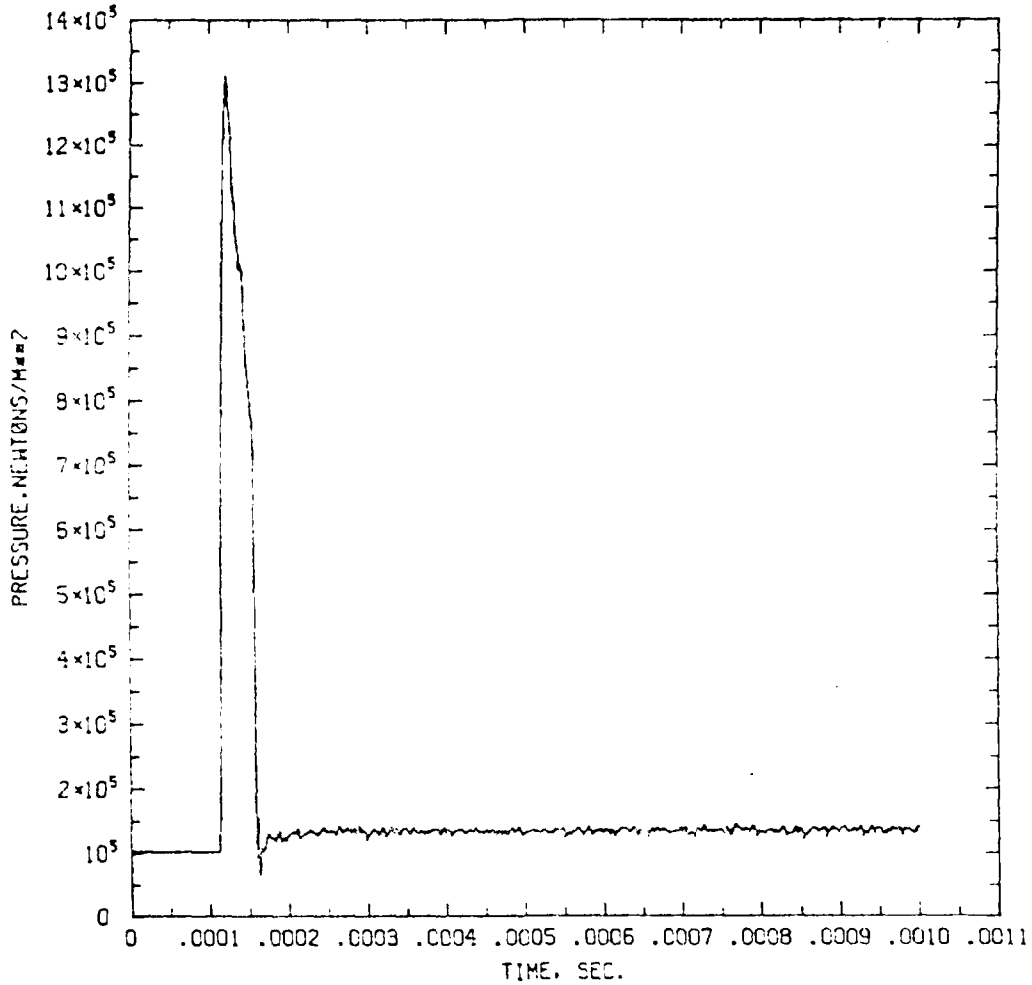


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS 46420000

Figure 43c

STATION 6. XS,YS= 0.182E+00 0.415E+00 M

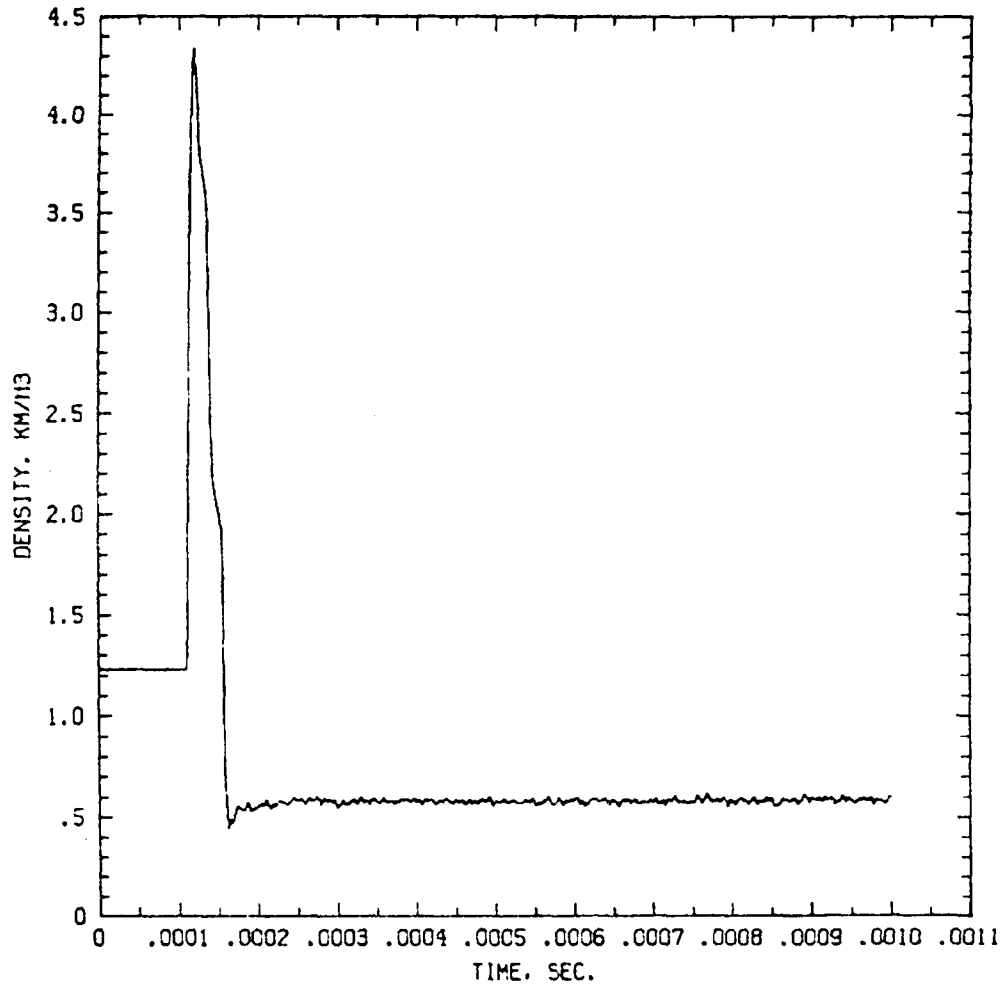


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS HOWZ0000

Figure 44a

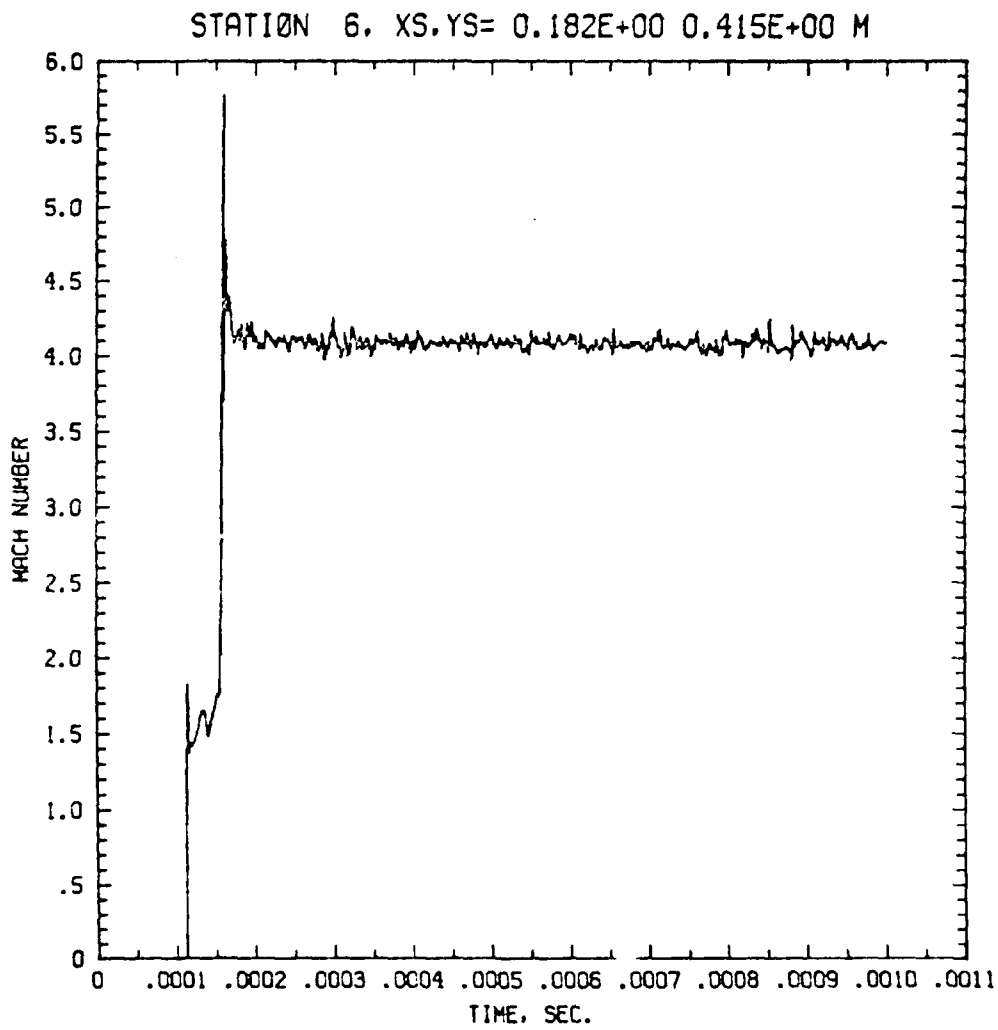
STATION 6. XS,YS= 0.182E+00 0.415E+00 M



105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS HS-Z0009

Figure 44b

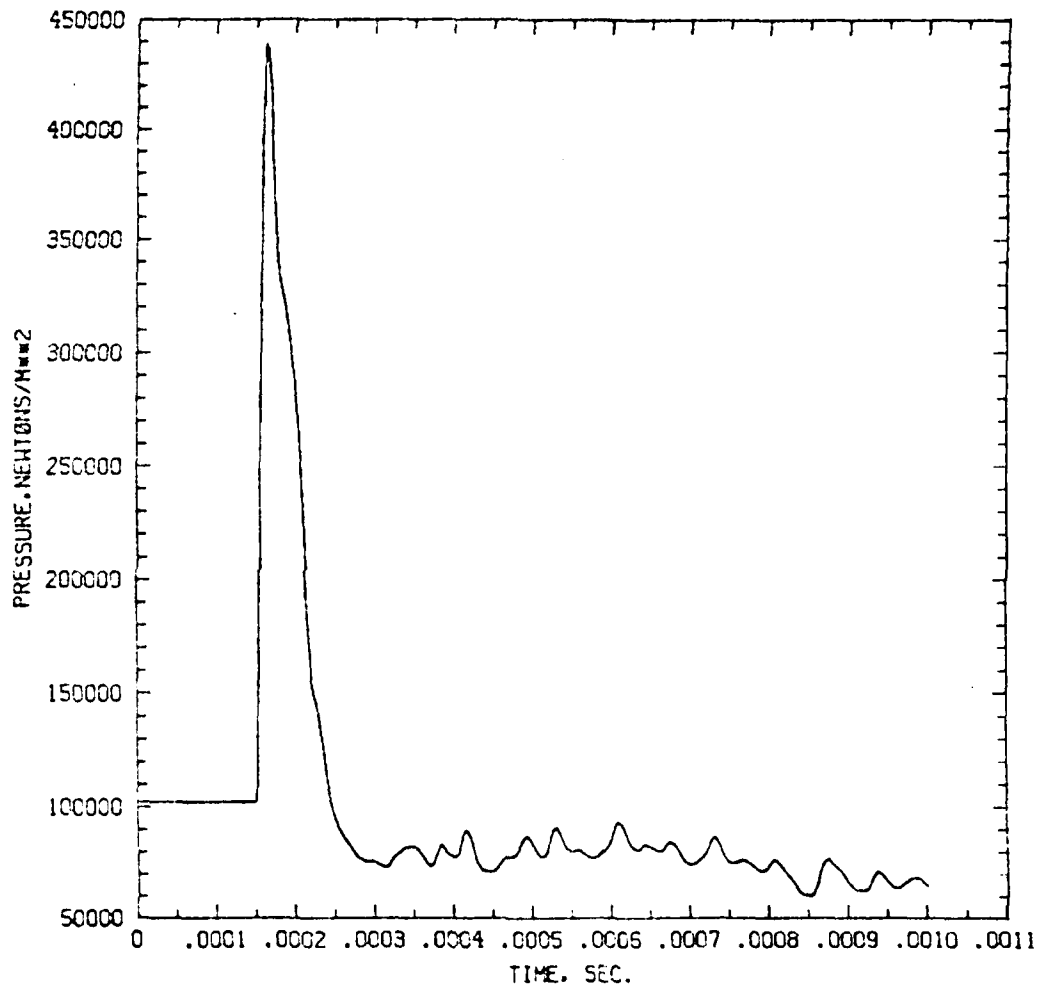


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS HENZO009

Figure 44c

STATION 7. XS.YS= 0.210E+00 0.315E+00 M

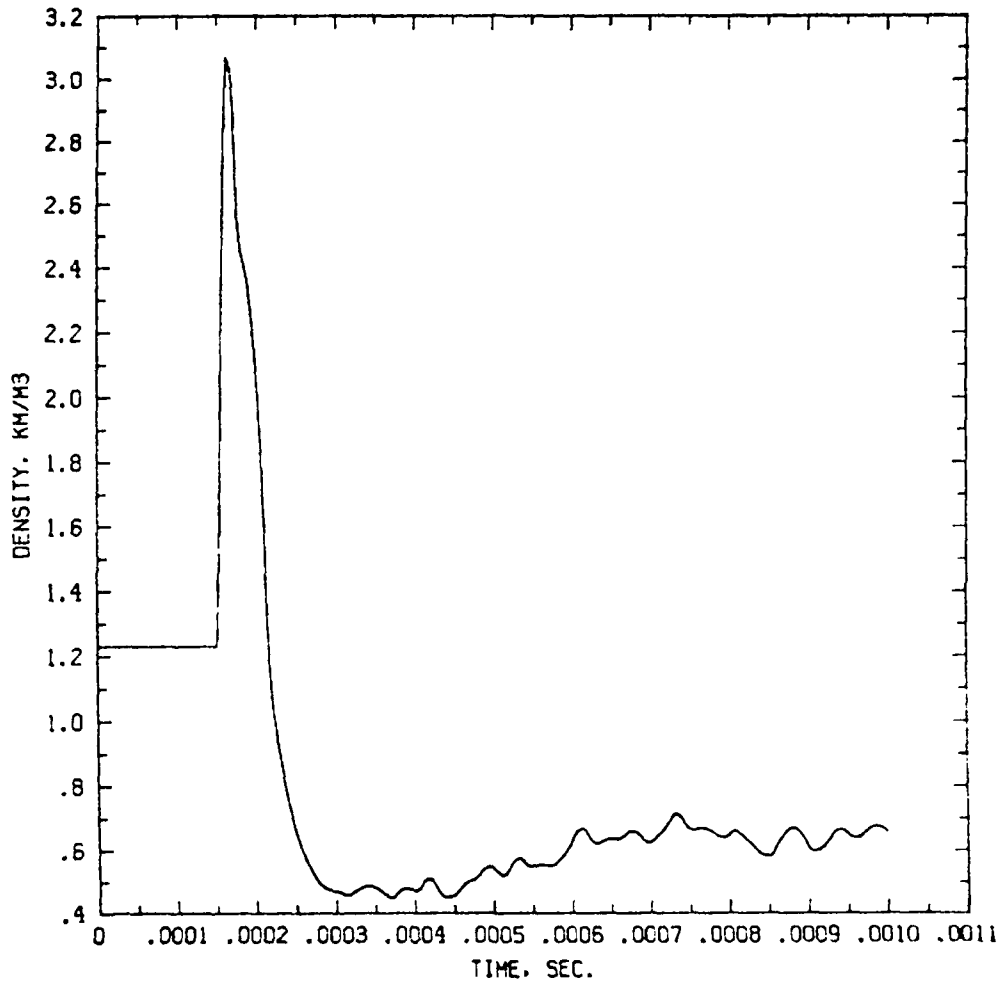


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS HOWZDOOS

Figure 45a

STATION 7, XS,YS= 0.210E+00 0.315E+00 M

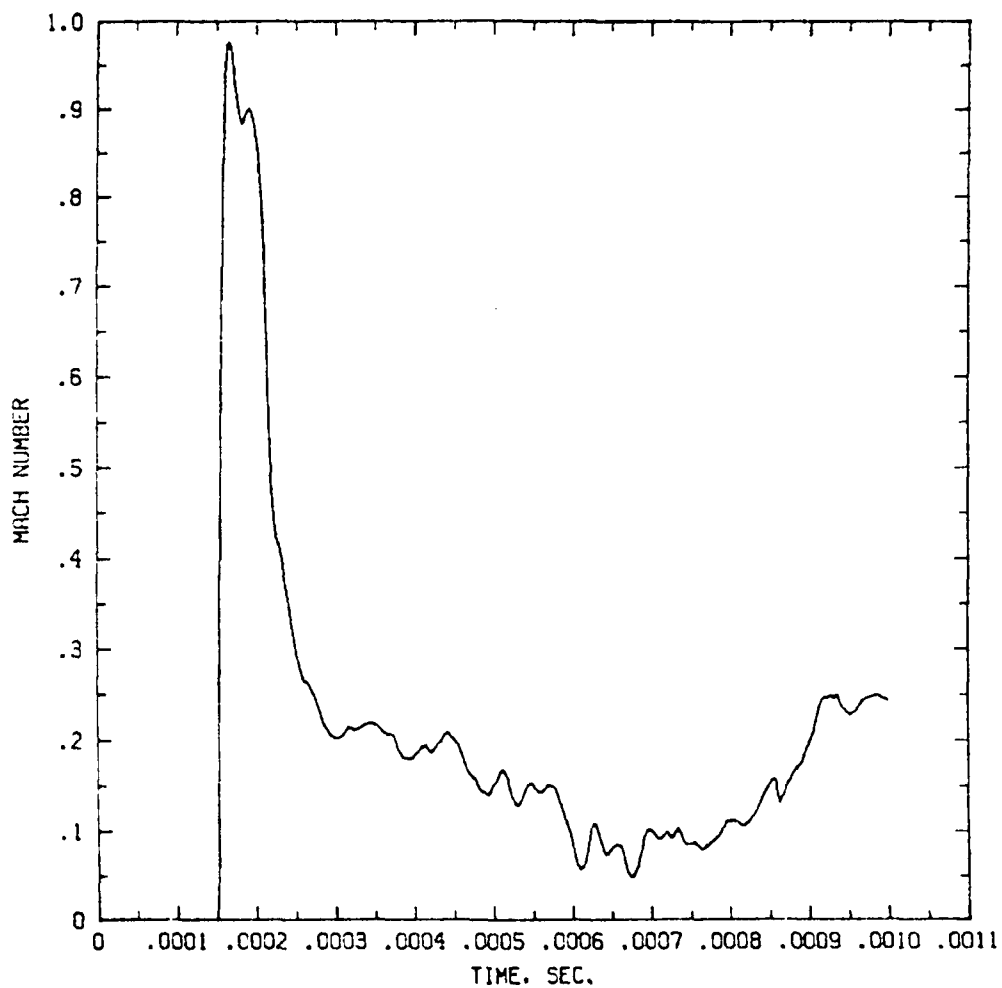


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS NONZERO

Figure 45b

STATION 7. XS.YS= 0.210E+00 0.315E+00 M

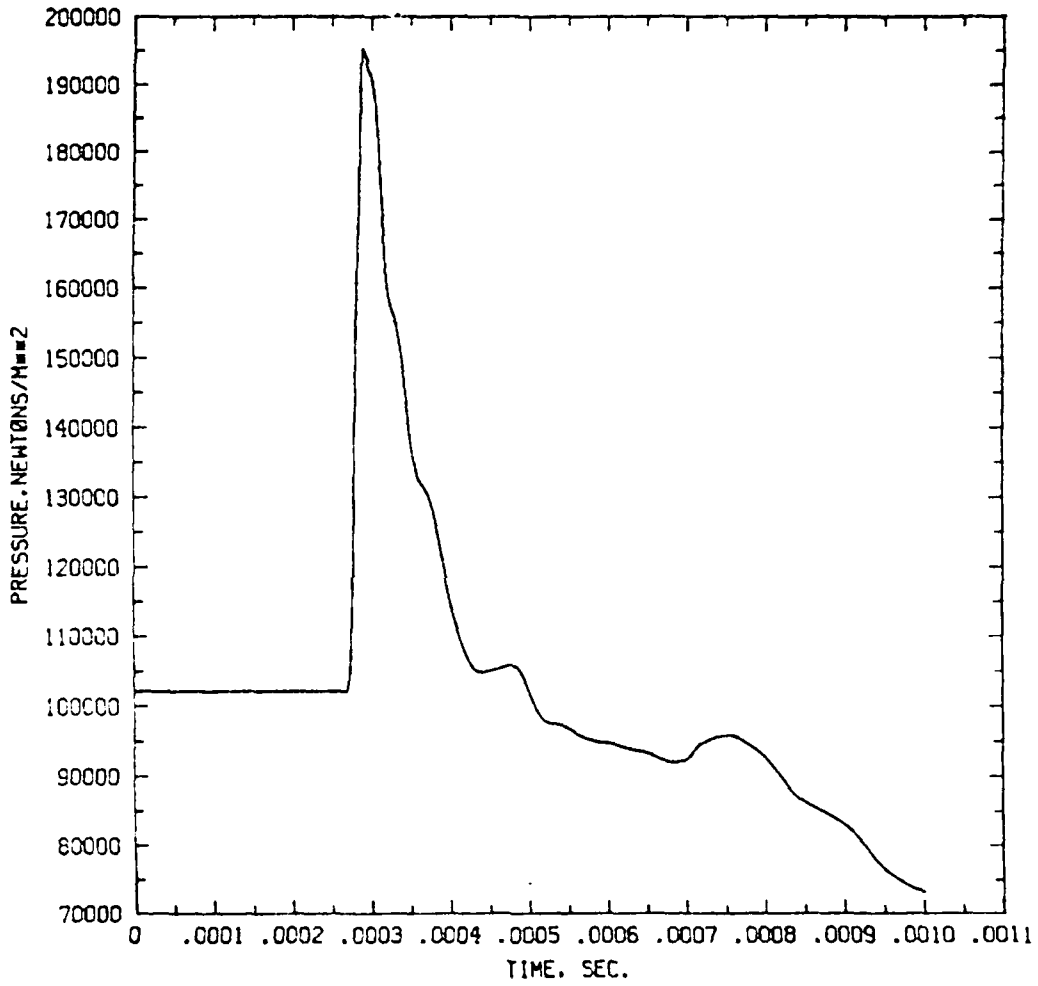


105 MM HOWITZER MUZZLE FLOW

8 DUMPS. LAST DUMP IS HOWZ0008

Figure 45c

STATION 8. XS,YS= 0.182E+00 0.210E+00 M

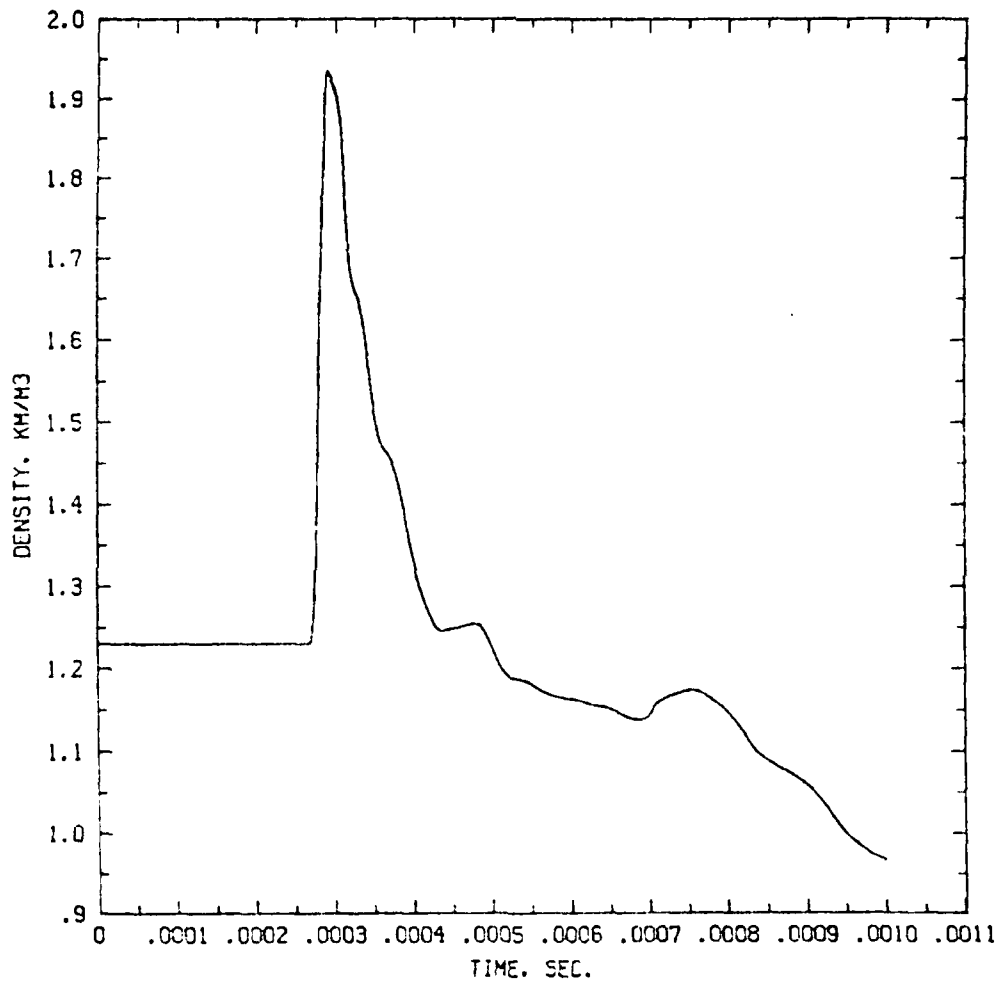


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS HSHZ0009

Figure 46a

STATION 8. XS.YS= 0.182E+00 0.210E+00 M

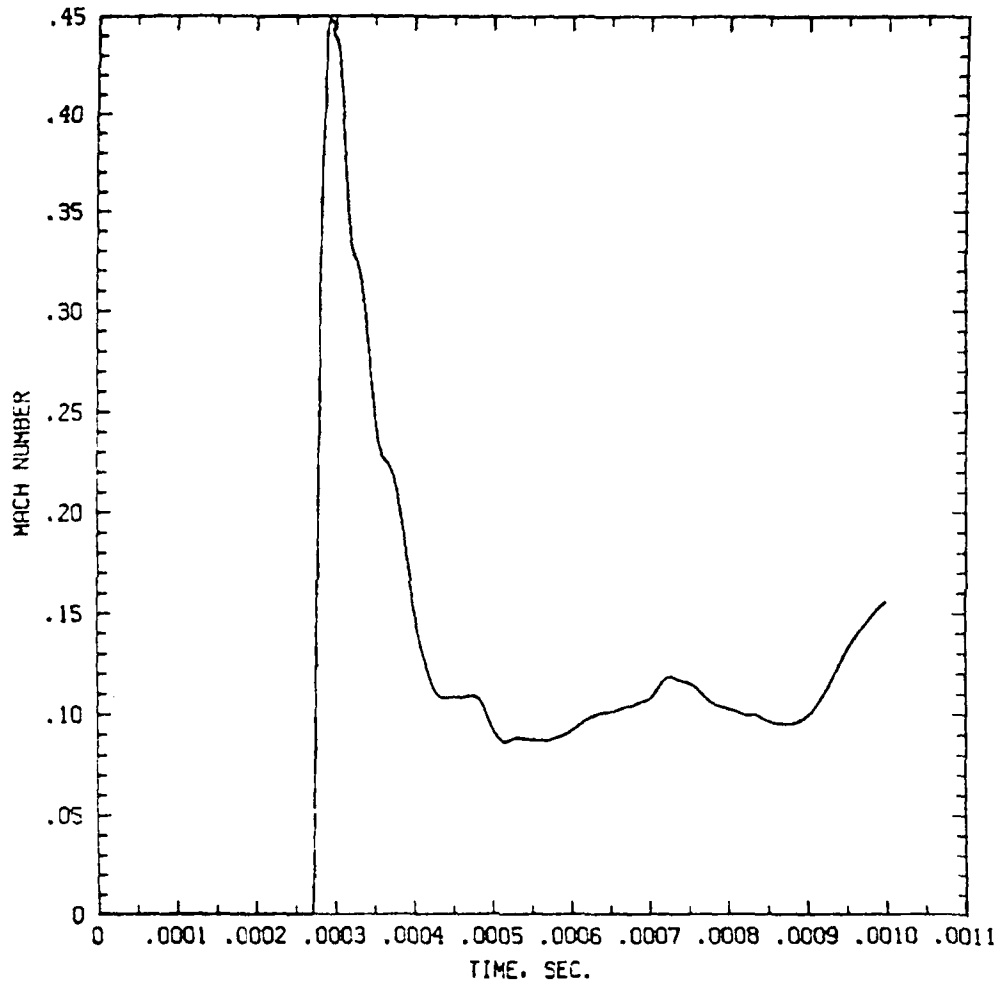


105 MM HOWITZER MUZZLE FLOW

9 DUMPS. LAST DUMP IS HOWZ0003

Figure 46b

STATION 8. XS,YS= 0.182E+00 0.210E+00 M

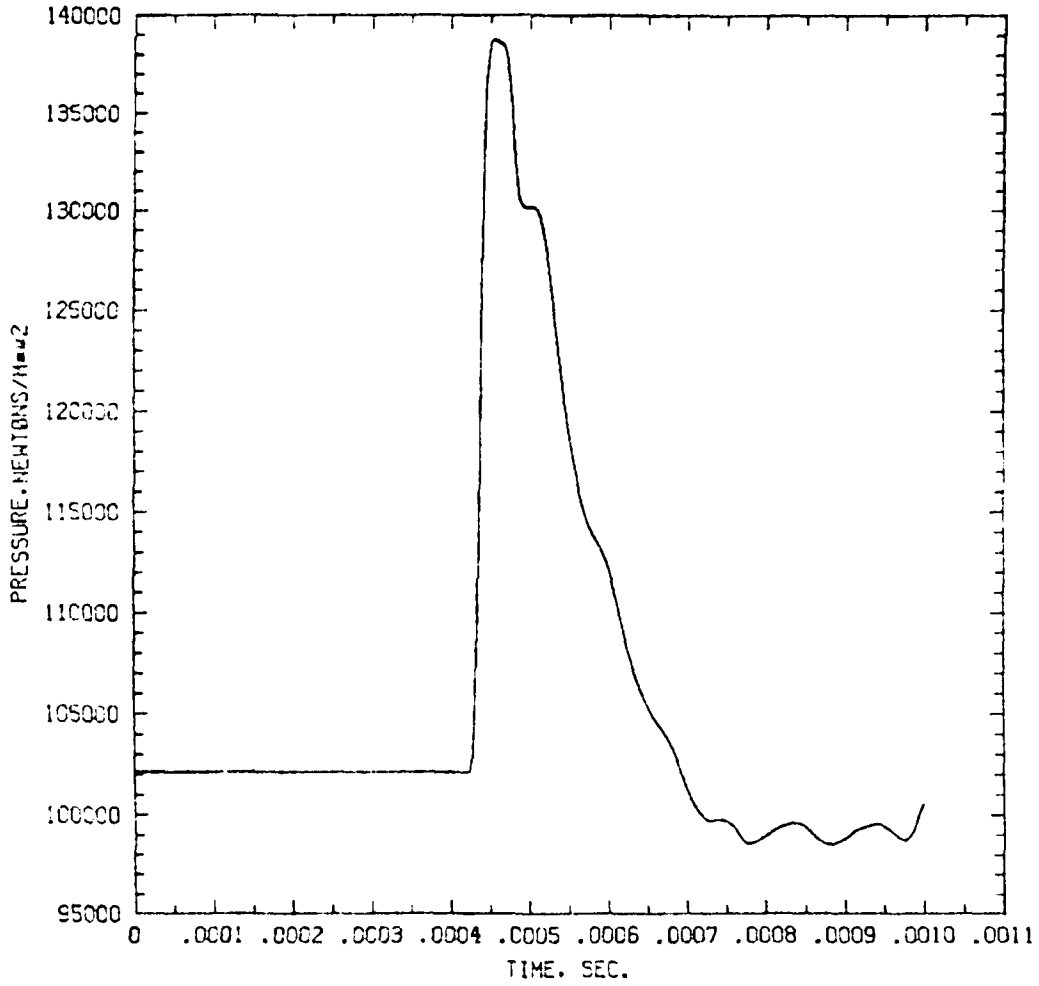


105 MM HOWITZER MUZZLE FLOW

• DUMPS. LAST DUMP IS NONZERO

Figure 46c

STATION 9, XS,YS= 0.105E+00 0.133E+00 M

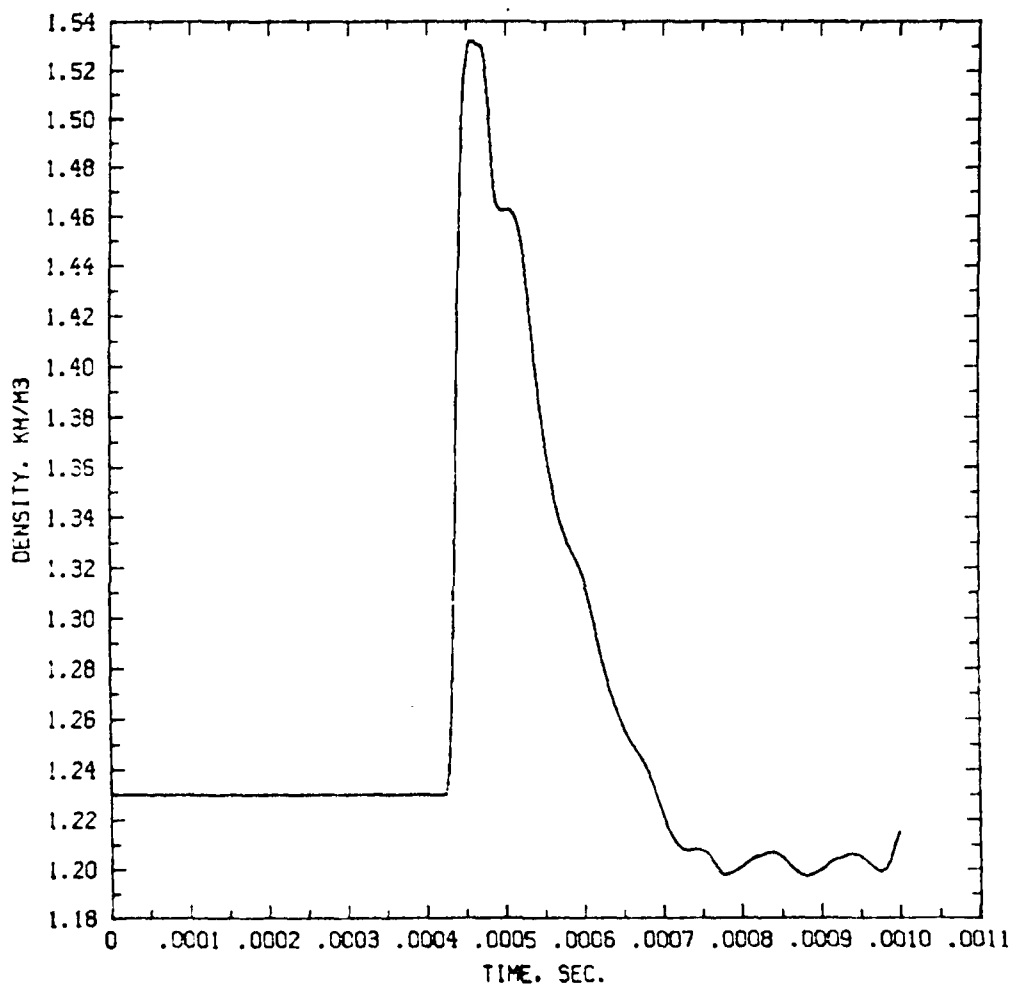


105 MM HOWITZER MUZZLE FLOW

9 DUMPS, LAST DUMP IS 40420009

Figure 47a

STATION 9, XS,YS= 0.105E+00 0.133E+00 M

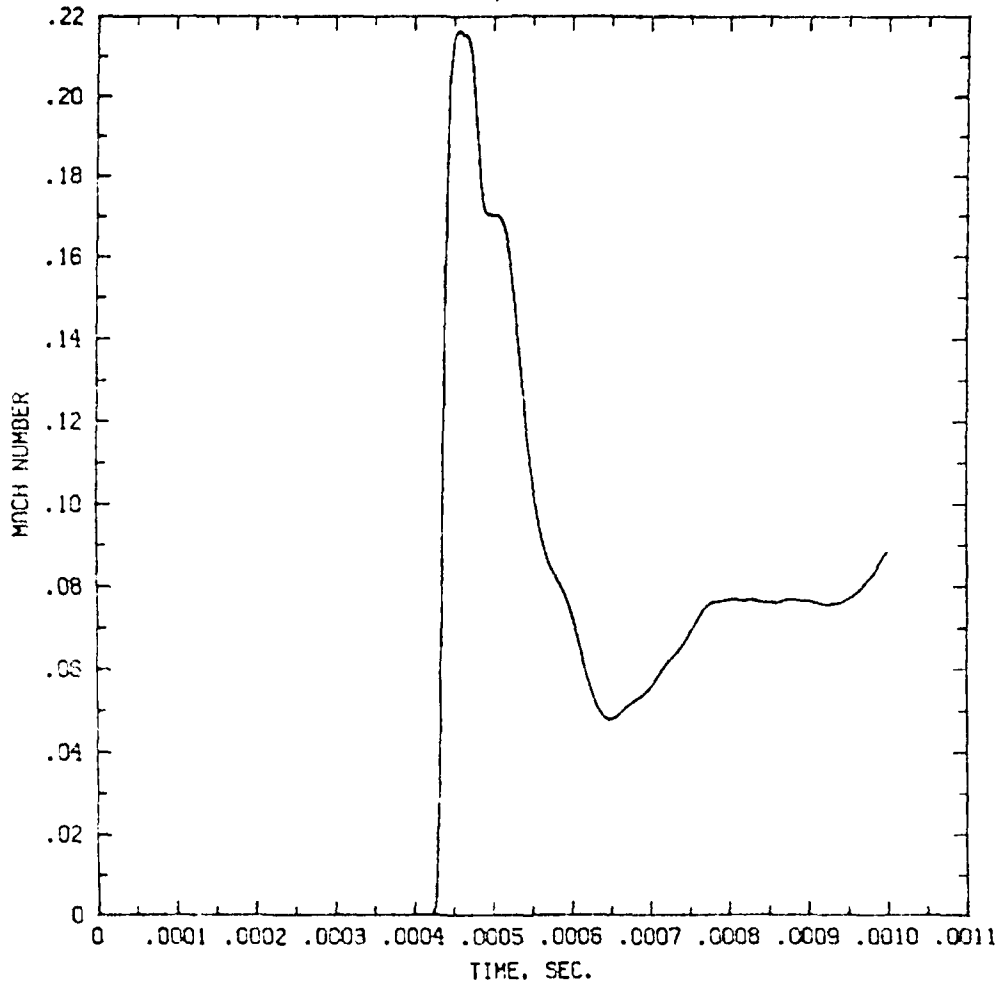


105 MM HOWITZER MUZZLE FLOW

6 DUMPS. LAST DUMP IS HENZO000

Figure 47b

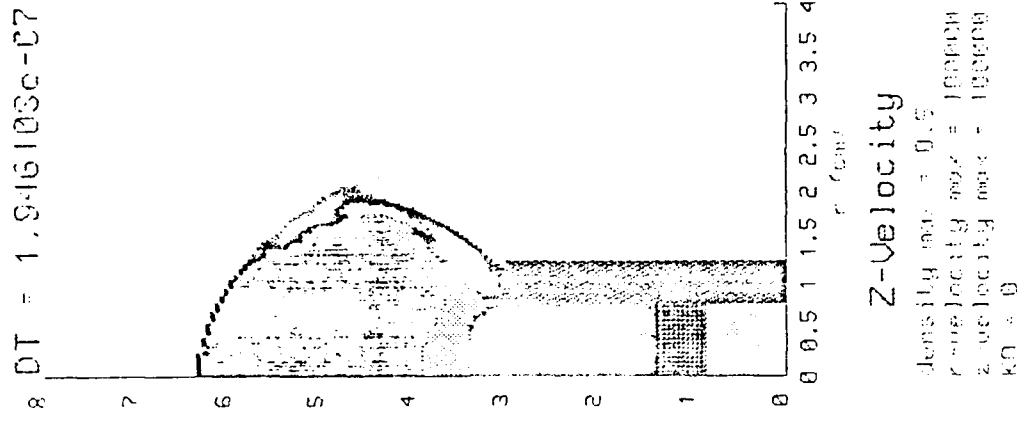
STATION 9. XS,YS= 0.105E+00 0.133E+00 M



105 MM HOWITZER MUZZLE FLOW

● DUMPS. LAST DUMP IS HEX-Z0002

Figure 47c



RFM Parallel Benchmark

Figure 48

## REFERENCES

1. Book, D.L., Boris, J.P., and Hain, K., "Flux-Corrected Transport: II. Generalizations of the Method," *J. Comp. Phys.* 18, 248 (1975).
2. Boris, J.P., "Flux-Corrected Transport Methods for Solving Generalized Continuity Equations," *NRL Memo Report No. 3237* (1976). ADA023891
3. Boris, J.P., and Book, D.L., "Flux-Corrected Transport: I. SHASTA, A Fluid Transport Algorithm that Works," *J. Comp. Phys.*, 11, 38-69 (1973).
4. Boris, J.P., and Book, D.L. "Flux-Corrected Transport III. Minimal-Error FCT Algorithms," *J. Comp. Phys.* 20, 397-431 (1976).
5. Colella, P., and Woodward, P.R., *J. Comp. Phys.* 54, 174 (1984); see also Woodward, P.R., and Colella, P., "High Resolution Difference Schemes for Compressible Gas Dynamics" in Proc. Seventh Inter. Conf. Num. Methods in Fluid Dynamics, Spring-Verlag, New York (1981), p. 434.
6. Harten, A., *Math. Comput.* 32, 363 (1978).
7. Schmidt, E.M., Specifications of Joint Computation of Weapon Blast Overpressures (personal communication Jan. 4, 1985).
8. Townend, I.H., and Edwards, D.G., "Numerical Simulation of Blast," *TICP JRA, Dover, NJ*, May 29, 1982.
9. Van Leer, B., *J. Comp. Phys.* 32, 101 (1979).
10. Zalesak, S.T., "Fully Multidimensional Flux-Corrected Transport Algorithms for Fluids," *J. Comp. Phys.* 31, 335-362 (1979).

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