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THE MEASUREMENT OF PARTICLE VELOCITY IN PRESSED TETRYL

By
D. J. Edwards
J. O. Erkman
Donna Price

3 AUGUST 1972

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13 ABSTRACT

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Particle Velocity						
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C-J parameters						
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THE MEASUREMENT OF PARTICLE VELOCITY IN PRESSED TETRYL

The work described in this report was carried out under IR 159, Task MAT-03L-000/ZR011-01-01 (Transition from Deflagration to Detonation) of NOL's Independent Research Program.

The work described is the measurement of particle velocity vs. time in detonating pressed tetryl by the electromagnetic gage technique. The C-J parameters determined in this study are in agreement with interpolated Russian values and with Ruby code results. The identification of commercial materials implies no endorsement or criticism by the Naval Ordnance Laboratory.

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Captain, USN
Commander

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THE MEASUREMENT OF PARTICLE VELOCITY IN PRESSED TETRYL

INTRODUCTION

The particle velocity (u) vs time (t) behavior in the detonation zone of pressed tetryl has been investigated using the electromagnetic velocity (EMV) gage. The EMV gage and associated instrumentation are described in previous reports.[1,2,3,4] The particle velocity is obtained from

$$u = V \cdot 10^4 / (\ell \cdot H) \tag{1}$$

where u is in mm/µsec, V is the emf generated across the gage base in volts, H is the magnetic field in gauss, and ℓ is the gage base length in mm.

The objective of this study was to obtain the C-J parameters of tetryl at $\rho_o = 1.51$ gm/cc. These results could then be compared with values obtained for pressed[4] ($\rho_o = 1.60$ gm/cc) and cast[1,3] ($\rho_o = 1.62$ gm/cc) TNT. Tetryl has been shown to have a much shorter reaction time (τ) than pressed TNT at approximately the same density.[5] Our smallest previously reported[4] value of τ obtained, using the EMV gage, was 141 ns for pressed TNT. In this study we attempt to resolve a reaction time of ~ 100 ns. The C-J particle velocity (u_{CJ}) will also be used to obtain the pressure at x = 0 mm in the NOL Large Scale Gap Test (LSGT) in which tetryl was used.

EXPERIMENTAL

Material. Two different lots of tetryl were used in this work, X573 and X682. Both lots are Grade 1, Class A explosives. X573, which contains 0.5% graphite, was obtained in the form of pellets 50.8 mm in diameter and 25.4 mm long. X682 was pressed isostatically at NOL and machined into pellets of 50.8 mm diameter and the required length, x (25.4 or 50.8 mm). Charges from both lots had a density of 1.51 ± 0.01 gm/cc. The reported detonation velocity is 7.17 mm/µsec.[6]

Experimental Setup. The explosive charge and booster configuration used in this work is shown in Figure 1. Baratol-pentolite plane wave boosters, PWB (50.8 mm diameter), were used for the plane wave initiated shots. The PWB was initiated by a primacord lead (120 grain/foot, RDX) 30 cm long which in turn was initiated by an exploding bridgewire detonator. For the point initiated shots, the primacord lead initiated the tetryl directly. The primacord isolates the charge from the detonator to prevent possible stray signals from the firing unit being picked up by the gage.

The EMV gage consists of a rectangular loop of aluminum foil 0.025 mm (1 mil) thick and ~ 5 mm wide. It is mounted in a tetryl back-up assembly whose thickness. F, is 25.4 mm. The length of the base of the gage, ℓ, is determined by the width(2 - 10 mm) of piece B in Figure 1. The gage is mounted in the tetryl by shaping the foil around piece B; a thin layer of silicon grease is placed on pieces B, C and D except near the gage. Then pieces B, C and D are placed together and cemented with Duco cement under a slight pressure. The gage circuit is completed by connecting the foil leads (30-35 mm long) to a RG 58 C/U coaxial cable (50 ohms nominal impedance) with a 50 ohm resistor in series with the foil.

Instrumentation and Data Reduction. The instrumentation and data reduction used in this study are exactly the same as those described in references (2,3).

Spurious Electrical Noise. In the study of pressed and cast TNT[1,3,4], it was found that the grounded Al baffle shown in Figure 1 (0.013 cm thick, 6.4 cm square) greatly reduced spurious electrical noise. This procedure did not work for PWE graphited tetryl (X573). The noise in that case was greatly reduced by using non-graphited tetryl in conjunction with the grounded Al baffle. For the point initiated work, two small grounded strips of Al at the edge of the charge eliminated this noise for both graphited and non-graphited tetryl.

RESULTS AND DISCUSSION

A total of 39 shots were attempted in this investigation; of these 19 resulted in useful records. Of the remaining 20, the records were deemed useless because of either irrelevant noise or malfunction of the oscilloscope. Table 1 contains the list of shots which will be used in the following discussion.

Comparison of u,t Curves in Tetryl for Different Thickness Gages.

With the EMV gage method, one has to decide what thickness foil to use as the gage in the explosive under investigation. One problem with the EMV gage is that, as the gage material heats up, its resistance increases. The rate of heating depends on the gage thickness for a given material (in this case, aluminum). Also the thinner the material, the higher the initial resistance of the gage. If the resistance of the foil becomes comparable with the resistance of the reacting explosive and its detonation products, then the voltage generated by the reacting explosive and its detonation products will be picked up by the gage leads. This will result in the oscilloscope recording an average of the voltage generated by three sources instead of one: the reacting explosive, its detonation products, and the gage base. The results of using 1 and 5 mil gages in tetryl are shown in Figure 2. As can be seen from the figure, the 1 mil gage u,t curve lies ~ 0.125 mm/μsec below and parallel to the 5 mil curve. The difference, which is ~ 7%, is less than that observed in TNT[3,4] (both cases, cast and pressed). The difference depends in part on the precision with which we can locate the beginning of the trace. Because the signals rise abruptly, there is the possibility of an uncertainty of ± 30 ns[4] in locating the beginning of the traces. Moving curve 1 in Figure 2 to the right by 30 ns (or curve 2 to the left) reduces the apparent effect of foil thickness. Thus, the true difference could be smaller (or larger). More experiments would be required to determine if the apparent difference is real and, if so, its true size. Nevertheless, we believe that the 1 and 5 mil gages give approximately the same results in tetryl. We know that measuring the short reaction time of tetryl requires as short a rise time (enhanced by a thin foil) as possible. Consequently the 1 mil gage was chosen for measurements in tetryl.

Comparison of Results from Graphited and Non-graphited Tetryl

Graphited (G) tetryl (0.5% C) was used in most of this work because it was readily available. This explosive was formerly used in the NOL Large Scale Gap Test (LSGT). It was also used in the earlier work in which the EMV method was checked out. Its use in this study was a natural consequence of earlier work.

It was found that graphited tetryl produced a noisy signal when the charge was initiated by a PWB. Records were rendered useless by this noise even when the grounded Al baffle was used. This noise appears to be induced by the same mechanism observed when we investigated cast TNT. In that case, it was concluded that conduction (electrical) in the reaction zone and in the detonation product gases was responsible for the noise. It is assumed that the addition of graphite makes the material in the detonation reaction zone of tetryl more conductive. In order to test this hypothesis, samples of non-graphited (N-G) tetryl (X682) were used. Results from G and N-G tetryl are shown in Figure 3A. A PWB was used in each case. The large oscillations at the beginning of the curve for G tetryl is the noise mentioned above. Note that the N-G curve is relatively free from noise. These results do not prove that the noise is generated in the G tetryl. It is probable that electrical signals are generated in the two component PWB's. The 0.5% C may provide enough conductivity in the detonation products to transmit these signals to the EMV gage.

Figure 3B shows results for G and N-G tetryl which were obtained from point initiated charges. The u,t curves show no appreciable difference, except possibly in rise time which depends on factors other than conductivity. Hence, when we point initiate, we cannot tell the difference between G and N-G tetryl. This observation backs up the statement made above that the source of the electrical noise is probably in the PWB.

Point Initiated Tetryl. For the point initiated case, EMV gages were located at x = 12.7, 25.4, 50.8 and 76.2 mm from the primacord.

Replicate shots were fired at all but x = 12.7 mm. The agreement between replicate shots is good except for shot 137 (x = 76.2 mm) which lies below the other 76.2 mm shots. To avoid possible errors due to the curvature of the wave front, the length of the probe was reduced for the shorter charges. At x = 12.7 and 25.4 mm, the gage length, ℓ, was 2 mm; at x = 50.8 mm, ℓ was 5 and 10 mm; at x = 76.2 mm, ℓ was 10 mm. The only difference observed at x = 50.8 mm was that the smaller gage had a shorter rise time which was expected.

A sharp break in the u,t curve which might be associated with the C-J point was not apparent in the records of the point initiated shots. The method used to determine the C-J parameters was pair comparison of the u,t curves.[4] That is, the u,t curves from different stations are compared two at a time, and the time axis is shifted until the initial portion of the curves coincide. This procedure is based on the assumption that the detonation was steady state at all x so that the reaction zone propagated unchanged. The u,t curve for x = 12.7 mm was not included because some noise was evident on the record; shot 137 was not included for the reason mentioned above. The results of this comparison are listed in Table 2. The resulting C-J values for the point initiated case are

$$u_{CJ} = 1.76 \text{ mm/}\mu\text{sec} \quad \text{and} \quad \tau = 68 \text{ ns.}$$

The spread in τ is ± 12 ns which is considerably better than the ± 30 ns found in pressed TNT.[4]

Extrapolation of Ruby code computations for tetryl[7] to $\rho_o = 1.51$ g/cc gives C-J values of 195 kbar, 7.02 mm/μsec, and 1.84 mm/μsec for P, D, and u, respectively. Interpolation of the LASL code computations[8] to the same density produces 193 kbar, 7.00 mm/μsec, and 1.827 mm/μsec. In both cases the computed detonation velocity is low compared to the experimental value of 7.17 mm/μsec. When the computed D is corrected to 7.17 mm/μsec and the computed u correspondingly reduced, the adjusted values are

	P(kbar)	D(mm/μsec)	u(mm/μsec)	Ad. Exp. k
RUBY	195	7.17	1.80	2.98
LASL	193	7.17	1.78	3.02

The set of values selected as being in best agreement with the measured D and the code computations are 194 kbar, 7.17 mm/μsec, 1.79 mm/μsec and 3.00 for P_{CJ}, D, u_{CJ} and k, respectively. These values in conjunction with the high pressure shock Hugoniot for PMMA indicate an interface pressure of 155 kbar, fortuitously the same value as that estimated in Ref. 9.

Our measured value of 1.76 mm/μsec is therefore 1.7% lower than the computed value (adjusted to the correct D value). The interface pressure obtained from it is 153 kbar or 1.3% lower than that predicted from the computed and adjusted data. These differences are well within experimental error as well as errors to be expected in the computed results.

The computed interface pressures are listed in Table 3 along with the value of the pressure 0.25 mm inside the PMMA obtained using the EMV gage. This latter value is greater than the computed interface values because reaction zone effects were neglected in the computations. This shows that the calibration of the gap test should include reaction zone effects for small lengths of the attenuator. In fact (Ref. 2), reaction zone effects extend out to about 1 mm PMMA in the NOL Large Scale Gap Test configuration where the donor charge is point initiated.

Plane Wave Initiated Tetryl. There are four ways to determine the C-J point for this situation: 1) determine a break point in individual records, 2) compare experimental u,t curves with u,t curves calculated from plane Taylor wave theory, 3) compare u,t curves in the same manner as in the point initiated case (pair comparison), and 4) obtain the u,t curve at a tetryl/inert boundary and calculate the u_{CJ} from that curve. The method employed to determine a break point was to approximate portions of the u,t curves by straight lines. A total of 8 shots (9 records) resulted in u,t curves which are relatively free of noise. Of these, only 5 shots (6 records) have a fast enough rise time to show a break in the initial part of the u,t curve. The record for shot 209 shows two breaks in the initial part of the u,t curve (points A and B of Figure 4). This situation and how it is treated is fully discussed in Ref. (4). Briefly we chose point C (see Figure 4) as the value to be associated with the C-J point for that record. Table 4 lists the C-J values for each record obtained by this method. The average values for this method are

$$u_{CJ} = 1.77 \text{ mm}/\mu\text{sec} \quad \text{and} \quad \tau = 93 \text{ ns}.$$

The second method we used to determine the C-J parameters was to compare experimental u,t curves with u,t curves obtained from plane Taylor wave theory. In contrast to spherical expansion, the plane Taylor wave expansion yields with litte effort a usable equation (because of its complexity no attempt was made to derive an expression for spherical expansion). The equation for u(t) is[3]

$$u(t) = \frac{2\,c_o}{\gamma-1}\left[-1 + \left(\frac{t}{t_R + \tau}\right)^{-\left(\frac{\gamma-1}{\gamma+1}\right)}\right] + u_{CJ} \qquad (2)$$

where c_o = sound speed at the C-J point

$t_R = x/D$

γ = adiabatic exponent.

Table 5 lists the results for the individual records. There is no significant difference in the values obtained at $x = 25.4$ mm and $x = 50.8$ mm; this supports the earlier assumption that steady state detonation had been achieved at $x < 25.4$ mm. The average value for the C-J parameters using this approach is

$$u_{CJ} = 1.75 \text{ mm}/\mu\text{sec} \quad \text{and} \quad \tau = 113 \text{ ns}.$$

The third approach used to determine the C-J parameters was the pair comparison technique which is discussed in the section Point Initiated Tetryl. Of nine possible pair comparisons, only four yielded a point of divergence; the presence of noise interfered in the other cases. The results are listed in Table 6. The average values of the C-J parameters determined from these four pair comparisons are

$u_{CJ} = 1.74$ mm/μsec and $\tau = 119$ ns.

There is one more situation in which the EMV gage can be used to determine the C-J point: place the EMV gage at the interface between tetryl and an inert (such as PMMA). This method was used in pressed TNT[4] and gave results which were consistent with the other methods. For tetryl, unfortunately, the rise time for this configuration is approximately the same as the time to the break. Thus no definite break was seen for this situation.

Table 7 lists the results obtained for the C-J parameters by using the various techniques. The average value from Table 7 for the C-J parameters for 50.8 mm diameter, PWB tetryl are

$u_{CJ} = 1.75$ mm/μsec and $\tau = 109$ ns.

Break in u,t Curve at ~ 600 ns. In previous reports on cast and pressed TNT[1,3,4], it was noted that an additional break was observed in the u,t curve at ~ 600 ns. This same break is seen in PWB tetryl at approximately the same time on records 157 and 158. These two records are the only ones which cover a time interval long enough to show this break. Since the geometry and dimensions were the same for all three different explosive charges, the probable cause is the two-dimensional flow behind the C-J plane.

Comparison with Previous Results

The only other work found by the authors which gives experimental C-J parameters for tetryl is by Dremin, et al.[5] They do not have a result for $\rho_o = 1.51$ gm/cc but have values for $\rho_o = 0.9-0.95$, 1.36 and 1.68 gm/cc. These are listed in Table 8. For $\rho_o = 1.68$ gm/cc they could not observe a break; they obtained u_{CJ} by extrapolating u to t ≈ 100 ns. The interpolated value for $\rho_o = 1.51$ gm/cc obtained from Dremin's results is $u_{CJ} = 1.67$ mm/μsec, see Figure 5. This is 5% lower than our result. However, since Dremin does not see the C-J break for $\rho_o = 1.68$ gm/cc, his result is probably low; thus, the interpolated value is low. A similar situation existed for pressed TNT.[4] In that case, our result was 6% higher than Dremin's. In view of this, our result agrees with Dremin's within his experimental error but we believe our result is more accurate.

SUMMARY AND CONCLUSIONS

The C-J parameters of tetryl (ρ_o = 1.51 gm/cc, 50.8 mm diameter) obtained in this study are:

	Point Init.	PWB
u_{CJ}	1.76 mm/μsec	1.75 mm/μsec
τ	68 ns	109 ns
P_{CJ}	191 kbar	189 kbar

where P_{CJ} was calculated from

$$P_{CJ} = 10 \cdot \rho_o \cdot u_{CJ} \cdot D \tag{3}$$

The C-J particle velocity is almost identical for both types of initiation as would be expected, but the reaction time for plane initiated tetryl is ~ 50% longer than for point initiated tetryl. However, the difference in τ is just within the ± 20 ns uncertainty of the zero point in time and well within the ± 30 ns found for TNT. Since small gages were used in the point initiated shots to reduce effects from wave front curvature, the difference may not be as great as indicated. The point initiated value, 68 ns, was obtained from pair comparisons only. (The PWB value of τ using pair comparisons was 119 ns.) The 109 ns for τ in the PWB case is the shortest reaction time we have reported for which the C-J break could be observed on individual records. Previous work[3,4], which involved a larger number of experiments, using the EMV gage in TNT showed that u_{CJ} and τ could be obtained to within 4% and ± 30 ns, respectively.

The value reported here for u_{CJ} of PWB tetryl is about 5% greater than the value inferred from the work of Dremin.[5] The difference could be due to the fact that the Russian oscilloscopes had longer rise times than ours. Our results also check to within 2% of the results obtained from hydrodynamic-thermodynamic code calculations adjusted to the correct experimental value of the detonation velocity.

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TABLE 1

List of Tetryl Experiments

x, mm	Shot No.	Foil Thickness mils	G = Graphited N-G = Non-Graphited
		Point Initiated	
12.7	159	1	G
25.4	160	1	G
25.4	165	1	G
50.8	150	1	G
50.8	152	1	G
50.8	189	1	G
50.8	204	1	N-G
76.2	137	1	G
76.2	151	1	G
76.2	167	1	G
		Plane Wave Boostered	
25.4	157	5	G
25.4	158	5	G
25.4	179	1	G
25.4	209	1	N-G
25.4	212	1	N-G
50.8	142	1	G
50.8	143	1	G
50.8	146	1	G
		Tetryl/PMMA Interface	
0(25.4 mm of Tetryl, PWB)	185	1	G

TABLE 2

Pair Comparison of Point Initiated Tetryl

x, mm	Shot No.	x, mm	Shot No.	u, mm/μsec	τ ns.
25.4	160	50.8	150	1.71	67,74
25.4	160	50.8	152	1.71	67,76
25.4	160	50.8	204	1.76	63,69
25.4	165	50.8	150	1.73	66,72
25.4	165	50.8	152	1.76	60,69
25.4	165	50.8		1.76	60,69
25.4	160	76.2	151	1.83	56,60
25.4	160	76.2	167	1.78	60,64
25.4	165	76.2	167	1.77	60,64
25.4	165	76.2	151	1.81	56,56
50.8	150	76.2	151	1.75	75,78
50.8	150	76.2	167	1.75	75,78
50.8	152	76.2	167	1.75	75,75
50.8	152	76.2	151	1.78	70,70
50.8	204	76.6	151	1.75	72,78
50.8	204	76.2	167	1.75	78,78

TABLE 3

Comparison of $x = 0$ LSGT Pressures

Reference	Pressure, kbar	Comment
Present Result	153	Computed from measured u_{CJ}
Ref (9), Table A1	155*	Computed from calculated u_{CJ}
Ref (2), Table 4 ($x = 0.25$ mm)	166.6	Computed from measured u in PMMA

*Also interface value found by using "best" of computed C-J parameters for tetryl ($\rho_o = 1.51$ g/cc). See text.

TABLE 4

C-J Parameters Using Break in Curve (PWB)

x mm	Shot No.	u_{CJ} mm/µsec	τ_{CJ} ns
25.4	209	1.75	80
25.4	-209	1.81	65
25.4	212	1.84	80
50.8	142	1.73	140
50.8	143	1.76	95
50.8	146	1.75	95

TABLE 5

C-J Values Obtained from Plane Taylor Wave Comparison

x mm	Shot No.	u_{CJ} mm/µsec	τ_{CJ} ns
25.4	-209	1.75	110
25.4	209	1.75	80
25.4	212	1.75	130
50.8	142	1.73	135
50.8	143	1.76	105
50.8	146	1.73	120

TABLE 6

Pair Comparison of u,t Curves in Tetryl (PWB)

x, mm	Shot No.	x, mm	Shot No.	u mm/μsec	τ ns
25.4	-209	50.8	142	--	--
25.4	-209	50.8	143	--	--
25.4	-209	50.8	146	--	--
25.4	209	50.8	142	1.73	110,145
25.4	209	50.8	143	1.75	70,100
25.4	209	50.8	146	--	--
25.4	212	50.8	142	1.73	135,160
25.4	212	50.8	143	1.75	115,115
25.4	212	50.8	146	--	--

TABLE 7

Comparison of Results from Different Methods for P W B Tetryl

Method	u_{CJ} mm/μsec	τ_{CJ} ns
Single Record	1.77	93
Taylor Wave	1.75	113
Pair Comparison	1.74	119

TABLE 8

Previous Tetryl Results[5]

Density gm/cc	u_{CJ} mm/μsec	τ ns
.9-95	1.34	<100
1.36	1.54	210
1.68	1.87	410

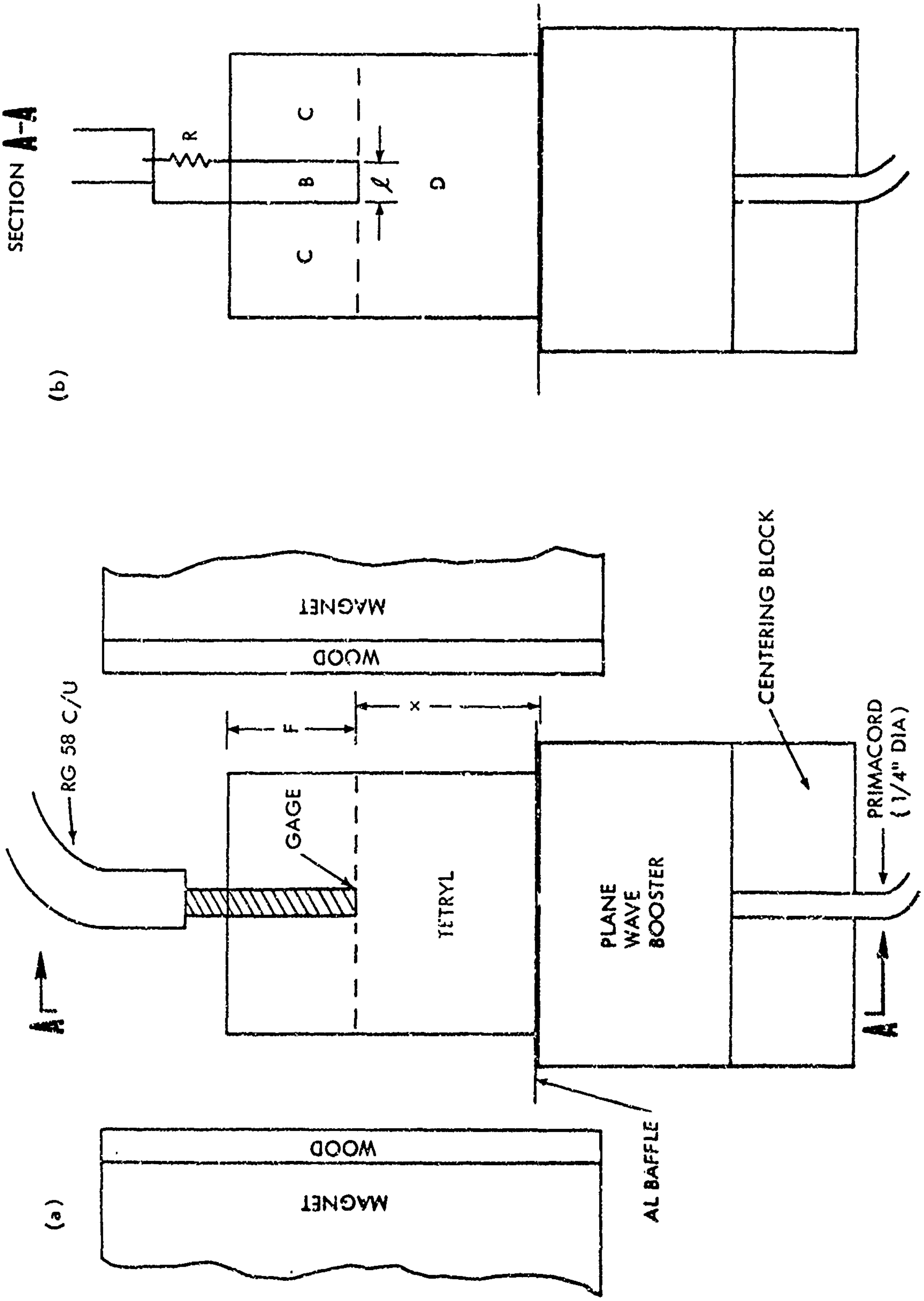

FIG. 1 EXPERIMENTAL SETUP

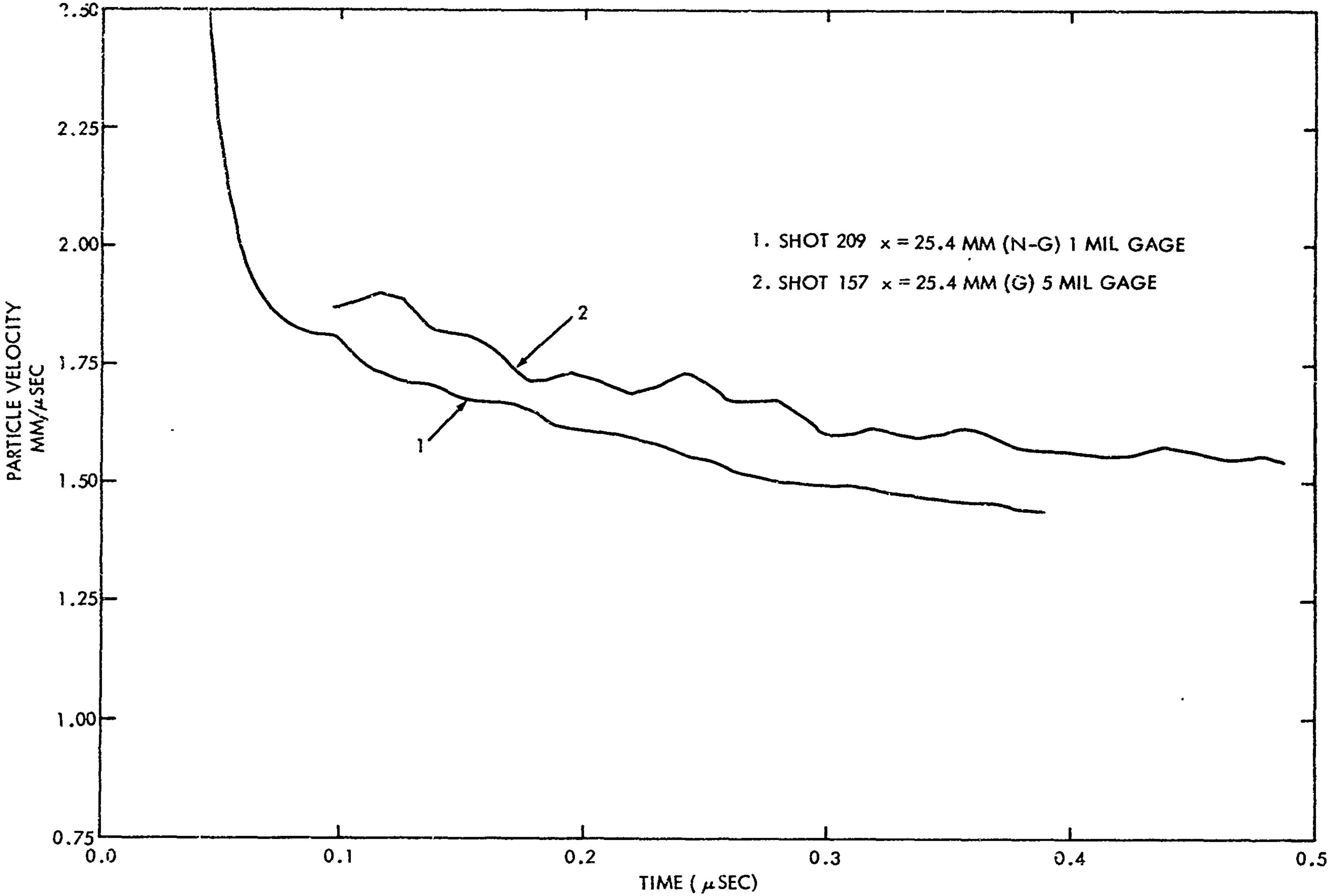

FIG. 2 COMPARISON OF u, t CURVES IN TETRYL FOR DIFFERENT THICKNESS GAGES

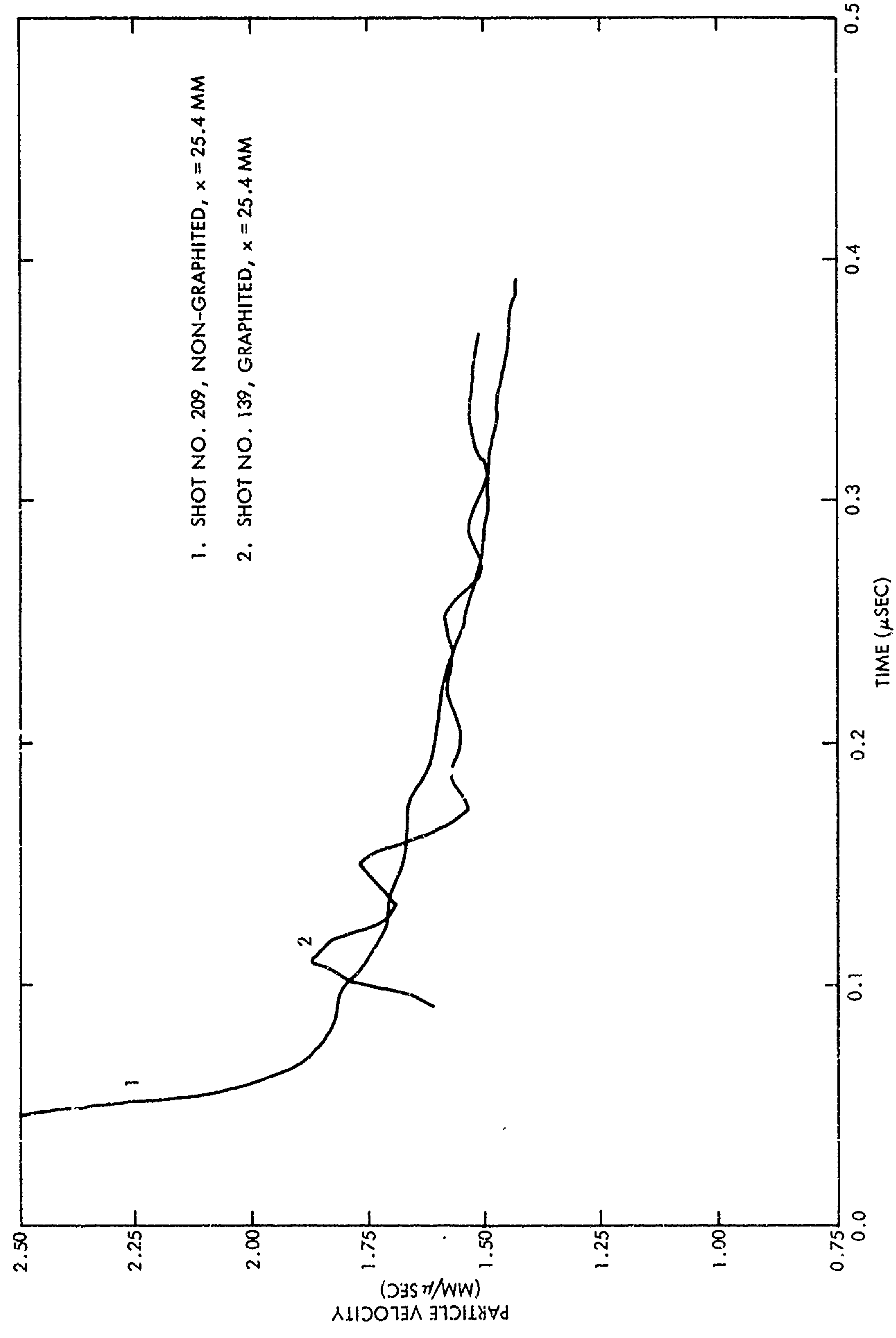

FIG. 3A COMPARISON OF GRAPHITED AND NON-GRAPHITE TETRYL (PWB INITIATED)

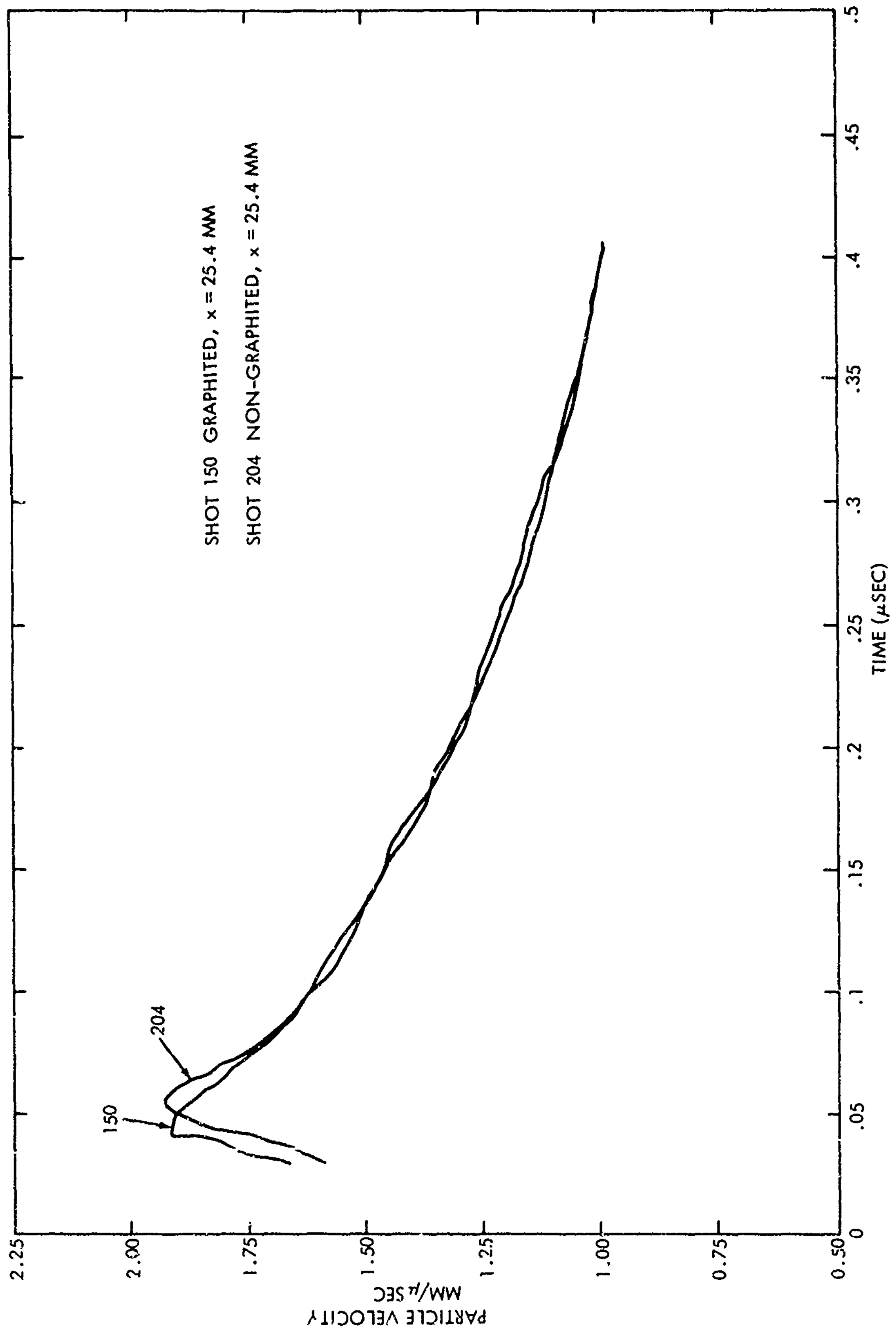

FIG. 3B COMPARISON OF GRAPHITED AND NON-GRAPHITED TETRYL (POINT INITIATED)

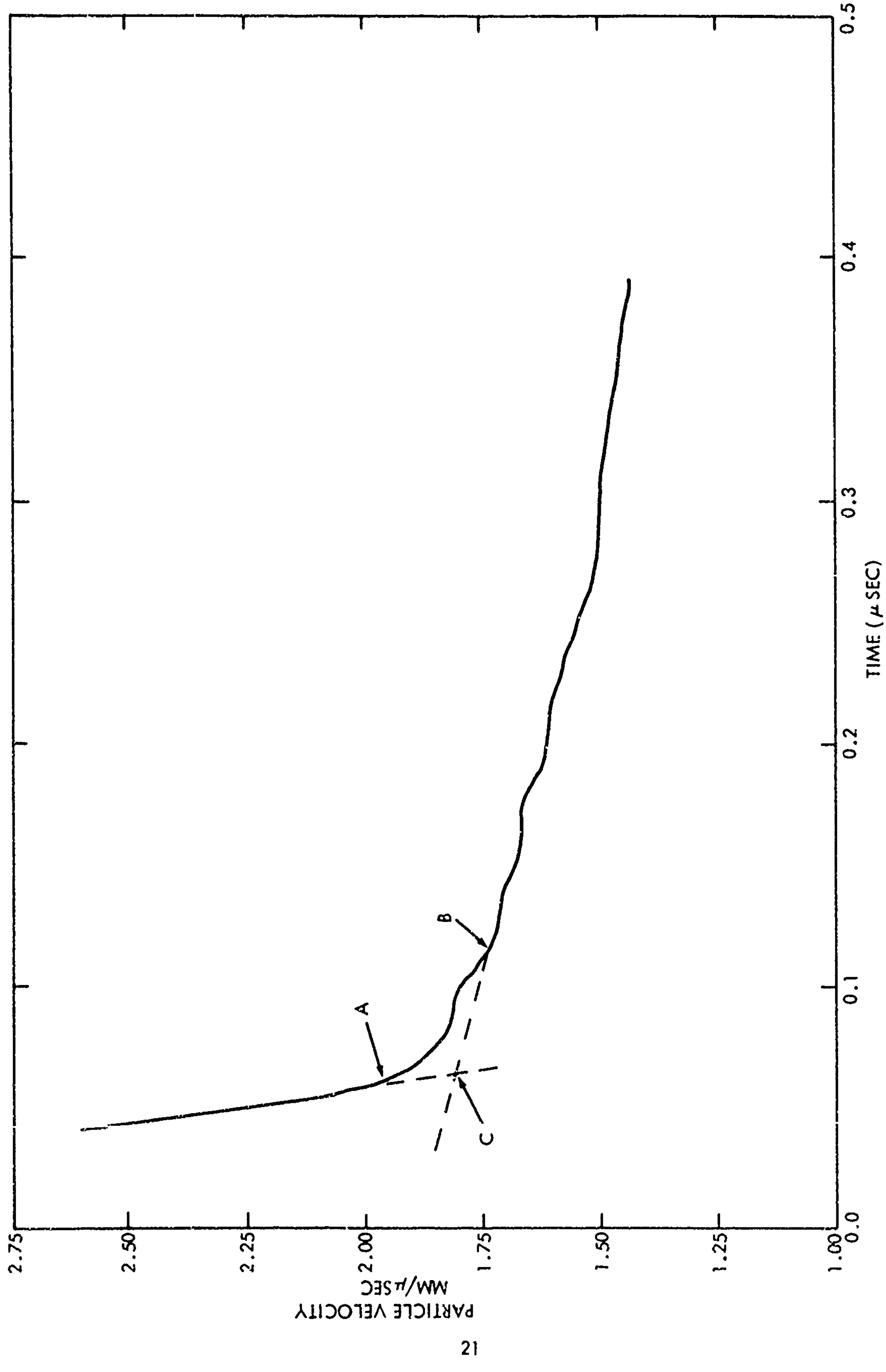

FIG. 4 u, t CURVE SHOWING TWO BREAKS (SHOT 209, x = 25.4 MM)

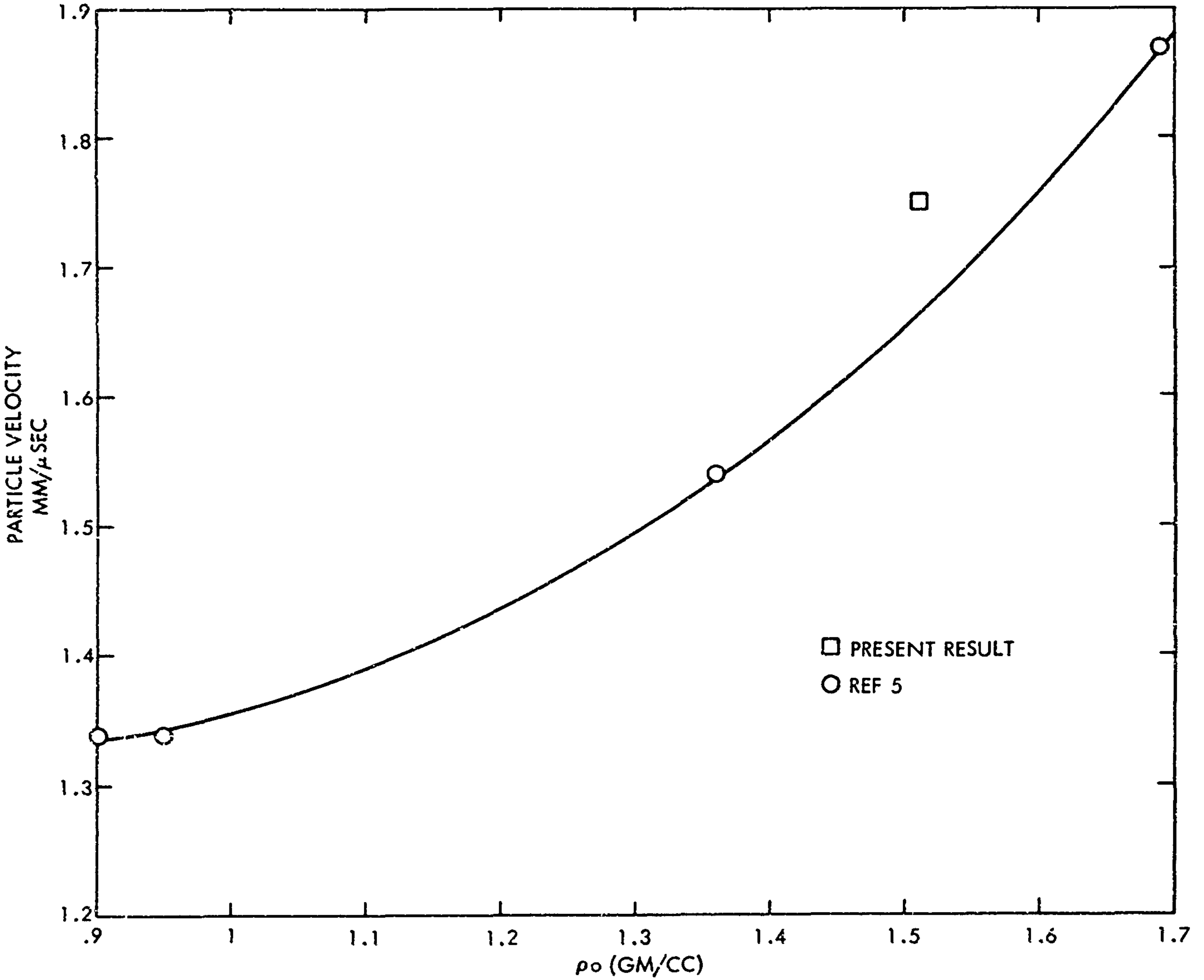

FIG. 5 COMPARISON OF PWB TETRYL RESULTS