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Analysis of the Motion of a Barrel-Tamped Explosively Propelled Plate

Robert A. Benham

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ANALYSIS OF THE MOTION OF A BARREL-TAMPED EXPLOSIVELY PROPELLED PLATE

Robert A. Benham
Coyote Test Field and Shock Simulation Division 1533
Sandia Laboratories
Albuquerque, NM 87185

ABSTRACT

A method for predicting the terminal velocity and rotation rate of a barrel-tamped explosively propelled plate has been developed. The technique utilizes the Gurney method of calculating an explosive mass discount factor to give a very simple set of equations for predicting the performance of a barrel-tamped explosive charge. Calculations are compared with results from numerous experiments. Velocities are calculated within ±5% in all cases and rotation rates to within about 10% of measured values.

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ANALYSIS OF THE MOTION OF A BARREL-TAMPED EXPLOSIVELY PROPELLED PLATE

Introduction

Experiments employing open-ended barrel-tamped explosively propelled flyer plates are currently being developed for "turn around" impacts of ballistic missile warhead fuzes at impact velocities up to 3650 m/s. Previous papers[1, 2, 3] have described the basic experimental concepts and have developed an analytical approach useful in predicting the behavior of explosively accelerated flyer plates. This approach relies on the empirical development of an explosive mass "discount factor" which is then used to analytically predict the behavior of similar systems. Recently, a simple analytical model of the explosive process was developed by modifying one initial basic assumption of the previous work. This achievement is significant in that it eliminates the need for new empirical data in the design of different barrel-tamped systems. The method employs the discount angle concept of Baum[4] and Kennedy.[5] The model allows prediction of flyer plate terminal velocity and rotation rate within a few percent. The system performance is calculated using only the explosive, the barrel and the flyer masses, the explosive diameter and length, along with explosive properties of detonation velocity and Gurney[6] velocity.

This paper presents the theory used in the development of the model of the open-ended barrel-tamped explosively propelled flyer plate.

The theory has been applied to 25 tests conducted during previous development work[1, 2, 3]. The Theoretical-Experimental correlation which indicates excellent agreement between theory and measured results is included.

Development of Theory

A simple approximate theory has been developed that can be used for predicting the terminal velocity and rotation rate of a flyer plate that has been accelerated by an open-ended barrel-tamped explosive charge. A requirement placed on the theory was that it be based on geometrical quantities that may be obtained directly from physical configuration and properties of the particular explosive used. This requirement eliminates the necessity of conducting preliminary experiments to determine any empirical correction factor. Figure 1 shows the configuration of the explosive assembly.

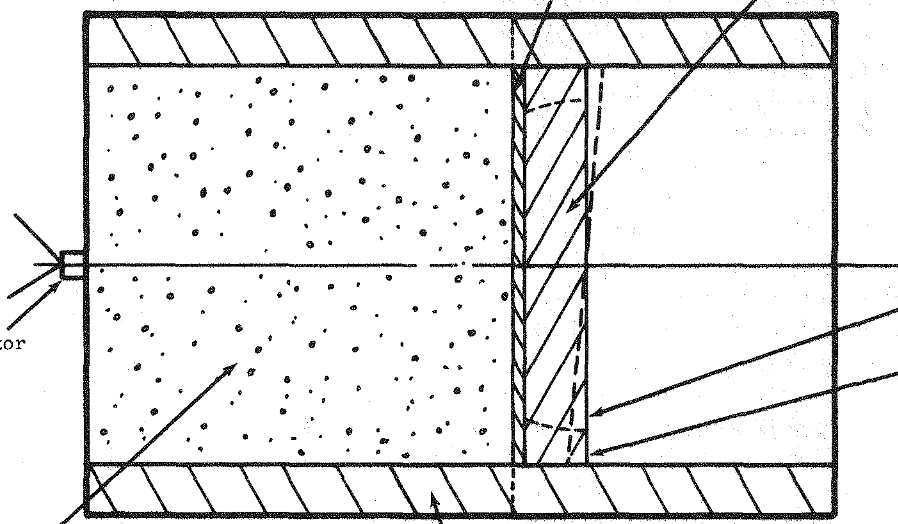

Figure 1. Experimental Configuration

The explosive is housed in a cylindrical barrel tamper. The barrel provides lateral confinement to the explosive expansion process, thus containing the explosive gas pressure behind the flyer for long enough to accelerate the plate to near terminal velocity. The cushion attenuates the shock pressure into the flyer plate, therefore decreasing the probability of its spallation. The flyer plate consists of an impact plate and a guard ring. The pressure exerted across the back face of the flyer plate is not exactly uniform (lower at the edges because of lateral rarefaction waves). The guard ring is included to isolate the impact plate from the edge pressure gradient as well as to separate the plate from any interactions between the guard ring and the barrel. The interface between the ring and the impact plate is spherical which prevents angular moments as well as shear stresses from affecting the impact plate motion. The flyer plate may be tapered to cause plate rotation which allows impact with the test item at a predetermined angular orientation.

Gurney's equations for predicting the velocity of fragments from bombs, shells, and grenades[6] have been used extensively in the design of explosive systems. J. E. Kennedy[5] reviewed the Gurney model and presented applications that illustrated the range of applicability of the model. One of the concepts of the Gurney model used in the present theory is the method of discounting the explosive mass to allow predictions of plate velocities for explosive systems with significant losses due to lateral rarefaction waves. Kennedy[5] discusses this method and concurs with Baum[4] that "explosive material within 30° of the normal at an edge of the charge cannot contribute to metal acceleration."[4] Figure 2 shows how the discount angle process works for a lossy system. The discount angle was estimated by Baum by assuming that the explosive that has experienced an "average or characteristic rarefaction wave" by the time the explosive was completely detonated, could not contribute to driving the flyer plate mass. Baum[4] estimates that the magnitude of the "average rarefaction wave" velocity, radially inward (for explosives with $\gamma = 3$), is approximately one-half of the detonation velocity (D), which leads to a discount angle of 26.56° $\left(\tan \frac{D}{2D}\right)$. Kennedy indicates that for solid secondary explosives, a discount angle of 30° agrees well with experimental results. This author also has verified a 30° discount angle. If the explosive length (ℓ) is less than the charge diameter divided by the tangent of the discount angle, then a truncated cone of half angle 30° and height (ℓ) is the effective mass used for driving the explosive (see Figure 2).

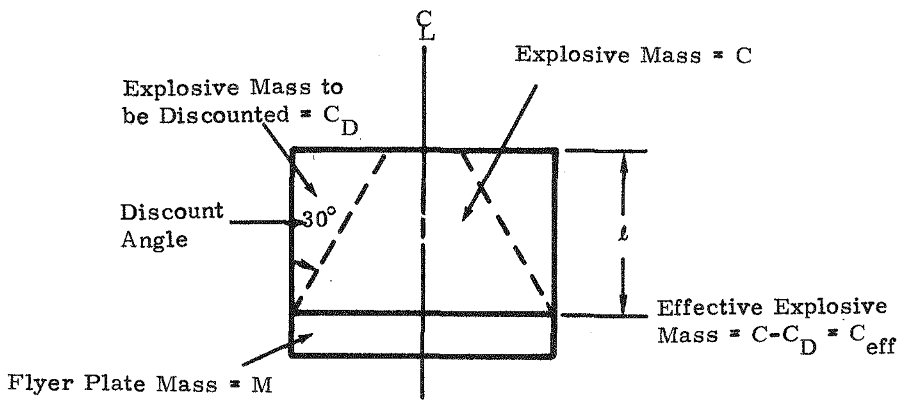

Figure 2. Mass Discount Method for Lossy Configurations

It is here assumed that the discount angle for a barrel-tamped system is controlled by the velocity of the characteristic rarefaction wave moving toward the axis of the explosive. The velocity of the characteristic wave is controlled by the escape velocity of the detonation products from the lateral surface of the explosive. The detonation products escape velocity is assumed to have a maximum value equal to the barrel terminal velocity. The barrel terminal velocity from a cylindrical explosive with a lateral barrel tamper (Figure 1) can be calculated using the Gurney relation shown in Equation 1.

$$\frac{V_T}{\sqrt{2E}} = \frac{1}{\left(\frac{N}{C} + 0.5\right)^{1/2}} \qquad (1)$$

V_T = barrel terminal velocity

$\sqrt{2E}$ = Gurney velocity of the explosive

N/C = ratio of the barrel mass to total explosive mass.

The lateral velocity of gas from an unconfined explosive charge can be found by setting N = 0 in equation 1 giving $V_o = \sqrt{2}\,\sqrt{2E}$.

For simplicity, the discount angle for a barrel-tamped system is chosen to be linearly related to the ratio of barrel terminal velocity to the unconfined gas velocity. The discount angle (θ) for the barrel-tamped system is then calculated, using Equation 2.

$$\theta = 30° \frac{V_T}{V_o} = 30° \frac{1}{\sqrt{2}\left(\frac{N}{C} + 0.5\right)^{1/2}} \qquad (2)$$

Figure 3 shows the physical interpretation of this process (V_F Flyer Plate Velocity). Equation 2 defines an angle θ that fits at the two limits, one at N = 0 (θ = 30°) and one at N = ∞, a rigid wall, where θ = 0°. As seen in later sections, this linear assumption does fit the experimental data.

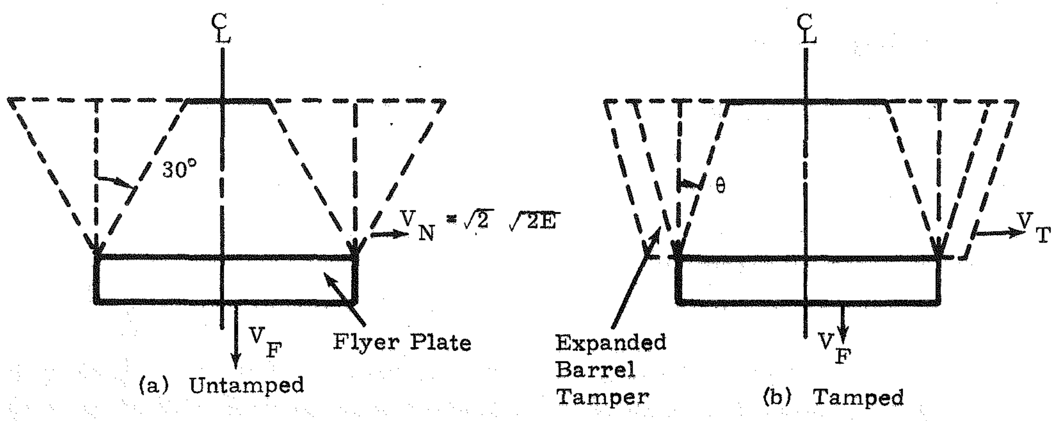

Figure 3. Discount Angle for Barrel Tamped Charges

The discount angle of Equation 2 can be used to determine the effective mass (C_{eff}) of explosive for driving the flyer plate. The effective mass is calculated as described for the unconfined explosive system in previous paragraphs. The effective mass is assumed to act in a one-dimensional manner and, therefore, can be used directly in the one-dimensional gas dynamics solution to move a piston with detonation loading.[7] Equation 3 shows the relation for the final velocity of the piston.

$$V_F = D\sqrt{\frac{8}{\gamma^2 - 1}}\left(\frac{Z-1}{Z+1}\right) \text{ where } Z = \left(1 + \frac{32\,C_{eff}}{27\,M}\right)^{1/2} \qquad (3)$$

D = Detonation velocity

M = Mass of the flyer plate

C_{eff} = Effective explosive mass

In Kennedy's paper[5] the gas dynamic solution ($\gamma = 3$) was compared to the Gurney solution with very good results. The author chose $\gamma = 3$ based on Kennedy's work and upon calculated average values of γ from the JWL Equation of State[8] (see Appendix A).

One limit that comes from the discount angle concept is that if the length of the explosive charge is greater than a critical length ℓ (the radius divided by the tangent of the discount angle), then the effective explosive mass is that of a cone with base equal to the charge radius and length equal ℓ. No additional velocity is achieved by adding explosive beyond length ℓ.

Equations 2 and 3 can be used to predict the velocity (V_F) of a flyer plate from an explosive assembly like that in Figure 1. The values for N (mass of the barrel tamper) and C (total mass of the explosive) are used to calculate θ (Eq. 2). The values of explosive diameter and length are used with θ to calculate the mass of the truncated cone (C_{eff}). The explosive detonation velocity (D) and flyer mass (M) are used with C_{eff} and γ to calculate the flyer terminal velocity using Eq. 3.

In some cases, it is desired to cause the flyer plate to rotate slowly so that oblique impacts with targets may be obtained. The flyer plate thickness is varied linearly across a diameter and since, for a constant quantity of explosive, the local flyer plate velocity is inversely proportional to thickness, then a velocity gradient is developed across the tapered plate. A method of designing a flyer plate taper was derived using the effective explosive mass (C_{eff}) from the results of Equation 2. The velocity gradient across the plate can be determined from the desired plate rotation rate. The absolute velocities at the edges of the plate can be calculated by adding the velocity at the center to the velocity differential between the center and edge of the plate. Equation 3 is used to determine the local mass of the flyer plate that will give the desired velocity at that location. The thickness of the flyer can then be determined by knowing the mass density of the flyer material. In the reverse manner, if the flyer plate taper is known, then the expected rotation rate for a given explosive system can be calculated.

A computer program has been written which incorporates the concepts of this method and allows calculation of terminal velocities and rotation rates for a barrel-tamped explosive system. The listing of the program is shown in Appendix B.

Theoretical-Experimental Correlation

Data from experimental work of Mathews and Duggin[1, 2, 3, 9] were available to the author and were used for comparison to this theory. The experiments consisted of detonating the test configuration shown in Figure 1 and measuring the flyer plate velocity and rotation rate. A flash x-ray system was used to obtain a multiple shadowgraph of the flyer plate at known times after the explosive initiation. Compensation for the effects of air drag on the plate and parallax associated with the x-ray system were made[1, 2, 3]. The results of the experiments were taken directly from Mathews' and Duggins' data with no additional adjustments being made.

Table I shows the results of 16 nonrotating tests with the tamper mass/explosive mass ratio ($\frac{N}{C}$) varying from 0.06 to 4.4 and with the explosive mass/flyer mass ratio (C/M) ranging from 2.99 to 20.14. The values of calculated final velocity (using the method of this report) were within ±5% of the measured velocity.

Even for charges of length greater than ℓ, the charge radius/tan θ (θ = discount angle), the agreement is excellent (the apex of the cone of the discount volume is within the explosive). Possible errors in experimental technique are of the same magnitude as the theoretical-experimental variance observed from the data.

Table II shows results on rotating systems. The agreement between the measured and calculated rotation rate magnitude is good, but not quite as good as the velocity calculations. Experiments are currently being designed to further investigate the rotation process which will hopefully give better agreement between the theory and experiment.

The theory was checked against three experiments using a mixture of PBX-9404 and Composition C-4 at a ratio of 8:2. The explosive was adjusted analytically to the PBX-9404 explosive by replacing the Composition C-4 volume by an energy equivalent of PBX-9404

$$\left(V_{PBX-9404} = V_{(C-4)} \frac{\sqrt{2E}_{(C-4)}}{\sqrt{2E}_{PBX-9404}}\right).$$

All three tests were designed for flyer rotation. The results are shown in Table III. The agreement in velocity is excellent and the agreement in rotation rate is acceptable. In every case, the measured value of rotation rate is less than the calculated values.

Summary and Conclusion

A theory for predicting the velocity and rotation rate of a barrel-tamped explosively driven flyerplate has been developed. A scheme for determining the mass of the explosive that is effective in driving the plate by discounting a quantity of explosive based on the amount of tamping present has been devised. The technique predicts terminal velocity of a barrel-tamped flyer plate to within ±5% and rotation rates that are about 10% higher than measured. Experimentation is continuing to further investigate the rotation process. The theory has also been used to predict with equally good results the performance of charge with multiple explosives.

TABLE I

Theory vs Experiment Correlation, Nonrotating Flyer Plates

Test Number[1]	C/M	N/C	Charge Diameter (in.)	Charge Length (in.)	Velocity: Average Measured (fps)	Velocity: Calculated (fps)	$V_{Measured}/V_{Calculated}$	Comments
10	4.478	1.67	2	3	7335	7506	.98	
20	6.076	1.75	2	1.5	10480	10875	.96	
21	8.110	1.77	2	2	11493	11533	1.00	
22	11.99	1.78	2	3	12440	11974	1.04	
23	20.14	1.76	2	5	13091	13265	.99	Cone apex inside HE Volume @ 3.8 in.
25	3.34	.06	2	1.5	6313[2]	6139	1.03[2]	
26	4.438	.06	2	2	6852[2]	6554	1.05[2]	Cone apex inside HE Volume @ 1.9 in.
3	4.458	4.40	2	3	8758	8821	.99	
5	6.698	4.40	2	3	10568	10643	.99	
6	12.116	4.40	2	3	13579	13299	1.02	
19	5.368	4.40	2	1.5	10889	10951	.99	
1	2.980	4.40	2	2	7577	7919	.96	
B	7.137	4.40	2	5	8954	9158	.98	
11	4.53	.84	2	3	6850	6689	1.02	Cone apex inside HE Volume @ 2.9 in.
24	5.986	.88	2	1.5	10217	10225	1.00	
15	6.240	.84	2	5	8290	8014	1.03	Cone apex inside HE Volume @ 2.9 in.

[1] See Figure 1 for description of terms.

[2] Flyer broken allowing venting and therefore lower terminal velocity.

NOTES:

1. All explosive is composition C-4, $\sqrt{2E}$ = 2750 m/s, detonation velocity = 8040 m/s.
2. All charges initiated by a single detonator placed on the axis of the charge opposite the flyer.
3. The mass of the cushion material is included in the flyer mass to determine M.
4. Reference 9.

TABLE II

Theory vs Experiment Correlation, Large Systems Rotating and Nonrotating Configurations

Test No.	C/M	N/C	Charge Diameter (in.)	Charge Length (in.)	Velocity: Average Measured (fps)	Velocity: Calculated (fps)	$\frac{V_{Measured}}{V_{Calculated}}$	Rotation Rate: Measured (rad/s)	Rotation Rate: Calculated (rad/s)	Comments
1-22	8.06	2.72	16.06	30.66	9880	9929	.99	570	600	Good resolution on rotation data
1-28	8.24	2.66	16.06	31.33	9900	9898	1.00	636	600	
1-13	4.998	2.71	16.06	30.09	7600	7896	.96	0	0	
1-29	8.06	2.72	16.06	30.66	9976	9929	1.00	616	600	Good resolution on rotation data
1-21	8.05	2.69	16.06	31.00	9706	9858	.98	-	-	
1-26	5.15	2.70	16.06	31.04	7707	7896	.98	316	400	Poor resolution on rotation data

NOTES:

1. All explosive is composition C-4, $\sqrt{2E}$ = 2750 m/s, detonation velocity = 8040 m/s.
2. Reference 9.

TABLE III

Theory vs Experiment Correlation, Large Systems Multiple Explosive

Test Number	C/M	N/C	Charge Diameter (in.)	Charge Length (in.)	Velocity (fps) Average Measured	Calculated	$\frac{V_{Measured}}{V_{Calculated}}$	Rotation Rate (rad/sec) Measured	Calculated
29	9.478	2.10	16.375	29.36	11710	11595	1.01	680	750
32	9.85	2.09	16.375	29.46	11750	11752	1.00	~173	200
33	9.478	2.10	16.375	29.36	11570	11595	1.00	692	750

NOTE:

1. Reference 9.

APPENDIX A

Determination of γ from the JWL, Equation of State

The value of the explosive used for γ in the barrel-tamped, flyer-plate system is important since the final plate velocity (V_F) is nearly linearly dependent on its value (see Equation A-1).

$$V_F = D\sqrt{\frac{8}{\gamma^2 - 1}}\left(\frac{\left(1 + \frac{32}{27}\frac{C_{eff}}{M}\right)^{1/2} - 1}{\left(1 + \frac{32}{27}\frac{C_{eff}}{M}\right)^{1/2} + 1}\right) \qquad \text{(A-1)}$$

where

D = Detonation velocity of the explosive

C_{eff} = Effective explosive mass

M = Flyer plate mass

Through calculations preformed as prescribed by Baum[4] and Gurney[6] it has been found that for this system 90% of the final flyer-plate velocity is attained after the explosive has expanded to 2.36 times its initial volume (95% at 3.15 times the initial volume). These values of percent of final flyer velocity vs expansion ratio are not affected by the quantity of tamping because of the nature of the explosive mass discount process.

The average value of γ for use in Equation A-1 is determined by using the JWL equation-of-state for various explosive product gases.

$$P = Ae^{-R_1 V} + Be^{-R_2 V} + \frac{C}{V^{(w-1)}} \qquad \text{(A-2)}$$

where

P = Pressure

$\bar{V}$ = Instantaneous volume

V_o = Initial volume

V = $\bar{V}/V_o$ = Specific volume

A, B, C, R_1, R_2 = Empirically determined/constants[10]

γ at any expansion V can be determined using Equation A-3 leading to a plot of γ vs V.

$$\gamma = -\frac{V}{P}\left(\frac{\partial P}{\partial V}\right)_S \qquad \text{(A-3)}$$

Figure A-1 shows the plots of γ vs V for the explosive Composition C-4 and PBX-9404. The average value of γ over a given expansion is determined from the data of the γ vs V plots by using the averaging Equation A-4.

$$\gamma \text{ average} = \frac{\int_1^V \gamma dv}{\int_1^V dv} \tag{A-4}$$

The results show that the average γ for Composition C-4 for V = 2.36 (90% of final velocity) is 2.94 and for V = 3.15 (95% of final velocity) is 2.91. For PBX-9404, the average γ for V = 2.36 is 2.96 and for V = 3.15 is 3.12. These values justify the use of γ = 3 for the process involved in the barrel tamped explosive system for propelling flyer plates to high velocities.

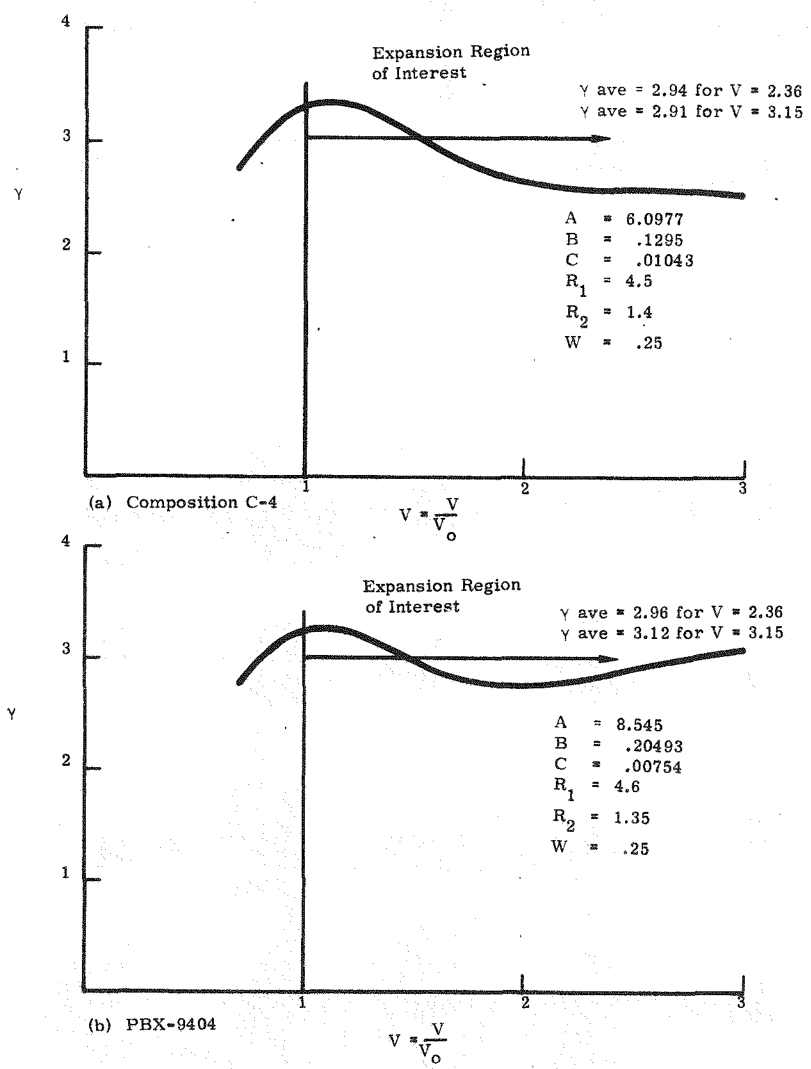

Figure A-1. γ vs V Plot for Explosives of Interest

APPENDIX B

Program Listing for Tektronics 4051

A program has been written which allows the design of a barrel-tamped explosively propelled flyer-plate system. The program is written in basic computer language for the Tektronix 4051 Desktop Computer.

The explosive, Composition C-4 or PBX 9404, may be chosen. The values of C/M, N/C, explosive diameter, and explosive length are inputs (C = explosive mass, M = flyer-plate mass, and N = tamper mass adjacent to the explosive). The effective C/M, discount factor, discount angle, and final flyer velocity are output.

A subroutine calculates the flyer plate thickness at the thick and thin edges with inputs of desired rotation rate and thickness at the center of the flyer. Another routine produces a displacement vs time plot and listing of the tamper material as it expands during the acceleration phase of the flyer. A third routine produces a similar displacement vs time plot and listing for the flyer plate. This third routine can be used to determine the length of the barrel (in front of the flyer plate) required to obtain a given efficiency of the system. The listing of the program is included.

```
100 INIT
110 Q=0
120 SET DEGREES
130 PRINT "JJIF H.E. TO BE USED IS C-4 ENTER 0,IF PBX 9404 ENTER 1"
140 INPUT A1
150 IF A1=1 THEN 190
160 A2=2750
170 A3=8040
175 B1=1.59
177 B5=3
180 GO TO 202
190 A2=2900
195 B5=3
200 A3=8800
201 B1=1.84
202 IF Q=1 THEN 210
204 PRINT "VELOCITY MUST BE CALCULATED THEN AN OPTION TO CALCULATE "
206 PRINT "ROTATION RATE WILL BE GIVENJJ"
210 IF Q=0 THEN 250
215 PRINT "JJ"
220 PRINT "TO CALCULATE FLYER VELOCITY ENTER 0,ROTATION RATE ENTER 1"
225 PRINT "TAMPER MOTION ENTER 2,FLYER MOTION ENTER 3"
230 INPUT A4
240 IF A4=1 THEN 510
242 IF A4=2 THEN 800
245 IF A4=3 THEN 1200
250 PRINT " ENTER C/M AND N/C"
260 INPUT R1,R2
300 R3=A2/(R2+0.5)↑0.5
310 A4=ATN(SQR(3)*A2/A3)
320 R4=A4/(SQR(2)*(R2+0.5)↑0.5)
330 PRINT "ENTER CHARGE DIAMETER, AND CHARGE LENGTH BOTH IN CM"
340 INPUT B,C
345 COPY
350 PAGE
352 PRINT "JCALCULATIONS ARE MADE USING   "
354 PRINT " SQR(2*E)= ";A2;" M/S"
356 PRINT " DETONATION VELOCITY = ";A3;" M/SJ"
360 IF C*TAN(R4)<B/2 THEN 380
370 GO TO 490
380 A5=(B/2)↑2+B/2*(B/2-C*TAN(R4))+(B/2-C*TAN(R4))↑2
390 A6=C*4*A5/(B↑2*3*C)
400 A7=R1*A6
410 A8=(1+32*A7/27)↑0.5
420 A9=A3*SQR(8/(B5↑2-1))*(A8-1)/(A8+1)
425 PRINT "C/M=";R1
426 PRINT "N/C=";R2
430 PRINT "EFFECTIVE C/M= ";A7
440 PRINT "DISCOUNT FACTOR= ";A6
450 PRINT "DISCOUNT ANGLE= ";R4
460 PRINT "FINAL FLYER VELOCITY= ";A9*39.36/12;" FPS"
470 Q=1
480 GO TO 202
490 PRINT "JGGCONE APEX INSIDE H.E.JJ"
491 B2=PI*B↑2*C*B1/4
492 B3=B2/R1
493 A7=B1*PI*B↑3/(3*8*B3*TAN(R4))
494 A6=A7/R1
500 GO TO 410
510 PRINT "ROTATION RATE CALCULATIONS"
520 PRINT "JENTER M AT THE FLYER CENTER ,AND ROTATION RATE"
530 INPUT J1,J2
540 J3=B/2*J2/100
```

```
550 J4=A9-J3
560 J5=A9+J3
570 J6=J1
580 J7=R1*J6*A6
590 J6=J6+1.0E-3
600 J8=J7/J6
610 J9=(1+32*J8/27)↑0.5
620 K0=A3*(J9-1)/(J9+1)
630 IF K0<J4 THEN 635
632 GO TO 590
635 PRINT "M THICK= ";J6
636 J6=J1
640 J6=J6-1.0E-3
650 J8=J7/J6
660 J9=(1+32*J8/27)↑0.5
670 K0=A3*(J9-1)/(J9+1)
680 IF K0=>J5 THEN 700
690 GO TO 640
700 PRINT "M THIN= ";J6
710 PRINT "M MIDDLE= ";J1
720 PRINT "ROTATION RATE= ";J2
730 GO TO 202
740 END
800 PRINT "RATIO OF R BURST TO R0(NUMBER>1)"
810 INPUT K
820 B6=R3↑2*B1/(R1*(2/(B5-1)-(1/K)↑(2*B5-2)*(2/(B5-1)-4/(2*B5-1))))
830 B6=B6*10000
840 PRINT "INITIAL PRESSURE= ";B6*1.0E-9;" KBARS"
850 COPY
860 PAGE
870 VIEWPORT 10,120,10,100
880 WINDOW 1,2,-500,12000
890 AXIS 0.1,1000
891 MOVE 1.001,-490
892 PRINT "1                     R BURST/R ZERO                      2"
893 MOVE 1.02,11800
894 PRINT "12000 FPS"
895 MOVE 1.05,10000
896 PRINT "TAMPER VELOCITY VS. R RATIO"
900 MOVE 0,0
910 FOR M=1 TO K STEP 0.01
920 B8=SQR(2/(B5-1)*B6*R1/B1*(1-(1/M)↑(2*B5-2)))
930 DRAW M,B8/(2.54*12)
940 NEXT M
950 MOVE 1.3,11500
960 PRINT "V BURST/V FINAL";(R3*39.36/12/(B8/(2.54*12)))↑-1
961 MOVE 1.3,10500
962 PRINT "V BURST=";B8/(2.54*12);"   V FINAL=";R3*39.36/12
965 COPY
1010 PAGE
1012 VIEWPORT 10,120,10,100
1014 V3=0
1015 H1=0
1016 V4=0
1020 WINDOW 0,B/(1*1*R3*100),-0.04*3*B/1,1.2*B/1
1030 AXIS 1.0E-6,1
1040 MOVE 0,-0.037*1.2*B/1
1050 PRINT "0                TIME(US/DIV.)                ";B/(1*R3*100)
1060 MOVE 5.0E-7,0.95*1.2*B/1
1070 PRINT " ";1.2*B/1;"  CM"
1071 MOVE 5.0E-7,0.8*1.2*B/1
1072 PRINT "TAMPER DISPLACEMENT VS. TIME"
1075 MOVE 0,0
```

```
1080 V=SQR(2/(B5-1)*B6*R1/B1*(1-(1/1)↑(2*B5-2)))
1090 FOR M=1.01 TO K STEP 0.01
1100 B8=SQR(2/(B5-1)*B6*R1/B1*(1-(1/M)↑(2*B5-2)))
1110 V1=0.01*B/2
1120 V2=V1*2/(V+B8)
1122 V3=V3+V2
1124 V4=V4+V1
1125 IF H1=1 THEN 1175
1130 DRAW V3,V4
1140 V=B8
1150 NEXT M
1160 COPY
1161 PAGE
1165 IF H1=1 THEN 202
1170 H1=1
1171 PRINT "TAMPER TIME","DISPLACEMENT (CM)"
1172 V3=0
1173 V4=0
1174 GO TO 1080
1175 PRINT V3,V4
1176 GO TO 1140
1180 GO TO 202
1200 PAGE
1210 PRINT "ENTER EXPANSION STEP FOR CALCULATIONS  (CM)"
1220 INPUT C9
1222 PRINT "ENTER TIME FOR PLOT"
1224 INPUT C2
1230 C3=PI*B↑2*C*B1/(4*R1)
1240 C4=A7*C3
1250 C5=C4/(2+2/A7)
1260 C6=4*C5/(PI*B↑2*B1)
1270 C7=0
1280 C8=C9
1285 PAGE
1290 VIEWPORT 10,120,10,100
1300 WINDOW 0,C2,-0.05*A9*100*C2,A9*100*C2/2
1310 AXIS C2/10,1
1320 FOR M=C6+C9 TO 3*C6 STEP C9
1330 C7=C7+1/(1-(C6/M)↑(B5-1))↑0.5*C9/(A9*100)
1340 DRAW C7,C8
1350 C8=C8+C9
1360 NEXT M
1370 MOVE 0.01*C2,-0.05*A9*100*C2/2
1380 PRINT "0                    TIME (SEC)                         ";C2
1390 MOVE 0.01*C2,0.95*A9*100*C2/2
1400 PRINT " ";A9*100*C2/2;"  CM"
1410 MOVE 0.1*C2,0.8*A9*100*C2/2
1420 PRINT "FLYER VS. TIME"
1430 COPY
1435 PAGE
1440 C7=0
1450 C8=C9
1455 PRINT "TIME","DISPL","VELOCITY","VEL/VEL FINAL"
1456 PRINT " SEC","  CM","   FPS"
1460 FOR M=C6+C9 TO 5*C6 STEP C9
1470 C7=C7+1/(1-(C6/M)↑(B5-1))↑0.5*C9/(A9*100)
1480 D5=(1-(C6/M)↑(B5-1))↑0.5
1490 D6=D5*A9*39.36/12
1500 PRINT C7,C8,D6,D5
1510 C8=C8+C9
1520 NEXT M
1530 GO TO 202
1540 END
```

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