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COMPUTER CODE FOR CALCULATING  
ONE-DIMENSIONAL FLOW

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COMPUTER CODE FOR CALCULATING ONE-DIMENSIONAL FLOW

By

John O. Erkman and David J. Edwards

ABSTRACT: This report describes the implementation of the computer code "Wondy" for one-dimensional hydrodynamic computations. The code was written at Sandia Laboratory for a Control Data Corp. computer. It has been put into Fortran IV form by the authors for use on the IBM 7090 computer. The code was selected because it is adequately documented and because it handles problems involving elastoplasticity, porosity, fracture, and release of the reaction energy of explosives. The code is expected to be useful in simulating, designing, and interpreting experiments.

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Carl Boyars, Chief  
Advanced Chemistry Division  
CHEMISTRY RESEARCH DEPARTMENT  
U. S. NAVAL ORDNANCE LABORATORY  
White Oak, Silver Spring, Maryland

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This work was carried out under ORDTASK No. ORD 331-002/092-1/UF 19-332-302 and MAT O3L 000 R011 01 01 FR 59. The computer code which is described will be used to supplement and support the experimental work of both tasks on detonation properties of solid propellants and explosives.

E. F. SCHREITER  
Captain, USN  
Commander

*Albert Lightbody*  
ALBERT LIGHTBODY  
By direction

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COMPUTER CODE FOR CALCULATING  
ONE-DIMENSIONAL FLOW

INTRODUCTION

1. The usefulness of a computer code for calculating one-dimensional flow is obvious. An application of such a code is the simulation of experiments. Such simulation may affect both the design of the experiments and their interpretation. For example, the study of attenuation of shock waves in aluminum was more understandable after a series of calculations were performed.<sup>1</sup> Also, the design of the explosive system for throwing an aluminum plate was expedited by the use of such a computer code.<sup>2</sup>

2. There are at least two situations for which a 1-D code could give useful results immediately. One of these involves the detonation of charges which have been overboosted. Obviously, the flow in a cylindrical charge is two-dimensional. Some insight, however, may be obtained by calculating the flow in a semi-infinite slab. The calculation should show how the effects of overboosting decay. Also pressure-time profiles from the calculation should serve as a guide for experimental work with the electromagnetic probe.

3. The other situation is the flow induced by detonating a charge of explosive in contact with Plexiglas (PMMA). Both the rate of decay of the stress in the shock front and the stress-time and particle velocity-time profiles will help interpret experiments.

4. Obviously, a computer code can be acquired by either writing one, or by using an existing code. One of us (Erkman) has had considerable experience at putting together such codes. Unfortunately, his best effort was a code written in ALGOL. Translating his code into FORTRAN IV seemed a long and unrewarding task. Other versions of Erkman's earlier work are available in FORTRAN IV but they are poorly documented. Thus it appeared desirable to find a code which we could put into operation with only moderate effort and which both of us could use with some facility.

5. Some of the requirements for a code are that it be in FORTRAN IV (or closely similar language), that it be well documented, that it should be thoroughly checked out and in continuous use elsewhere. We wanted a code with versatility so that we could use multiple material regions (including voids) and elastoplastic equations of state as well as fluid types. Versatility was also needed to treat shock-induced effects from simple compression through material fracture up to actual detonation of explosives.

6. The Sandia Corporation WONDY Code. A code which met our specification was the WONDY code from Sandia Corporation.<sup>3</sup> The documentation is very good compared to the usual effect. The code is the results of several years experience with such codes on the part of Dr. Herrmann. It is in use at Sandia Corporation and errata have been distributed since the original publication. Two reports containing new subroutines for use with WONDY have also been published.<sup>4,5</sup> Thus, not only is the code in use, but also it is being developed so that it becomes progressively more useful. WONDY handles all of the equations of state of current interest. This includes the elastoplastic equation of state which has considerable flexibility in the choice of the yield condition. Modifications of the code can be made with a minimum amount of trouble (or so it appears).

7. A code for two-dimensional flow, TOODY, is also available from the Sandia Corporation. Acquaintance with WONDY should help with implementing TOODY because of the common nomenclature, common theoretical basis and style of coding.

8. The code for one-dimensional flow consists of the following:

1. WONDY - the main program.
2. GENERATE - reads input and initializes arrays.
3. MORSTORE\* - initializes extra arrays.
4. BOUNDARY\* - handles special boundaries.
5. JLOOPING - handles logic to advance through meshes.
6. MOTION - computes conservation of mass and momentum.
7. STATE1\*\* - first of six subroutines for equation of state.
8. OUTPUT\* - handles special output.
9. OUTL\* - handles special output.

\* May be dummies

\*\* Up to five equations of state subroutines may be dummies

The code is much like that of Wilkins<sup>6</sup> which has also been used extensively and widely copied. Provisions are included for "spall and join" so that some of the effects of fracturing can be simulated. Other useful features are the dump and restart option, the energy and momentum checks, tests for overflow and for activity; these features are described adequately in reference 3.

9. Implementing WONDY on the IBM 7090 Computer. The code is written in FORTRAN for the CDC 3600 Computer. As in many more modern (and more useful) computer languages, CDC-3600 FORTRAN permits the use of words of more than six characters. In order to run the code on the IBM 7090 it was necessary to shorten those words which contained more than six characters. We think we have accomplished this without giving any two identifiers the same name. The process was simplified to some extent by the use of the SHARE program; UNRAVL<sup>7</sup>, which gives a dictionary of the identifiers used in a program, and the line number on which they are used. We also changed a number of control statements from the CDC format to the IBM format.

10. An undesirable feature of the WONDY code was the out-of-sequence numbering of the statements. This situation exists in most codes which are written in a language such as FORTRAN which requires numbering of some statements. The situation was rectified by using the SHARE code, STNORD.<sup>8</sup> The resulting code is now easier to follow because of the new numbering system, and is even better documented because of the use of UNRAVL.

11. It is probable that no two persons will want exactly the same output from any code. We have made some modification in WONDY in order to give the output which we desire. One of our requirements was that the results of the computations for the first 10 cycles be printed. This is a help in determining if the computations are started properly. So far no use has been made of special output subroutines.

12. The subroutine for "explosive burn" causes the explosive to detonate at a steady rate prescribed by an input quantity. This has many applications such as calculating the velocity given a plate by a charge of explosive. In some cases, however, the explosive should burn at a variable rate. This can be accomplished by calculating a "burn fraction" based on the volume of the "cell".<sup>6</sup> A subroutine has been written to perform this function and has been used in a sample calculation.

13. Computation on the IBM 7090. Three computations have been performed on the IBM 7090. These are described to some extent in Table I.



T A B L E I  
DESCRIPTION OF COMPUTED CASES

CASE	PLATE I				PLATE II			
	Material	Equation of State	No. of Cells	Plate Thickness	Material	Equation of State	No. of Cells	Plate Thickness
1.	Aluminum	EP*	25	0.5cm.	Al	EP	100	2.0cm.
2.	Pentolite	Gas	25	0.5cm.	Al	EP	100	2.0cm.
3.	Pentolite	Gas	25	2.5cm.	NH <sub>4</sub> ClO <sub>4</sub>	Gas**	500	25.0cm.

\*Elastoplastic

\*\*Burn fraction computed on basis of volume

14. The first case was a computation of the effects of one aluminum plate hitting another. The equation of state for aluminum was elastoplastic with a constant yield of 2.7 kbars. This case gave an illustration of the way the code handles fractures, six of which formed in close proximity in the target plate. Their proximity was caused by the flatness of the stress profile (stress vs distance). Finer zoning would be required before much confidence could be placed in the computed number of fractures and the location of each fracture.

15. The second case was computed so that we could familiarize ourselves with the explosive burn option of the code. The polytropic gas equation was used for the detonation product gases and the elastoplastic equation of state was used for the aluminum target.

16. The third case was a simulation of an overboosted detonation. A conventional burn fraction which produces a steady detonation was used for the donor explosive. In the acceptor explosive, the detonation energy was released after a cell was partially compressed. Thus the computation contains nothing in the way of chemical reactions. Wave interaction should be reproduced rather faithfully, however, Figure 1 shows the computed path of the detonation in the acceptor charge. Distance is measured from the plane of the detonator-booster interface. This cannot be compared readily with experimental results which are for cylinders of finite diameter. Because of the side effects, the experimental results should show a faster decay of the transient than do the computed results.

17. The polytropic gas equation of state was used for the detonation products in these computations. Parameters required by the code and the values used are:

Parameter	Pentolite	AP
$\rho_0$ g/cc	1.72	0.7
$c_0$ cm/ $\mu$ sec	0.588	0.211
$\gamma$	2.77	2.5
D cm/ $\mu$ sec	0.801	0.295

where  $\rho_0$  is the density of the undetonated explosive,  $c_0$  is the sound speed at the Chapman-Jouguet plane,  $\gamma$  is the adiabatic exponent and D is the detonation velocity. No claim is made as to the accuracy of the parameters or the form of the equation used. At this point we are interested in learning to use the code. More accurate equations of state can be used when our interest requires them.

18. Other results obtained from the code for the overboosted charge shown in Figure 2. This is a plot of the particle velocity at the detonation front, i.e., the peak particle velocity vs the distance. Elementary theory of detonation gives a particle velocity at the C-J plane of  $D/(\gamma+1)$ , or 0.85cm/ $\mu$ sec. At 26cm. from the initial plane of detonation, the value of the calculated particle velocity is greater than 0.10 cm/ $\mu$ sec. This means the detonation is still being over-driven.

19. Peak pressure is shown in Figure 3 as a function of distance. This also shows that the detonation is over-driven because the C-J pressure in the charge is 17 kbars.

20. Particle velocity profiles are shown in Figure 4 for three locations in the AP charge. The electromagnetic probe should give profiles similar to these. If side rarefactions penetrate to the probe, the experimental results will differ considerable from the computed results. If probes are exposed to side rarefactions, we will need computations for two-dimensional flow as a guide in understanding the experimental results.

21. Figures 1-4 are shown only to illustrate the proper functioning of the code. The names of the materials have been deliberately omitted from the graphs to emphasize the fact that inputs were reasonable but not necessarily accurate.

22. Suggestions for potential users of WONDY. Anyone interested in using WONDY should acquire reference 3 either from Sandia Corporation or the NOL Library. A listing of the modified code can be obtained from the authors of this report. Changes in the glossary, and the code will be documented for distribution as needed. The results of UNRAVL will also be available as a supplement to the original documentation. The authors will attempt to answer questions concerning the implementations of the code. If necessary, questions can be directed to the originator of the code at Sandia Corporation. These people have displayed a cooperative spirit in the past, and it is expected that they will maintain interest in helping others to use the code.

REFERENCES

1. J. O. Erkman and A. B. Christensen, J. A. P. 38 5395 (1967)
2. J. O. Erkman, A. B. Christensen and G. F. Fowles "Attenuation of Shock Waves in Solids," Stanford Research
3. W. Hermann, P. Holzhauser and R. J. Thompson, "WONDY, A Computer Program for Calculating Problems of Motion in One-Dimension," SC-RR-66-601, (Feb 1967)
4. D. B. Hayes, W. Hermann and P. Holzhauser, "Subroutine for Calculating Radioactive Energy Addition for Use with the One-Dimensional Wave Propagation Program WONDY." SC-RR-67-572, (July, 1967).
5. W. Herrmann, "Equation of State of Crushable Distended Materials" SC-RR-66-2678, (March 1968)
6. M. L. Wilkins, "Calculation of Elastic-Plastic Flow" Methods in Computational Physics, edited by Berni Alder, Sidney Fernbach, and Manuel Rotenberg, Vol 3, Academic Press N. Y. (1964).
7. T. Orlow, "Unravel-Generate Reference Table for Fortran Programs", NOL Computer Library No. 1.06.01
8. N. K. McElroy, "Stnord-Fortran Statement Number Reordering Program", NOL Computer Library No. 1.07.16

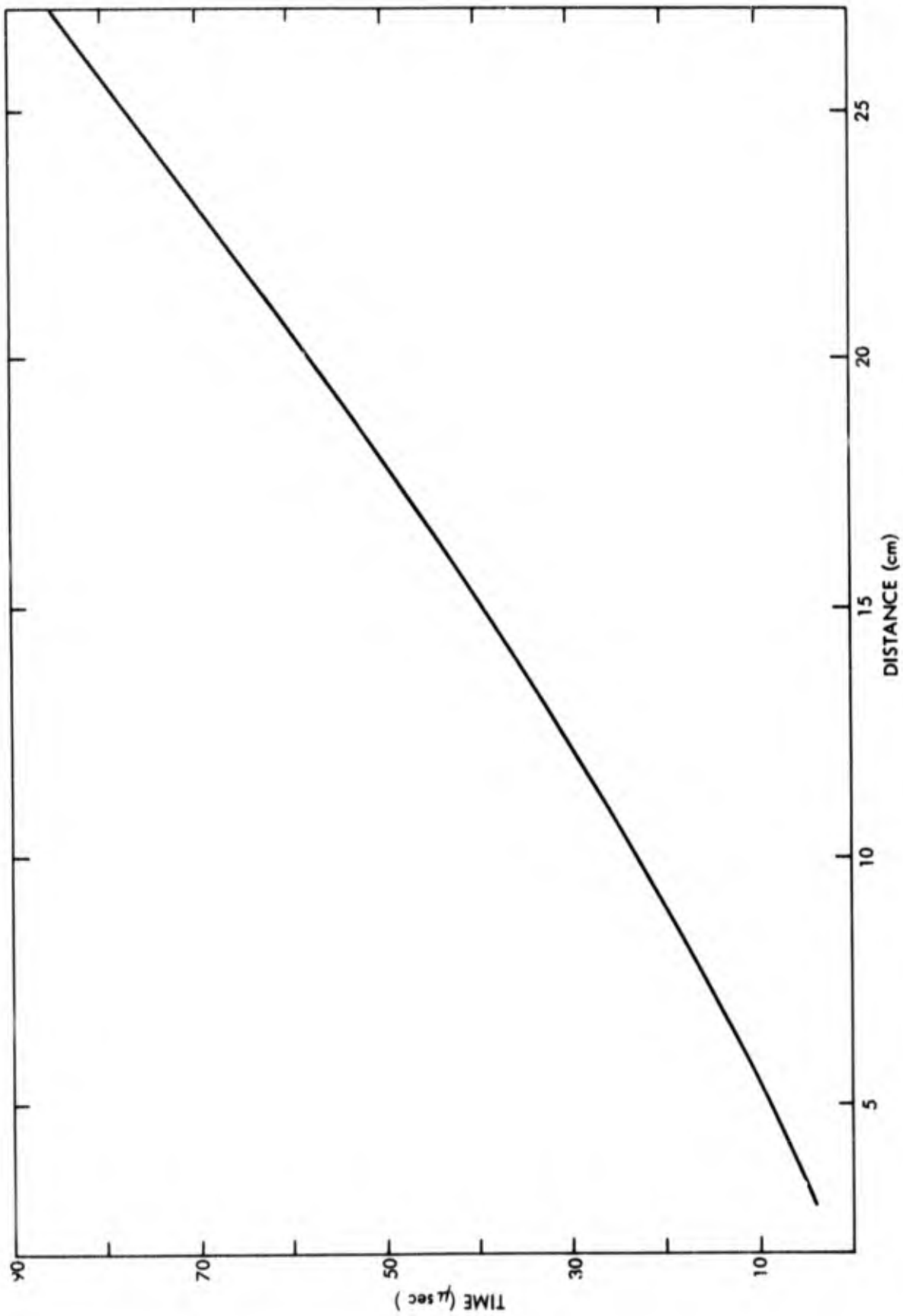


FIG. 1 TIME VS DISTANCE FOR OVERBOOSTED DETONATION

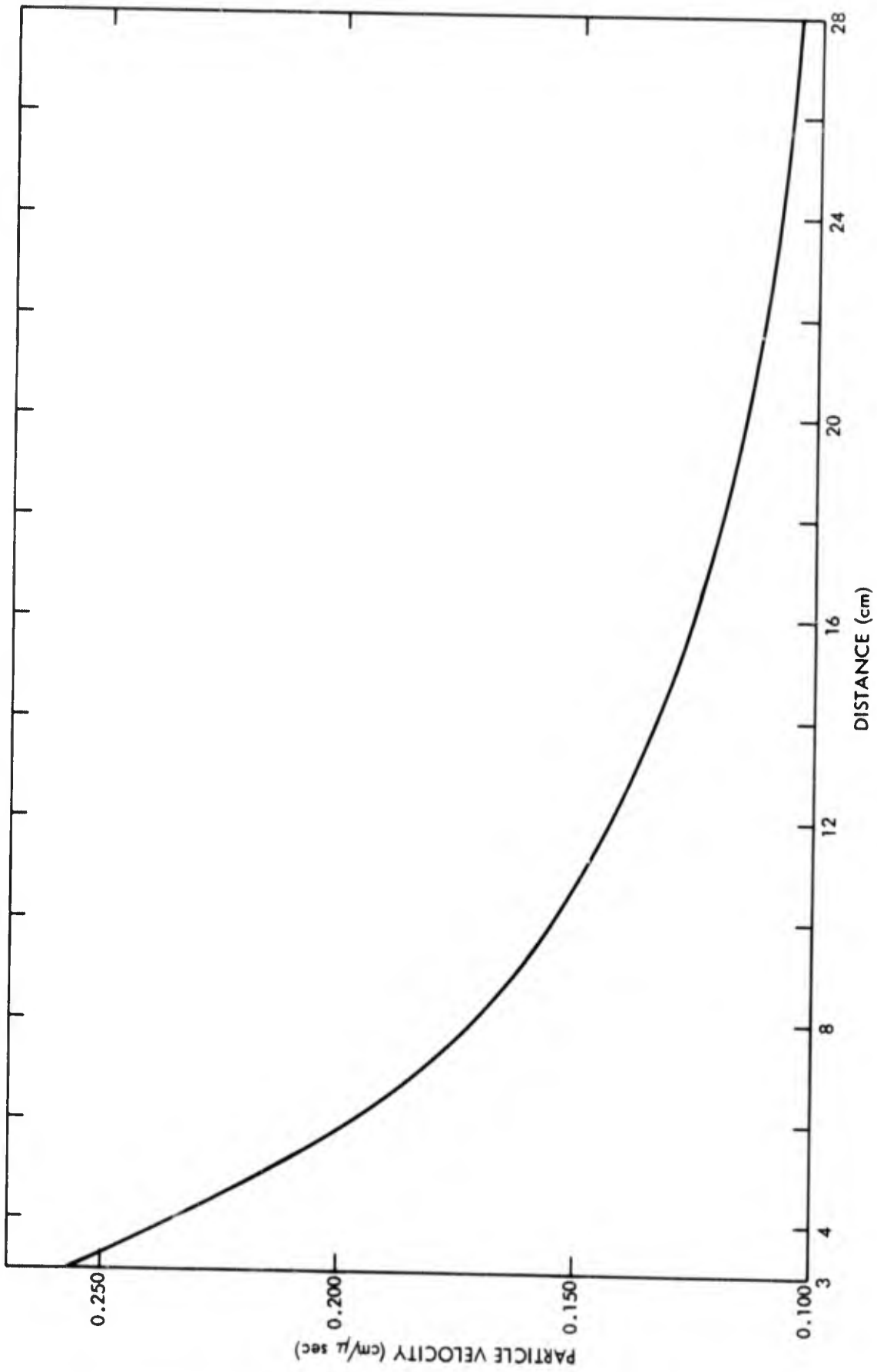


FIG. 2 PARTICLE VELOCITY AT DETONATION FRONT VS DISTANCE

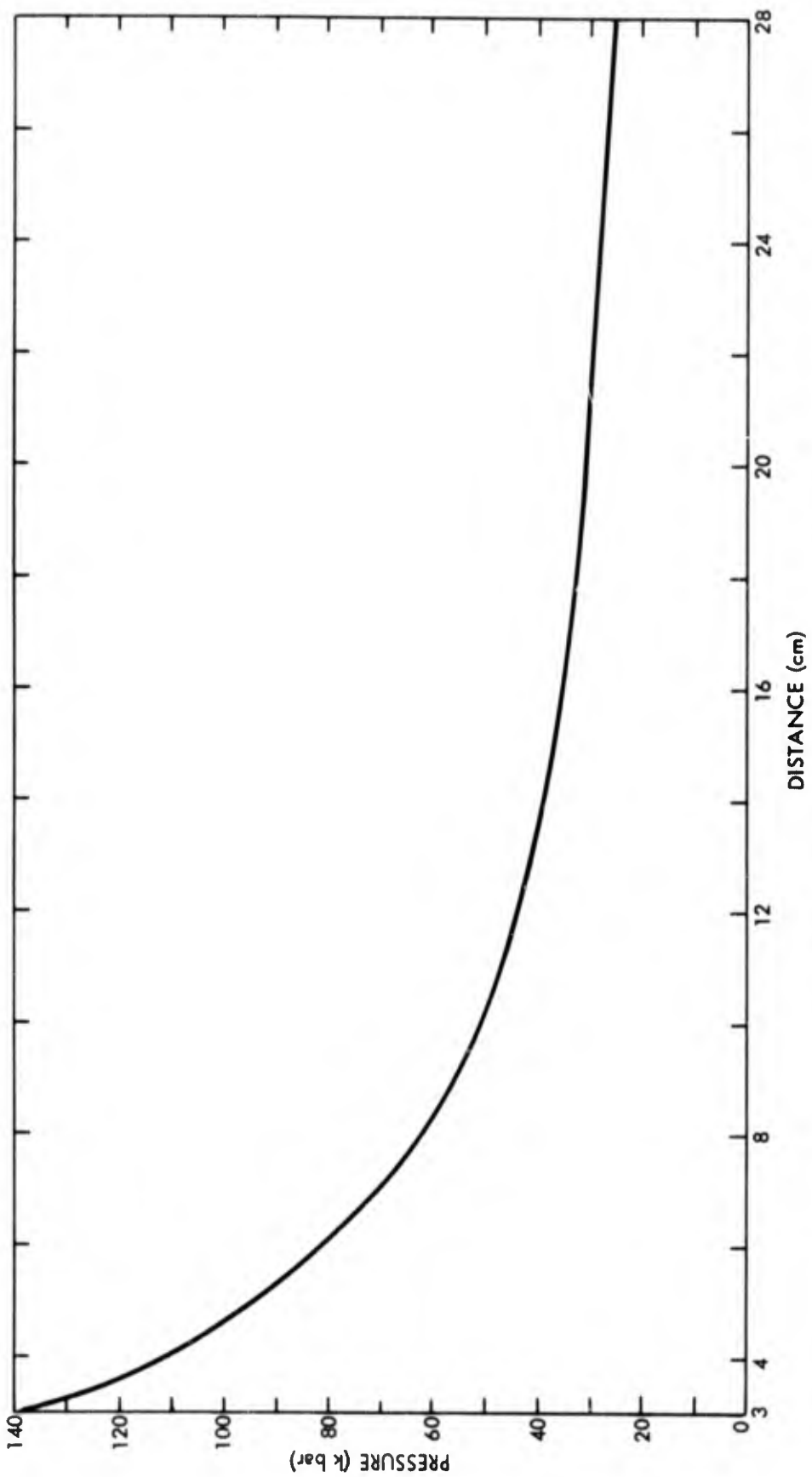


FIG. 3 PRESSURE AT THE DETONATION FRONT VS DISTANCE

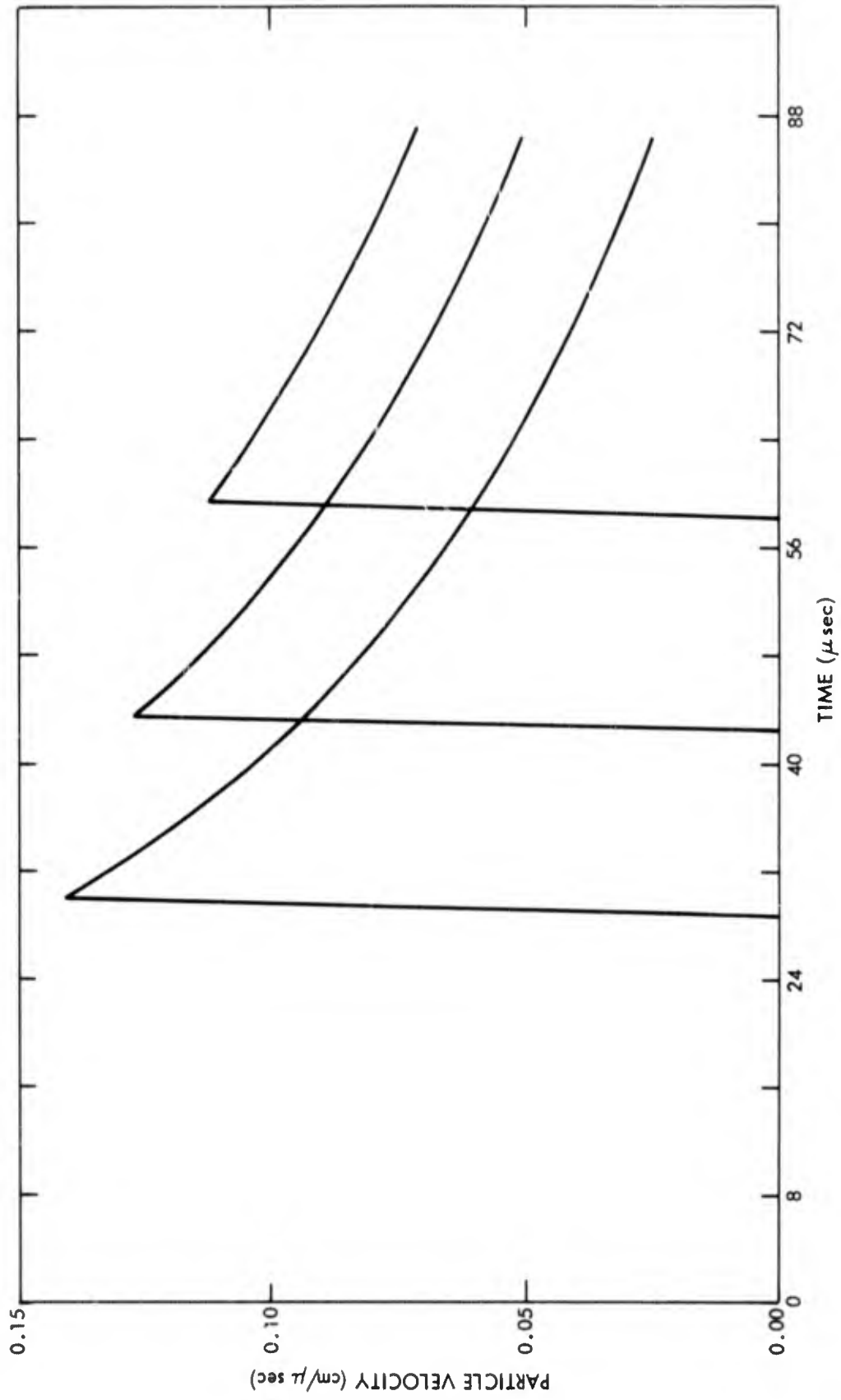


FIG. 4 PARTICLE VELOCITY PROFILE



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