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Graphical Analysis of Barrel-Tamped Explosively Accelerated Flyer Plates

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GRAPHICAL ANALYSIS OF BARREL-TAMPED EXPLOSIVELY ACCELERATED FLYER PLATES

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ABSTRACT

Analytical equations for barrel-tamped explosively accelerated flyer plates are used to generate graphical solutions to flyer problems. Given the problem geometrical dimensions, explosive weight, detonation velocity, explosive exponent, barrel-tamping weight, and flyer weight, the graphical representation of the calculated data allows for a fast approximation of the final or maximum flyer plate velocity. Graphically obtained flyer velocities are compared to experimentally published data. The graphical solution for flyer velocity is particularly useful when a computer is not available. The graphical representation of the various barrel-tamped flyer parameters results in a parametric study which illustrates the effect on final flyer velocity in varying parameters. The graphical analysis scheme can be used with any explosive, tamper and flyer materials.

CONTENTS

FIGURES

TABLES

LIST OF SYMBOLS

a	Number of atoms per molecule of carbon
b	Number of atoms per molecule of hydrogen
α	Explosive discount factor (ALFA)
c	Number of atoms per molecule of nitrogen
C	Explosive actual weight
Ce	Explosive effective weight
d	Number of atoms per molecule of oxygen
D	Explosive detonation velocity
Do	Barrel tamping outside diameter
Di	Barrel tamping inside diameter
d	Explosive diameters
d_1	Truncated explosive frustrum of cone minimum diameter
E	Gurney energy
G	Gamma, detonation gas product exponent
Hf	Heat for formation
L	Explosive length
Lm	Maximum explosive length
M	Flyer plate weight
MG	Grams of detonation product gases per mole of gas
MW	Molecular weight
N	Barrel-tamping cylinder weight
NM	Molecules of detonation product gases per gram of explosive
OMB	Oxygen mass balance
Pcj	Chapman-Jouget pressure

PHI	Non-dimensional explosive constant
Q	Detonation energy
RHOcj	Chapman-Jouget density
t	Flyer plate thickness
T	Barrel-tamping cylinder thickness
V	Volume
Va	Actual explosive volume
V_c	Explosive frustrum of a cone/effective volume
Vf	Flyer plate maximum velocity
Vfm	Measured flyer maximum velocity
V_T	Tamping cylinder maximum velocity
V_o	Detonation product gas untamped velocity
θ	Explosive discount angle (THETA)
ρ_f	Density of flyer plate (RHOf)
ρ_N	Density of barrel-tamping cylinder (RHOn)
ρ_c	Density of explosive (RHOc)
(2E)^0.5	Gurney Velocity $(2E)^{0.5}$

GRAPHICAL ANALYSIS OF BARREL-TAMPED EXPLOSIVELY ACCELERATED FLYER PLATES

INTRODUCTION

Sandia National Laboratories (SNL), Explosive Components Department has responsibilities for the design of components that involve barrel-tamped explosively accelerated flyer plates. Hot wire and explosive bridgewire detonator components used to initiate larger explosive charges are examples of barrel-tamped flyer configurations. Barrel-tamped or untamped flyer plates have been designed to perform many varied functions [1-4].

The theory for barrel-tamped explosively driven flyers has been developed and published [5-7]. Benham [1] and Mathews [2-4] have expanded the analytical solutions to include methods for calculating the fraction of the total or actual explosive weight that effectively propels or accelerates the flyer.

Benham's approach is the most general and was selected to generate the graphical solutions presented. The graphical representation of the calculated data allows for a fast approximation of the final or maximum flyer velocity when a calculator or computer is not available.

GENERAL CONFIGURATION

The general barrel-tamped explosively driven flyer configurations are shown in Figures 1 and 2. The cushion material between the explosive and flyer is required for certain configurations to prevent spallation or breakup of the flyer before impacting the desired target. Spallation of the flyer is more of a concern when the flyer is accelerated for a relatively large distance before impact. Most flyer components are designed so the flyer impacts the target about the time it is accelerated to about 90% of its maximum velocity. This acceleration distance is very short and, therefore, spallation is usually not a concern. The following sections present a step-by-step description of the procedures, equations, and graphical representations used to obtain the maximum velocity for barrel-tamped flyers. All equations used to generate the graphical solutions are included in Appendix A.

TAMPING TO EXPLOSIVE WEIGHT

This is the beginning of the analysis sequence. Barrel-tamping to explosive weight ratio (N/C) versus tamping to explosive density ratio (RHOn/RHOc) and outside to inside barrel diameter ratio (Do/Di) data are shown in Figure 3. The following equation obtained from geometrical and material considerations was used to calculate N/C:

$$(N/C) = (RHOn/RHOc)[(Do/Di)^2 - 1] \tag{1}$$

If N/C is already known or has to be calculated because parameters fall outside the ranges of Figure 3, then proceed to the next section.

EXPLOSIVE DISCOUNT ANGLE

Explosive discount angle [1] (THETA) versus barrel-tamping to explosive weight ratio (N/C) data are shown in Figure 4. The following equation derived from Gurney theory [1,13] was used to calculate THETA:

$$THETA = 30/\{1.44[(N/C) + 0.5]^{0.5}\} \tag{2}$$

The maximum value for THETA of 30 degrees corresponds to the untamped (no barrel-tamping) explosive configuration. Proceed to the next section.

MAXIMUM EXPLOSIVE LENGTH TO DIAMETER RATIO (Lm/d)

Maximum explosive length to diameter ratio (Lm/d) versus explosive discount angle (THETA) data are shown in Figure 5. The following equation obtained from geometrical considerations was used to calculate (Lm/d):

$$(Lm/d) = 1/[2\ TAN\ (THETA)] \tag{3}$$

The maximum effective explosive length (Lm) corresponds to a value of THETA (θ) in Figure 1. Lm can be calculated from Figure 5 or Equation 3. If the actual explosive length (L) is greater than Lm, proceed to the next section, otherwise skip the next section.

EFFECTIVE EXPLOSIVE DISCOUNT FACTOR (ALFA)

Effective explosive discount factor (ALFA) versus explosive diameter-to-length ratio (d/L) and explosive discount angle (THETA) data are shown in Figure 6. ALFA is read from this figure only if the actual explosive length (L) is greater than the maximum effective explosive length (Lm) as illustrated in Figure 1. The following equation was used to calculate ALFA:

$$\mathrm{ALFA} = (d/L)[1/6\ \mathrm{TAN}\ (\mathrm{THETA})] \qquad (4)$$

The effective explosive weight (Ce) is that calculated from the right circular cone volume (Equation A15 in Appendix A) as shown in Figure 1 and then skip the next section.

EFFECTIVE EXPLOSIVE DISCOUNT FACTOR (ALFA)

Effective explosive discount factor (ALFA) versus explosive length-to-diameter ratio (L/d) and explosive discount angle (THETA) data are shown in Figure 7. ALFA is read from this figure only if the actual explosive length (L) is less than the maximum effective explosive length (Lm) as illustrated in Figure 2. The following equation was used to calculate ALFA:

$$\mathrm{ALFA} = 1 - 2(L/d)[\mathrm{TAN}(\mathrm{THETA})] + (4/3)(L/d)^2[\mathrm{TAN}(\mathrm{THETA})]^2 \qquad (5)$$

The effective explosive weight (Ce) is that calculated from the frustum of a cone volume (Equation A14 in Appendix A) as shown in Figure 2 and go to the next section.

ACTUAL EXPLOSIVE-TO-FLYER WEIGHT RATIO (C/M)

Actual explosive to flyer weight ratio (C/M) versus explosive to flyer thickness ratio (L/t) and explosive to flyer density ratio (RHOc/RHOf) data are shown in Figure 8. The following equation obtained from geometrical and material considerations was used to calculate (C/M):

$$(C/M) = (L/t)(\mathrm{RHOc}/\mathrm{RHOf}) \qquad (6)$$

Proceed to the next section.

EFFECTIVE EXPLOSIVE TO FLYER WEIGHT RATIO (Ce/M)

Effective explosive [1] to flyer weight ratio (Ce/M) versus actual explosive to flyer weight ratio (C/M) and explosive discount factor (ALFA) data are shown in Figure 9. The following equation was used to calculate (Ce/M):

$$(Ce/M) = ALFA(C/M) \tag{7}$$

Proceed to the next section

MAXIMUM FLYER TO DETONATION VELOCITY RATIO (Vf/D)

Maximum flyer plate to explosive detonation velocity ratio (Vf/D) versus effective explosive to flyer weight ratio (Ce/M) and explosive product gas exponent (Gamma) data are shown in Figure 10. The following equation [1-4,5] was used to calculate (Vf/D):

$$(Vf/D) = A[(B-1)/(B + 1)] \tag{8}$$

where

$$A = [8/(G^2 - 1)]^{0.5} \tag{9}$$

$$B = [1 + (32/27)(Ce/M)]^{0.5} \tag{10}$$

$$G = Gamma \tag{11}$$

This section concludes the step-by-step analysis sequence for obtaining the maximum flyer plate velocity.

GRAPHICAL ANALYSIS VERSUS EXPERIMENTAL DATA

Data from graphical analysis presented here were compared to ten different barrel tamped flyer plate experiments published in the literature. The maximum flyer velocities resultant from the graphical analysis (Vf) are compared to the published measured value (Vfm) in Table I. About half of the compared cases in Table I are for $L < Lm$ (Frustrum of cone effective explosive volume) and half are for $L > Lm$ (right circular cone affective explosive volume).

Care must be taken when solving for flyer velocities from deflagration-to-detonation (DDT) detonator configurations. The theory presented here is only good for detonating explosives. Therefore, the explosive volume for a DDT detonator should be only that for the usually higher density or output pellet.

GRAPHICAL SOLUTION EXAMPLES

The use of the graphical representations of the analytical equations modeling barrel-tamped explosively driven flyer plates are demonstrated by two examples in Appendix B. The first example is for a flyer problem with geometrical configuration per Figure 1 (L > Lm). The second example is for a flyer configuration with geometrical configuration per Figure 2 (L < Lm). A step-by-step procedure using Figures 1-10 is listed in Appendix B for the two examples

EXPLOSIVE DETONATION VELOCITY

The next two sections include examples of some useful graphical and tabular information for flyer plate problems. Flyer maximum velocity (Vf) versus explosive to flyer weight ratio (C/M) and explosive detonation velocity data are shown in Figure 11. The effect of explosives with various detonation velocities on flyer velocity is illustrated in Figure 11. An explosive exponent of 3.0 (Gamma) was used to calculate the data of Figure 11.

EXPLOSIVE PRODUCT GAS EXPONENT

The Gurney velocity, $(2E)^{0.5}$, versus detonation velocity and explosive exponent (Gamma = G) data are shown in Figure 12. The effect of explosive exponent on Gurney velocity is illustrated in Figure 12. These data were calculated using the following equation [13-15]:

$$(2E)^{0.5} = 1.26D/(G + 1) \tag{12}$$

COMMON FLYER, TAMPER, AND EXPLOSIVE PARAMETERS

In an effort to make this report stand alone and more useful for practical flyer velocity solutions, the following additional information is provided. Table II lists common flyer plate and barrel-tamping materials and densities from References 10 and 11.

Table III and IV list common high explosives with composition comprised of carbon, hydrogen, nitrogen, and oxygen (CHNO) elements. The theory described in detail in References 12-14 was used to calculate the detonation parameters listed in Tables III and IV. Given the following explosive parameters listed in Table III [15]:

1. Carbon atoms per molecule (a),
2. Hydrogen atoms per molecule (b),
3. Nitrogen atoms per molecule (c),
4. Oxygen atoms per molecule (d),
5. Density (RHOc), and
6. Heat of formation (Hf).

The following explosive detonation parameters listed in Tables III and IV are calculated [12-14]:

1. Molecular weight (MW),
2. Molecules of detonation product gases per gram of explosive (NM),
3. Grams of product gases per mole of gas (MG),
4. Non-dimensional explosive constant [18-19] (PHI),
5. Chapman-Jouget density (RHOcj)
6. Oxygen mass balance (OMB),
7. Detonation velocity (D),
8. Chapman-Jouget pressure (Pcj),
9. Detonation energy (Q),
10. Gurney velocity (2E)^ 0.5

111 Detonation product gas exponent (Gamma).

Although not all of the above explosive parameters are necessary for the flyer velocity solution, they are included here because they could be useful in solving general explosively driven flyer problems such as open-face [13], symmetric [8], and asymmetric sandwich [8] configurations. The initial explosive density is listed in both Tables III and IV. Detonation parameters were calculated for several different densities for some explosives. The explosive chemical composition (a, b, c, d atoms per molecule), density and heat of formation data were obtained from Reference 15.

SUMMARY

Graphical representations of analytical equations modeling barrel-tamped explosively driven flyer plates have been shown to produce generally good estimates of maximum flyer velocity. The flyer velocities resultant from the graphical analysis were within 10% of the published experimental data. The parametric study showing the effect on final flyer velocity resultant from varying the various flyer parameters was presented. The graphs can be used to design flyer components. This graphical analysis scheme can be used with any detonating explosive, tamper, and flyer materials.

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Table I. Graphical Analysis Versus Published Experimental Data

Flyer Velocity Comparisons

All Reference 1 Data: COMP-C4 Explosive, D = 0.804 cm/μs)

TEST	REF	N/C	THETA	Lm/d	L/d	ALFA	C/M	Ce/M	G	Vf/D	Vf (cm/μs)	Vfm (cm/μs)	Vf/Vfm	Explosive Length (L)
26	1	.06	28.0	.97	1.0	.295	4.6	1.5	3.0	.281	.23	.21	1.07	>Lm
MC3644	9	70.0	3.0	9.8	1.0	.90	5.1	4.9	2.8	.48	.30	.28	1.06	<Lm
5	1	4.4	9.6	5.9	1.5	.65	6.7	4.5	3.0	.43	.35	.32	1.08	>Lm
1-13	1	2.71	11.8	2.5	1.87	.42	5.0	2.1	3.0	.30	.24	.23	1.04	>Lm
MC2984	-	3.55	10.6	2.7	1.33	.58	8.5	4.8	3.0	.44	.36	.33	1.09	>Lm
24	1	0.88	19.8	1.5	.75	.56	6.0	3.1	3.0	.36	.29	.31	0.94	<Lm
15	1	0.84	25.0	1.3	2.5	.28	6.2	2.0	3.0	.32	.26	.25	1.04	<Lm
23	1	1.76	14.5	2.1	2.5	.30	20.1	5.5	3.0	.53	.43	.40	1.08	<Lm
11	1	0.84	19.0	1.8	1.5	.26	4.5	1.4	3.0	.26	.21	.21	1.00	<Lm
6	1	4.40	9.5	3.1	1.5	.57	12.1	6.8	3.0	.51	.41	.41	1.00	>Lm

TABLE II. COMMON FLYER AND BARREL-TAMPING MATERIAL DENSITIES

MATERIAL	DENSITY(g/cc)
1. STEEL, AISI C1020(HOT-WORKED)	7.85
2. STEEL, AISI 304(SHEET)	8.03
3. ALUMINUM, 2024-T3	2.77
4. ALUMINUM, 6061-T6	2.70
5. ALUMINUM, 7079-T6	2.74
6. COPPER, PURE	8.90
7. LEAD, PURE	11.34
8. TANTALUM	16.60
9. TITANIUM	4.85
10. TUNGSTEN	19.30
11. URANIUM	18.97
12. KAPTON	1.41
13. PLEXIGLAS	1.18

TABLE III. CHNO EXPLOSIVE PARAMETERS

H.E. NAME	CHEMICAL FORMULA a	b	c	d	MW (g/mol)	NM (mole gas/ g H.E.)	MG (g gas/ mol gas)	Hf (Kcal/ mole)	PHI	RHOc (g/cc)
TNT	7.0	5.0	3.0	6.0	227.0	.025	28.5	-15.0	4.87	1.64
TNT	7.0	5.0	3.0	6.0	227.0	.025	28.5	-15.0	4.87	1.00
HNS	14.0	6.0	6.0	12.0	450.0	.023	32.0	13.9	4.86	1.69
HNS	14.0	6.0	6.0	12.0	450.0	.023	32.0	13.9	4.86	1.65
HNS	14.0	6.0	6.0	12.0	450.0	.023	32.0	13.9	4.86	1.60
HNS	14.0	6.0	6.0	12.0	450.0	.023	32.0	13.9	4.86	1.40
TATB	6.0	6.0	6.0	6.0	258.0	.029	27.2	-36.8	4.97	1.88
TATB	6.0	6.0	6.0	6.0	258.0	.029	27.2	-36.8	4.97	1.40
DATB	6.0	5.0	5.0	6.0	243.0	.028	28.4	-29.2	5.03	1.79
DATB	6.0	5.0	5.0	6.0	243.0	.028	28.4	-29.2	5.03	1.40
TETRYL	7.0	5.0	5.0	8.0	287.0	.027	30.5	4.7	5.62	1.71
TETRYL	7.0	5.0	5.0	8.0	287.0	.027	30.5	4.7	5.62	1.40
NM	1.0	3.0	1.0	2.0	61.0	.037	23.1	-27.0	6.55	1.13
NM	1.0	3.0	1.0	2.0	61.0	.037	23.1	-27.0	6.55	1.14
NQ	1.0	4.0	4.0	2.0	104.0	.038	23.0	-23.6	5.49	1.72
NQ	1.0	4.0	4.0	2.0	104.0	.038	23.0	-23.6	5.49	1.55
RDX	3.0	6.0	6.0	6.0	222.0	.034	27.2	14.7	6.78	1.80
RDX	3.0	6.0	6.0	6.0	222.0	.034	27.2	14.7	6.78	1.76
RDX	3.0	6.0	6.0	6.0	222.0	.034	27.2	14.7	6.78	1.71
RDX	3.0	6.0	6.0	6.0	222.0	.034	27.2	14.7	6.78	1.36
RDX	3.0	6.0	6.0	6.0	222.0	.034	27.2	14.7	6.78	1.00
HMX	4.0	8.0	8.0	8.0	296.0	.034	27.2	17.9	6.77	1.89
HMX	4.0	8.0	8.0	8.0	296.0	.034	27.2	17.9	6.77	1.40
PETN	5.0	8.0	4.0	12.0	316.0	.032	30.4	-128.7	6.79	1.77
PETN	5.0	8.0	4.0	12.0	316.0	.032	30.4	-128.7	6.79	.99
LX-13	1.8	3.6	1.0	3.3	92.3	.033	26.0	-44.4	6.38	1.53
PB9404	1.4	2.8	2.6	2.7	98.6	.034	27.0	.1	6.63	1.84
LX04-1	1.6	2.6	2.3	2.3	90.2	.033	26.4	-21.5	5.60	1.87
COMP B	2.0	2.6	2.2	2.7	100.2	.031	27.2	1.0	6.02	1.72
LX07-2	1.5	2.6	2.4	2.4	93.3	.033	26.7	-12.3	6.02	1.87
PB9011	1.7	3.2	2.5	2.6	100.0	.033	25.7	-4.1	6.21	1.77
CYCLTL	1.8	2.6	2.4	2.7	100.0	.032	27.5	3.0	6.29	1.75
LXO9	1.4	2.7	2.6	2.7	99.7	.034	27.1	1.8	6.64	1.84
BARATL	.7	.5	.9	2.4	60.1	.029	36.1	-70.8	4.79	2.55
COMP C	1.8	3.5	2.5	2.5	100.2	.034	24.5	3.3	6.23	1.59
COMP B	2.0	2.5	2.1	2.7	99.9	.030	27.6	.8	5.97	1.72
DIPAM	12.0	6.0	8.0	12.0	454.0	.025	31.7	-20.0	5.08	1.79
DNPA	6.0	8.0	2.0	6.0	204.0	.029	24.0	-110.0	4.68	1.47
EDNP	7.0	12.0	2.0	6.0	220.0	.032	19.4	-140.0	4.30	1.28

TABLE III. CHNO EXPLOSIVE PARAMETERS(CONTINUED)

H.E. NAME	CHEMICAL FORMULA a	b	c	d	MW (g/mol)	NM (mole gas/ g H.E.)	MG (g gas/ mol gas)	Hf (Kcal/ mole)	PHI	RHOc (g/cc)
FEFO	5.0	6.0	4.0	10.0	282.0	.030	31.1	-177.5	5.70	1.61
HNAB	12.0	4.0	8.0	12.0	452.0	.024	33.5	57.8	5.31	1.61
LX01-0	1.5	3.7	1.7	3.4	99.9	.035	26.1	-27.5	6.93	1.23
LX02-1	2.8	4.9	.9	3.0	99.0	.032	21.8	-49.1	5.16	1.44
LX08	1.9	4.4	.8	3.0	86.1	.035	22.7	-44.0	6.10	1.44
LX09-1	1.4	2.7	2.6	2.7	99.6	.034	27.2	2.0	6.65	1.87
LX10-0	1.4	2.7	2.6	2.6	97.0	.033	27.0	-3.1	6.38	1.90
LX11-0	1.6	2.5	2.2	2.2	86.7	.032	26.0	-30.7	5.13	1.87
MEN-II	2.1	7.1	1.3	3.1	100.0	.040	18.3	-74.3	5.63	1.02
NC12%N	6.0	7.0	2.3	9.5	262.5	.029	29.7	-216.0	5.06	1.58
NC13%N	6.0	7.0	2.5	10.0	274.0	.029	30.1	-200.0	5.37	1.58
NG	3.0	5.0	3.0	9.0	227.0	.032	31.7	-90.8	7.16	1.59
OCTOL	1.8	2.6	2.4	2.7	100.0	.032	27.5	2.6	6.28	1.81
PB9007	2.0	3.2	2.4	2.4	99.9	.032	25.1	7.1	6.06	1.66
PB9010	1.4	2.4	2.4	2.4	92.0	.033	27.2	-7.9	6.20	1.79
PB9205	1.8	3.1	2.5	2.5	100.1	.033	25.5	5.8	6.21	1.68
PB9407	1.4	2.7	2.5	2.5	95.8	.033	26.9	11.6	6.76	1.61
PB9501	1.5	2.9	2.6	2.7	99.9	.034	26.7	2.3	6.60	1.84
PB9502	1.5	2.9	2.6	2.7	99.9	.034	26.7	2.3	6.60	1.84
PENTLT	2.3	2.4	1.3	3.2	99.9	.029	29.6	-24.3	5.80	1.67
TNM	1.0	0.0	4.0	8.0	196.0	.031	38.7	13.0	8.48	1.65
TACOT	12.0	4.0	8.0	8.0	388.0	.023	31.1	128.0	4.76	1.61
BTF	6.0	0.0	6.0	6.0	252.0	.024	36.0	144.5	5.88	1.87
EL506A	2.4	4.3	1.1	3.3	100.7	.032	24.2	-39.9	5.85	1.48
EL506C	3.3	5.9	.9	2.7	100.0	.033	18.2	-42.5	4.72	1.48
RX08EL	9.0	14.0	12.0	18.0	578.0	.032	29.0	-81.6	6.57	1.80
CH-6	.2	0.0	.4	.4	14.1	.029	35.7	14.7	8.49	1.64
LX-14	1.5	2.9	2.6	2.7	100.0	.034	26.5	0.0	6.48	1.85

TABLE IV. CHNO EXPLOSIVE DETONATION PARAMETERS

H.E. NAME	RHOc (g/cc)	RHOcj (g/cc)	OMB (%)	D (cm/us)	Pcj (GPa)	Q (cal/g)	(2E)^.5 (cm/us)	Gamma
TNT	1.64	2.17	-74.0	.698	20.43	1295.2	.243	2.92
TNT	1.00	1.37	-74.0	.513	7.59	1295.2	.203	2.46
HNS	1.69	2.23	-67.6	.712	21.66	1356.2	.246	2.96
HNS	1.65	2.18	-67.6	.700	20.64	1356.2	.244	2.93
HNS	1.60	2.12	-67.6	.686	19.41	1356.2	.241	2.88
HNS	1.40	1.87	-67.6	.628	14.86	1356.2	.229	2.72
TATB	1.88	2.46	-55.8	.776	27.42	1075.8	.258	3.13
TATB	1.40	1.87	-55.8	.635	15.20	1075.8	.231	2.72
DATB	1.79	2.35	-56.0	.753	25.13	1151.4	.254	3.05
DATB	1.40	1.87	-56.0	.639	15.37	1151.4	.232	2.72
TETRYL	1.71	2.25	-47.4	.771	25.62	1420.5	.261	2.98
TETRYL	1.40	1.87	-47.4	.675	17.17	1420.5	.242	2.72
NM	1.13	1.53	-39.3	.638	13.04	1363.4	.236	2.53
NM	1.14	1.54	-39.3	.640	13.16	1363.4	.237	2.54
NQ	1.72	2.27	-30.8	.766	25.32	884.6	.259	2.99
NQ	1.55	2.05	-30.8	.713	20.56	884.6	.249	2.84
RDX	1.80	2.36	-21.6	.879	34.29	1482.5	.286	3.06
RDX	1.76	2.31	-21.6	.865	32.78	1482.5	.284	3.02
RDX	1.71	2.25	-21.6	.848	30.95	1482.5	.281	2.98
RDX	1.36	1.82	-21.6	.728	19.57	1482.5	.257	2.69
RDX	1.00	1.37	-21.6	.605	10.58	1482.5	.229	2.46
HMX	1.89	2.48	-21.6	.909	37.73	1476.8	.292	3.14
HMX	1.40	1.87	-21.6	.741	20.70	1476.8	.260	2.72
PETN	1.77	2.32	-10.1	.867	33.00	1514.2	.284	3.03
PETN	.99	1.36	-10.1	.602	10.38	1514.2	.228	2.46
LX-13	1.53	2.03	-36.6	.762	23.28	1416.8	.262	2.82
PB9404	1.84	2.41	-24.1	.882	35.00	1434.1	.286	3.09
LX04-1	1.87	2.45	-37.1	.820	30.54	1114.8	.270	3.12
COMP B	1.72	2.27	-43.3	.802	27.77	1404.1	.268	2.99
LX07-2	1.87	2.45	-31.6	.850	32.86	1244.2	.277	3.12
PB9011	1.77	2.33	-39.0	.831	30.34	1357.9	.275	3.03
CYCLTL	1.75	2.30	-34.6	.829	30.04	1433.4	.275	3.01
LX09	1.84	2.41	-24.2	.883	35.09	1449.2	.287	3.09
BARATL	2.55	3.29	16.9	.954	48.57	730.9	.286	3.78
COMP C	1.59	2.10	-46.9	.773	24.57	1401.1	.264	2.87
COMP B	1.72	2.27	-43.0	.799	27.57	1399.8	.268	2.99
DIPAM	1.79	2.35	-52.9	.757	25.38	1269.6	.255	3.05
DNPA	1.47	1.96	-78.4	.636	15.78	1054.9	.230	2.77
EDNP	1.28	1.72	-101.8	.558	10.99	940.0	.212	2.63

TABLE IV. CHNO EXPLOSIVE DETONATION PARAMETERS(CONTINUED)

H.E. NAME	RHOc (g/cc)	RHOcj (g/cc)	OMB (%)	D (cm/us)	Pcj (GPa)	Q (cal/g)	(2E)^.5 (cm/us)	Gamma
FEFO	1.61	2.13	-17.0	.746	23.06	1152.1	.256	2.89
HNAB	1.61	2.13	-49.6	.720	21.47	1423.5	.249	2.89
LX01-0	1.23	1.66	-24.3	.691	16.37	1521.7	.249	2.60
LX02-1	1.44	1.92	-80.5	.659	16.69	1189.1	.237	2.75
LX08	1.44	1.92	-57.7	.717	19.75	1374.8	.252	2.75
LX09-1	1.87	2.45	-24.0	.894	36.29	1451.1	.289	3.12
LX10-0	1.90	2.49	-27.0	.886	35.95	1360.4	.286	3.15
LX11-0	1.87	2.45	-42.9	.785	28.00	974.6	.261	3.12
MEN-II	1.02	1.40	-72.8	.556	9.08	1095.2	.215	2.47
NC12%N	1.58	2.09	-36.6	.694	19.71	1022.1	.243	2.87
NC13%N	1.58	2.09	-32.1	.715	20.92	1123.4	.249	2.87
NG	1.59	2.10	3.5	.829	28.22	1582.4	.279	2.87
OCTOL	1.81	2.38	-34.6	.849	32.09	1429.0	.278	3.07
PB9007	1.66	2.19	-49.8	.785	26.05	1393.1	.266	2.93
PB9010	1.79	2.35	-27.2	.837	31.01	1298.4	.276	3.05
PB9205	1.68	2.22	-43.5	.802	27.36	1405.7	.269	2.95
PB9407	1.61	2.13	-26.9	.812	27.32	1517.5	.274	2.89
PB9501	1.84	2.41	-26.9	.880	34.88	1442.6	.286	3.09
PB9502	1.84	2.41	-26.9	.880	34.88	1442.6	.286	3.09
PENTLT	1.67	2.20	-42.0	.771	25.22	1399.6	.262	2.94
TNM	1.65	2.18	49.0	.925	36.02	1984.7	.302	2.93
TACOT	1.61	2.13	-74.2	.682	19.26	1354.6	.239	2.89
BTF	1.87	2.45	-38.1	.840	32.06	1692.5	.275	3.12
EL506A	1.48	1.97	-58.7	.714	19.99	1360.6	.251	2.78
EL506C	1.48	1.97	-108.6	.642	16.14	1155.1	.231	2.78
RX08EL	1.80	2.36	-19.4	.865	33.20	1453.3	.283	3.06
CH-6	1.64	2.17	5.9	.922	35.61	2464.3	.302	2.92
LX-14	1.85	2.43	-29.4	.875	34.58	1408.2	.284	3.10

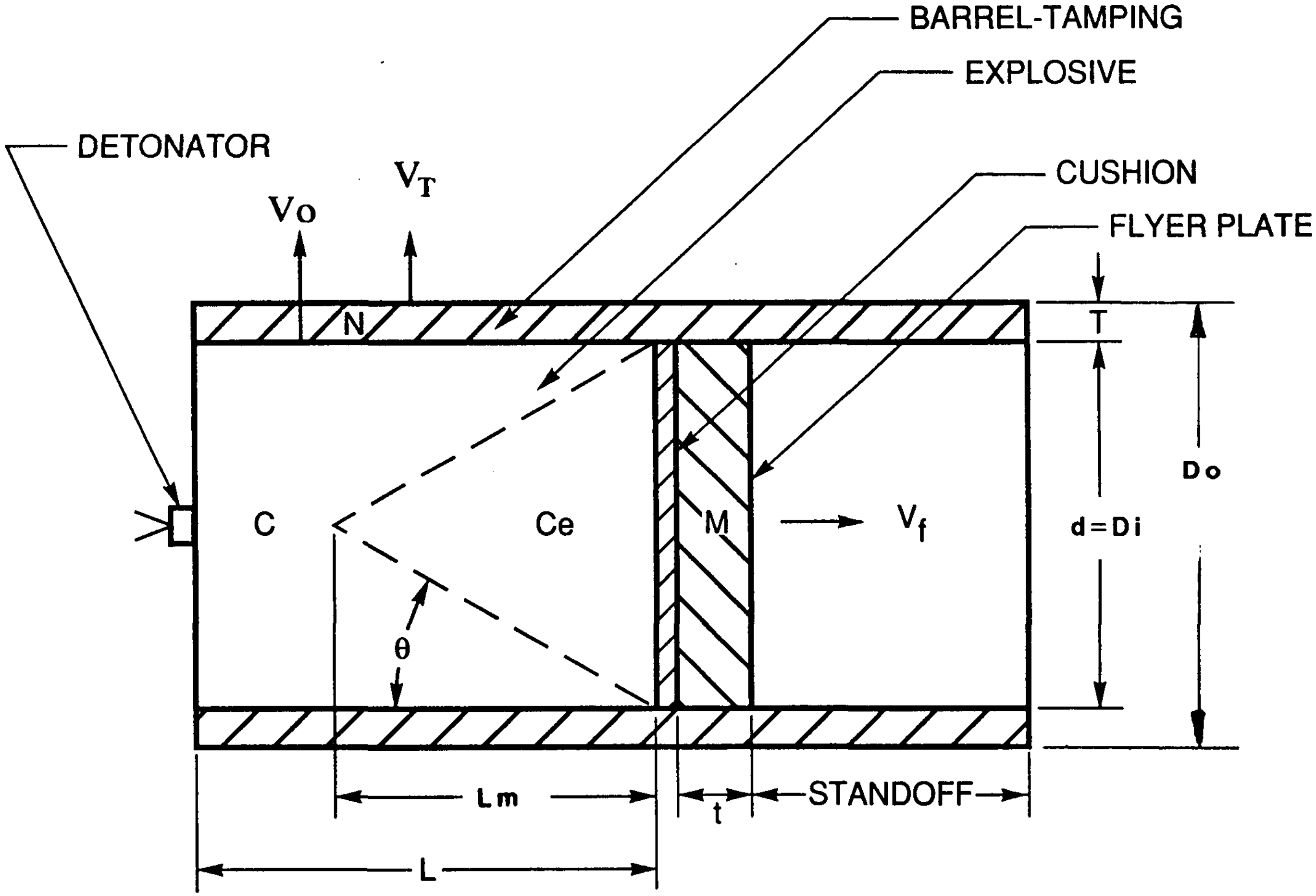

FIGURE 1. BARREL-TAMPED EXPLOSIVELY DRIVEN FLYER PLATE CONFIGURATION(L > Lm)

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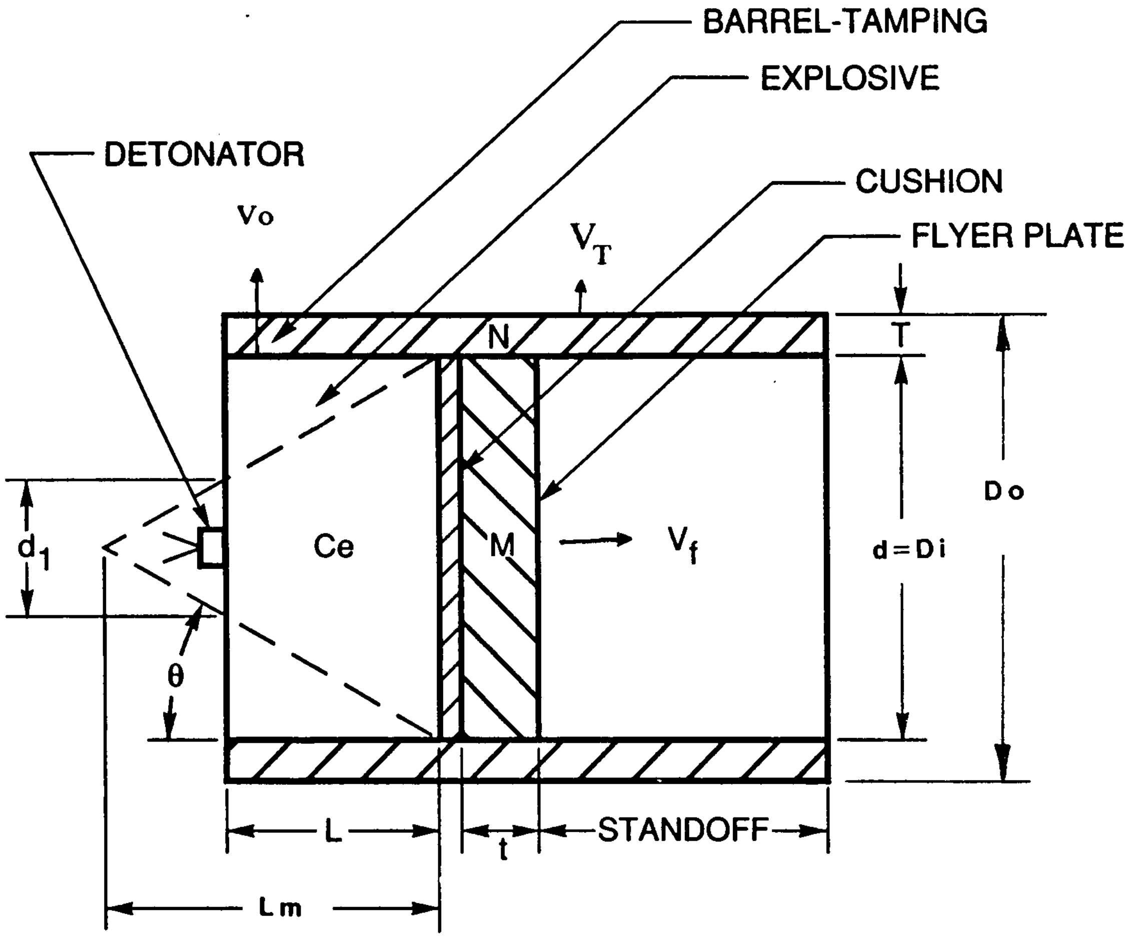

FIGURE 2. BARREL-TAMPED EXPLOSIVELY DRIVEN FLYER PLATE CONFIGURATION(L < Lm)

TA0067.07.01

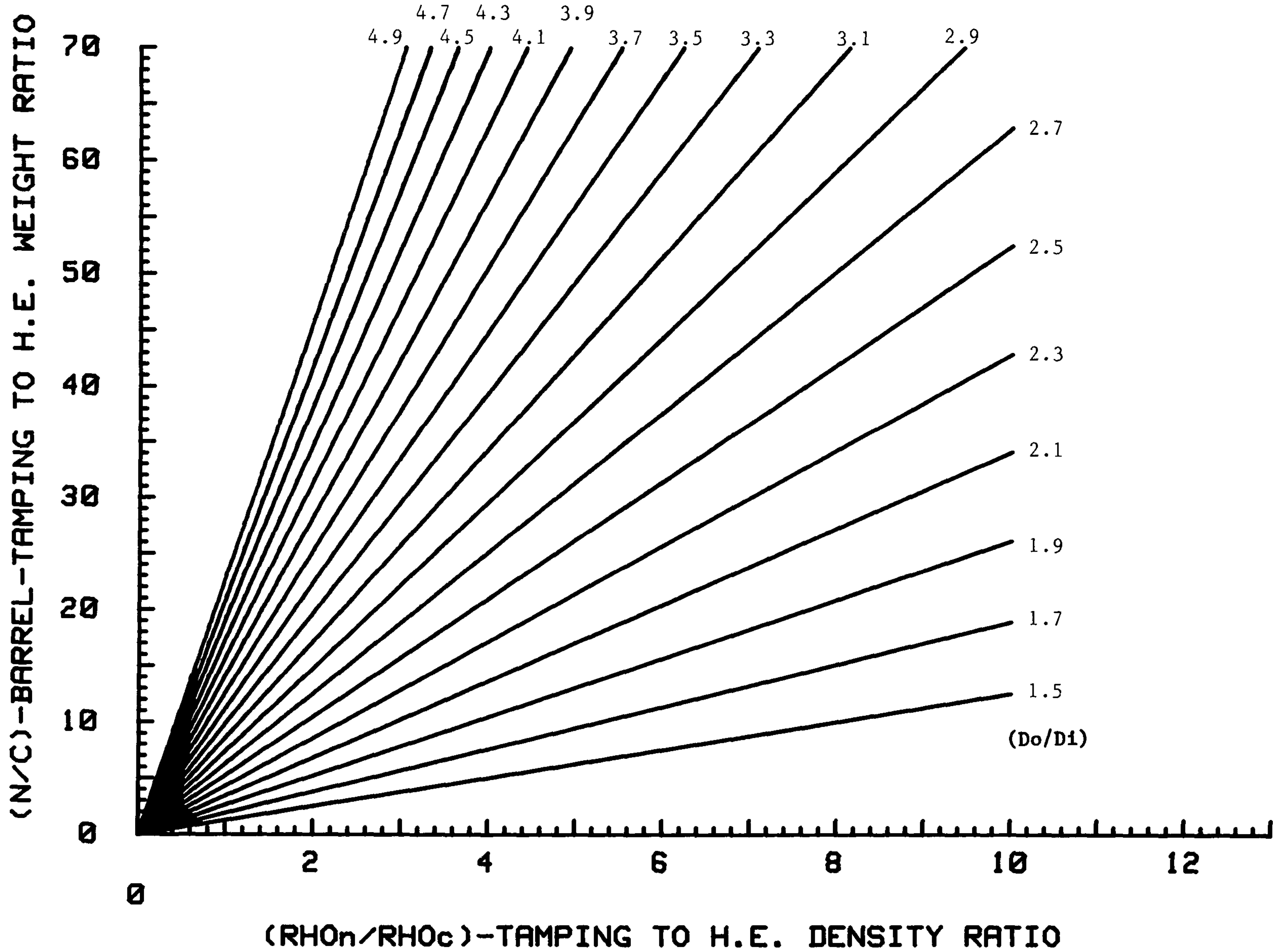

FIGURE 3. BARREL-TAMPING TO EXPLOSIVE WEIGHT RATIO VERSUS TAMPING TO EXPLOSIVE DENSITY RATIO AND DIAMETER RATIO

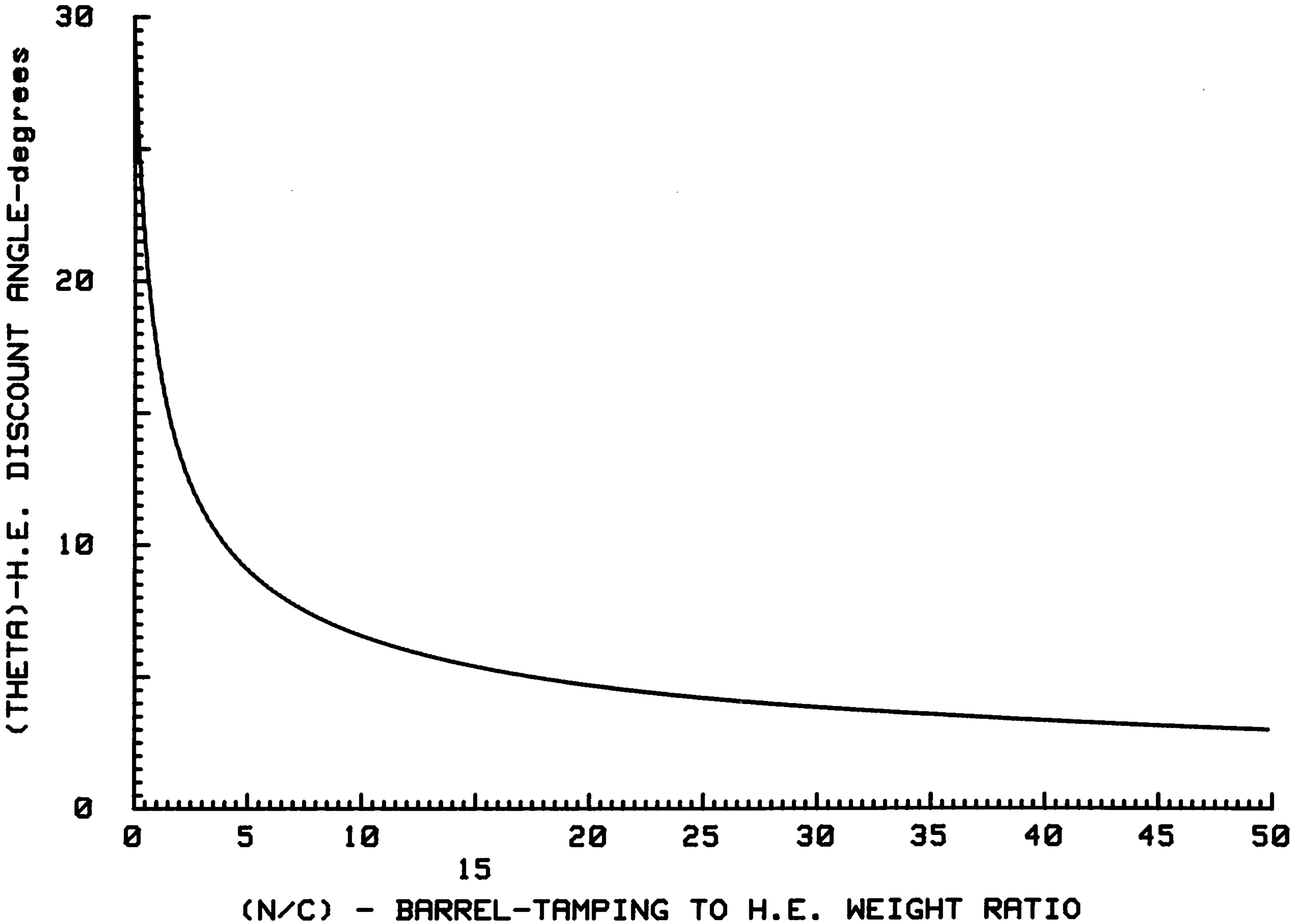

FIGURE 4. EXPLOSIVE DISCOUNT ANGLE VERSUS BARREL TAMPING TO EXPLOSIVE WEIGHT RATIO

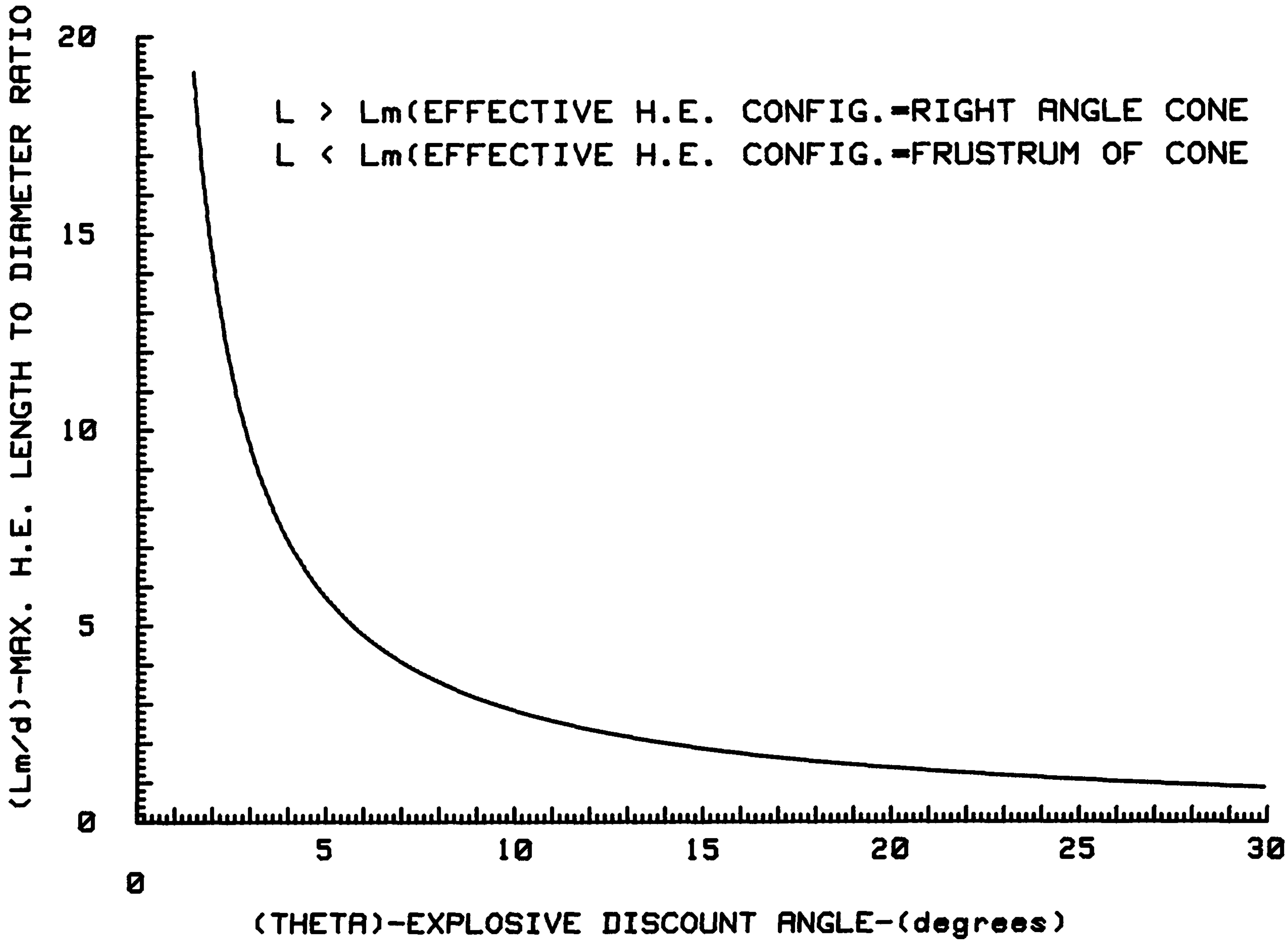

FIGURE 5. MAXIMUM FRUSTRUM OF A CONE EXPLOSIVE LENGTH VERSUS EXPLOSIVE DISCOUNT ANGLE

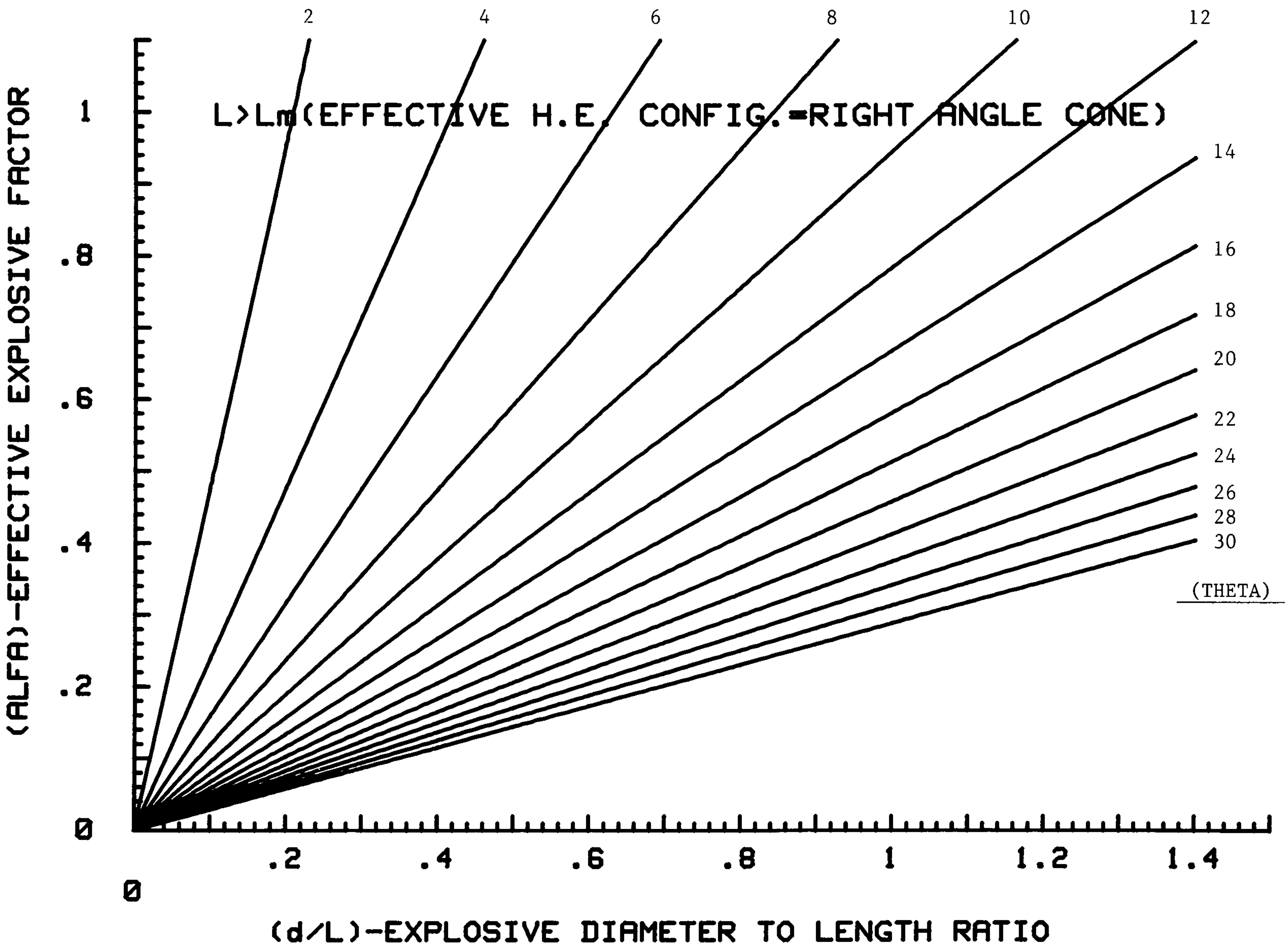

FIGURE 6. EFFECTIVE EXPLOSIVE FACTOR VERSUS EXPLOSIVE DIAMETER TO LENGTH RATIO AND H.E. DISCOUNT ANGLE

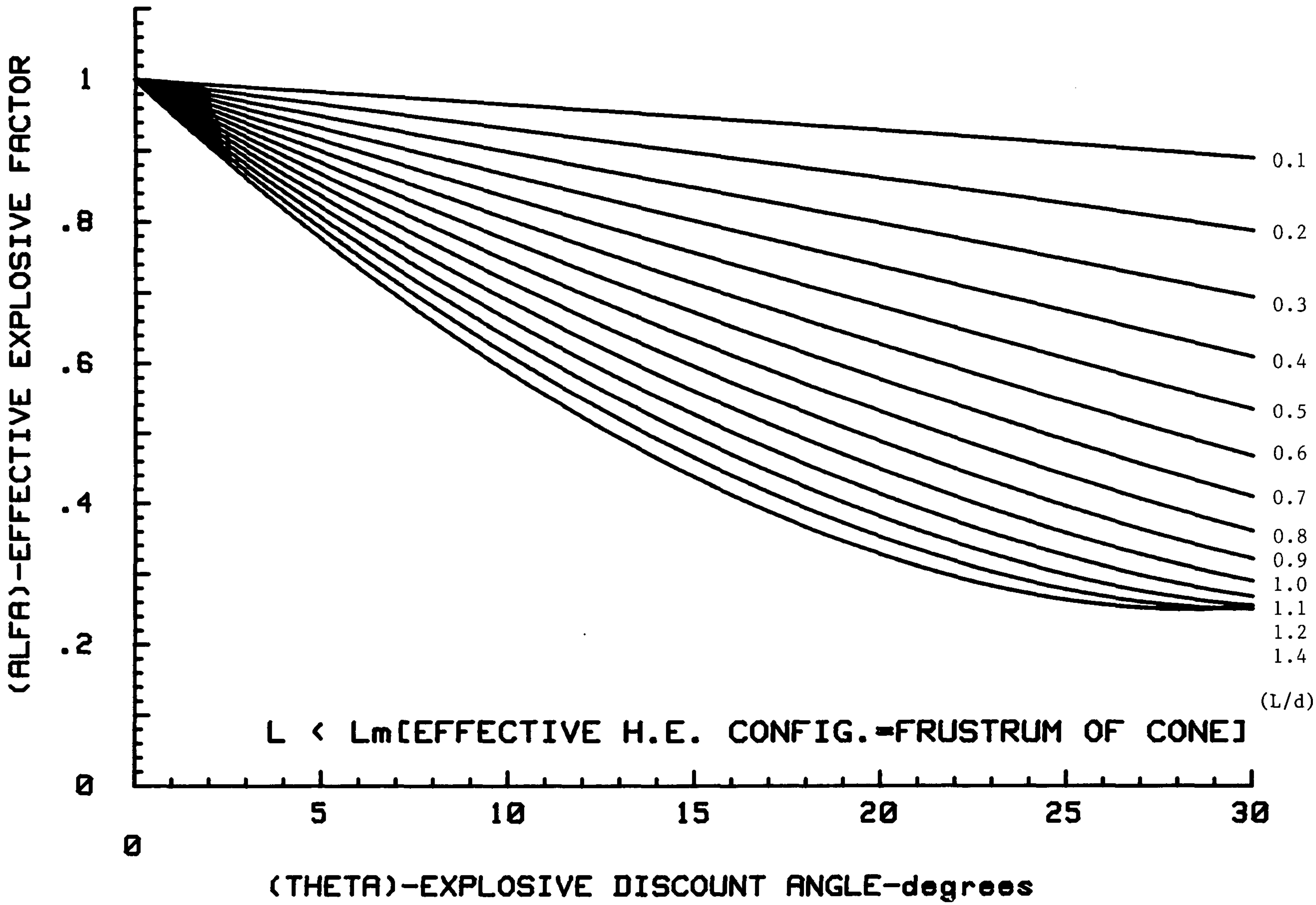

FIGURE 7. EFFECTIVE EXPLOSIVE FACTOR VERSUS EXPLOSIVE LENGTH TO DIAMETER RATIO AND H.E. DISCOUNT ANGLE

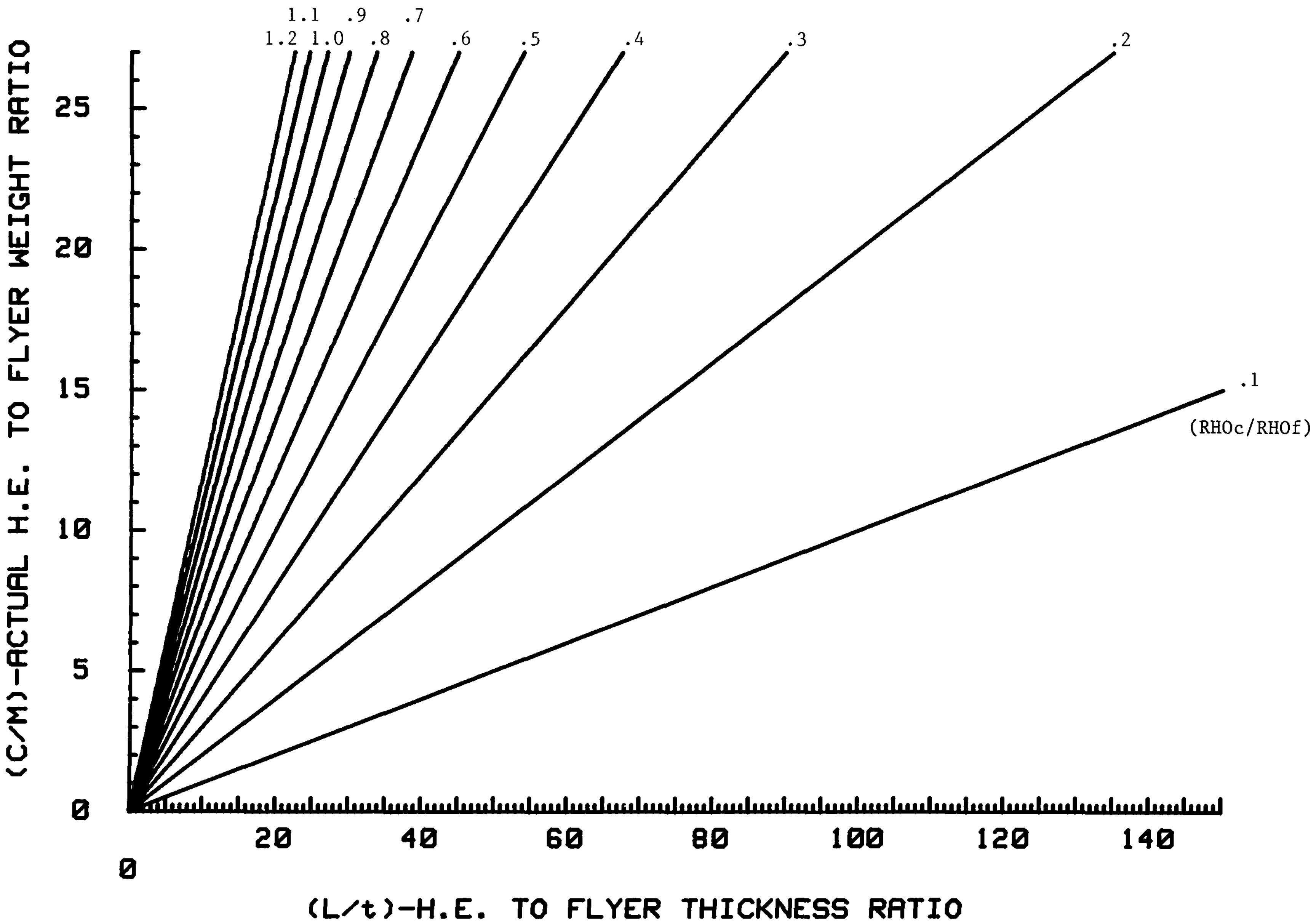

FIGURE 8. ACTUAL EXPLOSIVE TO FLYER WEIGHT RATIO VERSUS EXPLOSIVE TO FLYER THICKNESS RATIO AND EXPLOSIVE TO FLYER DENSITY RATIO

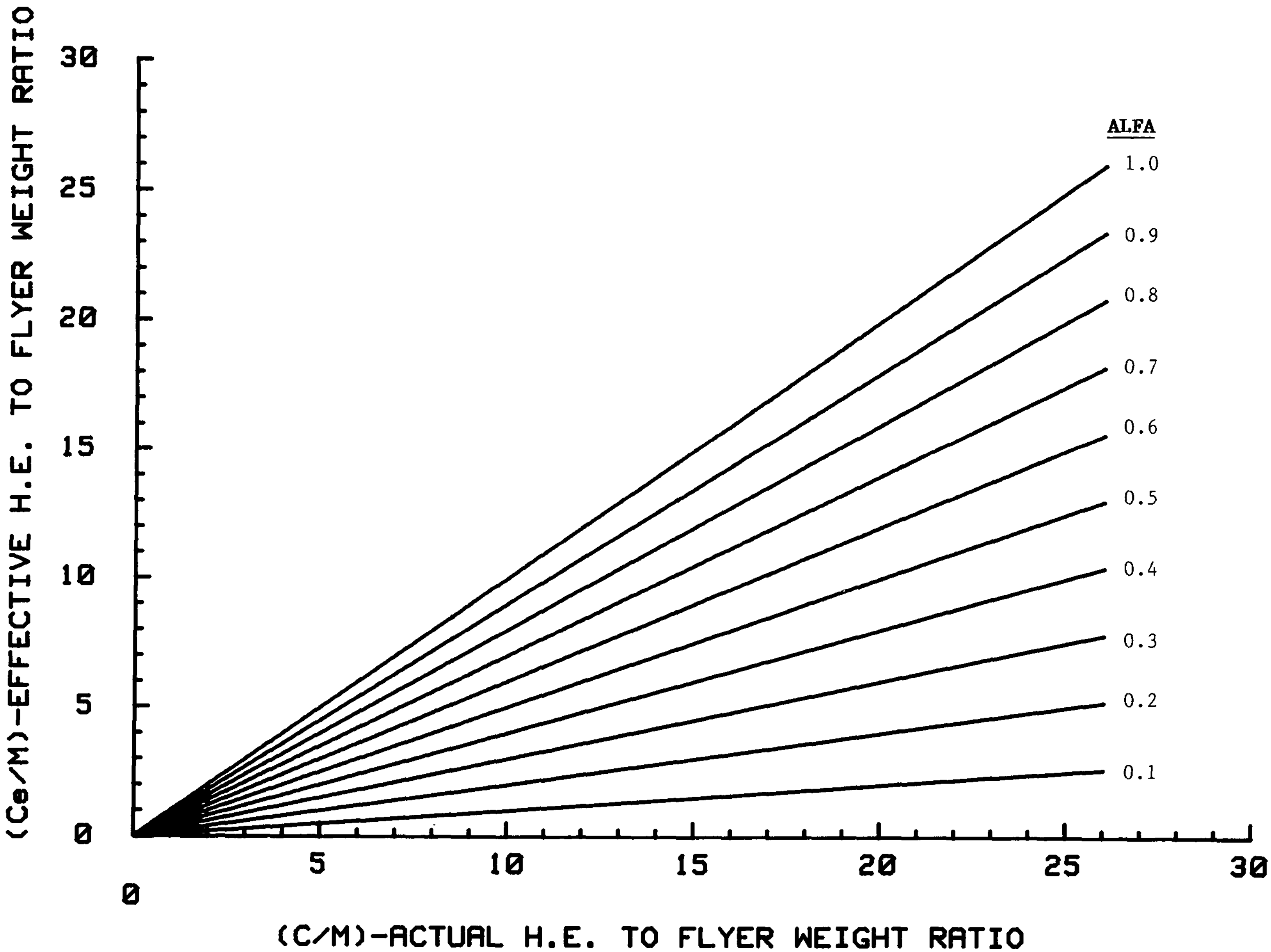

FIGURE 9. EFFECTIVE EXPLOSIVE TO FLYER WEIGHT RATIO VERSUS ACTUAL EXPLOSIVE TO FLYER WEIGHT RATIO AND H.E. DISCOUNT FACTOR

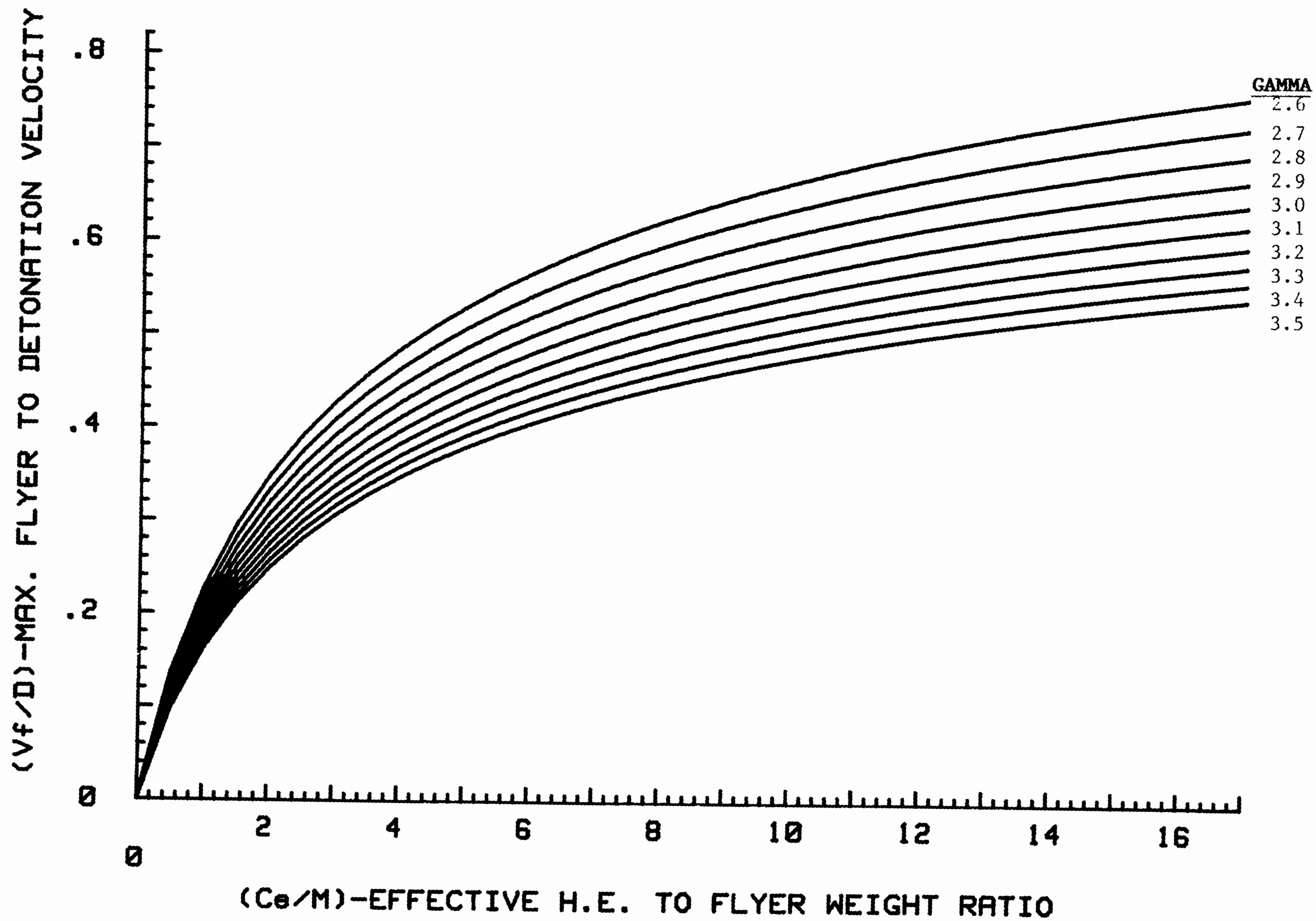

FIGURE 10. MAXIMUM FLYER PLATE TO DETONATION VELOCITY RATIO VERSUS EFFECTIVE H.E. TO FLYER WEIGHT RATIO AND H.E. EXPONENT

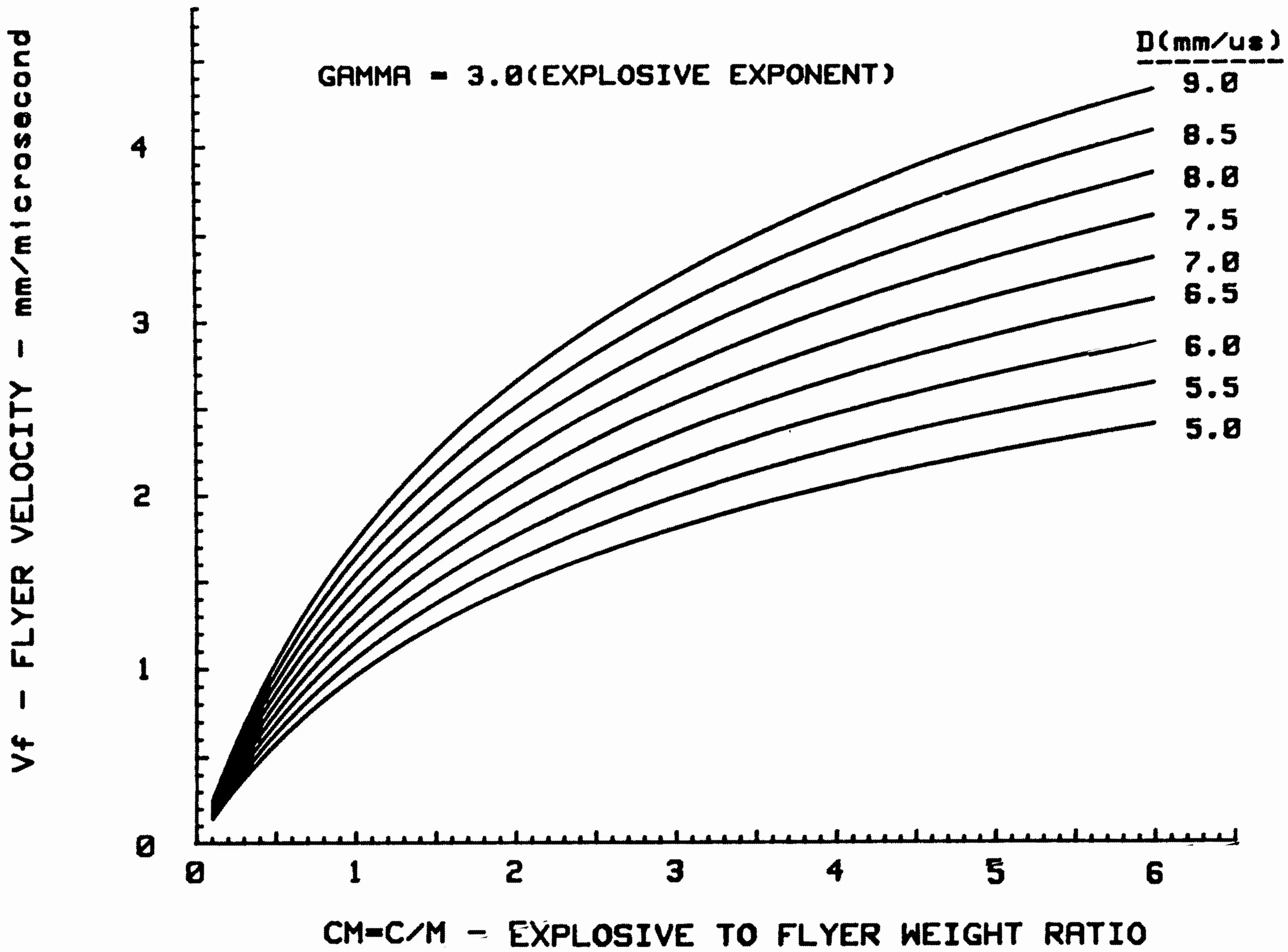

FIGURE 11. EXPLOSIVE DRIVEN FLYER VELOCITY VERSUS EXPLOSIVE TO FLYER WEIGHT RATIO AND DETONATION VELOCITY

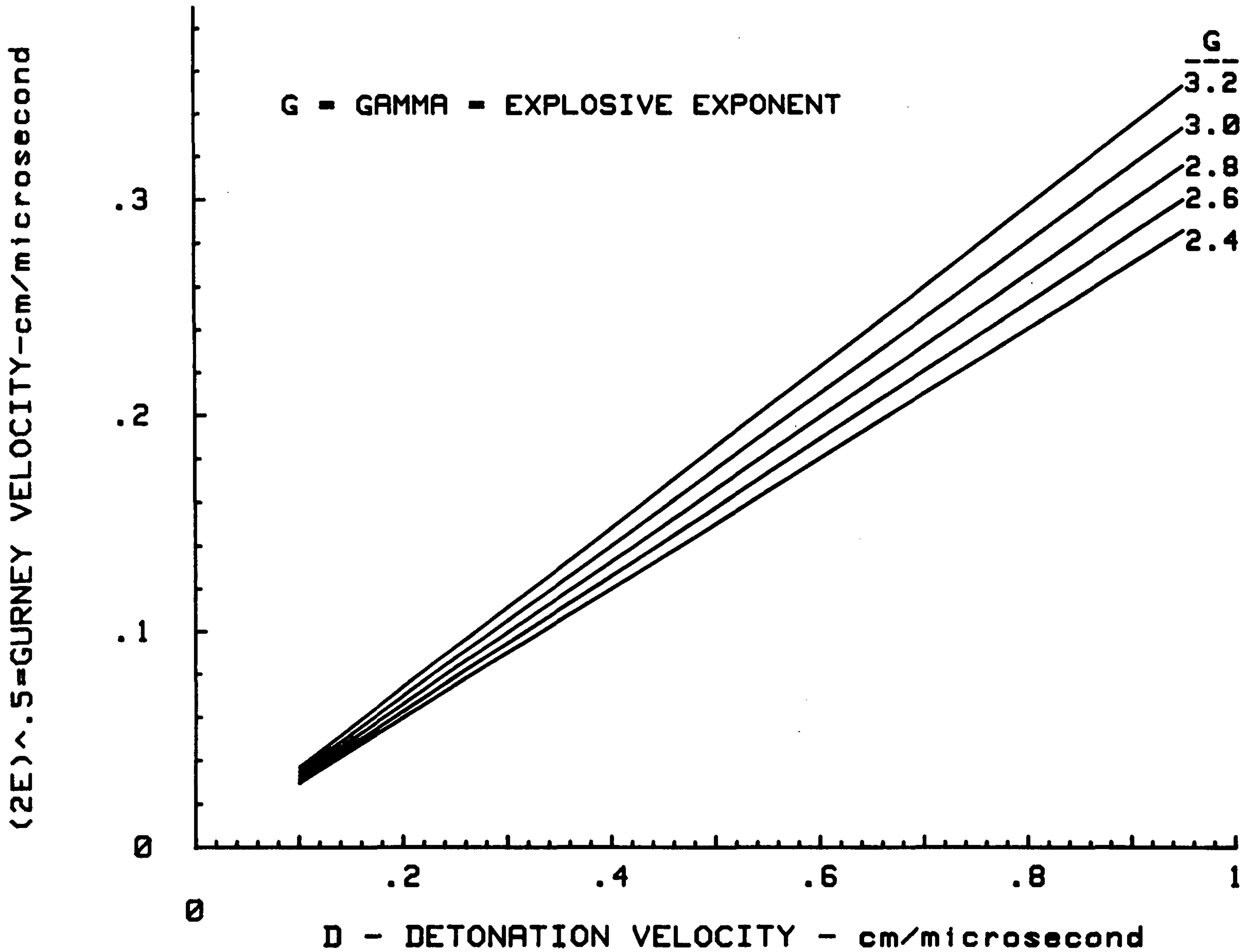

FIGURE 12. GURNEY VELOCITY VERSUS DETONATION VELOCITY AND EXPLOSIVE PRODUCT GAS EXPONENT

APPENDIX A

Analytical Equations for Barrel-Tamped Flyers

I. Barrel-Tamping to Explosive Weight Ratio (N/C)

$$(N/C) = (\rho_N/\rho_c)[(Do/Di)^2 - 1] \quad \text{(A1)}$$

II. Barrel-Tamping Maximum Velocity (V_T), Reference 8

$$V_T = (2E)^{0.5}/[(N/C) + 0.5]^{0.5} \quad \text{(A2)}$$

where,

$(2E)^{0.5}$ = Gurney Velocity of explosive

N/C = Barrel-tamping to explosiv weight ratio

III. Detonation Product Gas Velocity (V_o), (untamped case), Reference 1

for N = 0 in Equation A2,

$$V_o = 1.414\,(2E)^{0.5} \quad \text{(A3)}$$

IV. Explosive Discount Angle (θ), Reference 1

$$\theta = 30/\{1.414[(N/C) + 0.5]^{0.5}\} \quad \text{(A4)}$$

V. Maximum Explosive Length (Lm)

$$(Lm/d) = 1/[2\,TAN\,(\theta)] \quad \text{(A5)}$$

VI. Explosive Discount Factor (ALFA) for L > Lm

$$ALPHA = V_c/V_a = (d/L)\{1/[6\,TAN\,(\theta)]\} \quad \text{(A6)}$$

VII. Explosive Discount Factor (ALFA) for L < Lm

$$ALPHA = V_c/V_a = 1 - 2(L/d)\,TAN\,(\theta) + (4/3)[TAN(\theta)]^2(L/d)^2 \quad \text{(A7)}$$

VIII. Actual Explosive to flyer weight ratio (C/M)

$$(C/M) = (\rho_c/\rho_f)(L/t)$$

IX. Effective Explosive to flyer weight ratio (Ce/M)

$$(Ce/M) = ALFA\ (C/M) \qquad (A8)$$

X. Maximum flyer to detonation velocity ratio (Vf/D)

$$(Vf/D) = A[(B-1)/(B + 1)] \qquad (A9)$$

where

$$A = [8/(G^2 - 1)]^{0.5} \qquad (A10)$$

$$B = [1 + (32/27)(Ce/M)]^{0.5} \qquad (A11)$$

XI. Explosive Volume (V_c) of frustrum of cone as function of discount angle (θ) for L < Lm

$$V_c = (\pi L/12)(d_1^2 + dd_1 + d^2), \text{ Reference 14} \qquad (A12)$$

$$V_c = (\pi L/12)\{[d - 2L\ TAN(\theta)]^2 + d[d - 2L\ TAN(\theta) + d^2]\} \qquad (A13)$$

$$V_c = (\pi L/12)\{4L^2[TAN(\theta)]^2 - 2(2 - d)L\ TAN(\theta) + 3d^2\} \qquad (A14)$$

XII. Explosive Volume (V_c) for right angle cone for L > Lm

$$V_c = \pi d^2L/12 \qquad (A15)$$

XIII. Actual explosive volume (V_a)

$$V_a = \pi d^2L/4 \qquad (A16)$$

XIV. Explosive Discount Factor (ALFA)

$$ALFA = V_c/V_a \qquad (A17)$$

XV. Barrel-tamping weight (N)

$$N = \Pi L T \rho_N (d + T) \quad \text{(A18)}$$

XVI. Flyer plate weight (M)

$$M = \Pi \rho_f d^2 t/4 \quad \text{(A19)}$$

XVII. Actual explosive weight (C)

$$C = \Pi \rho_c d^2 L/4 \quad \text{(A20)}$$

APPENDIX B

The graphical solution for the maximum flyer velocity of barrel-tamped configurations is illustrated by two examples in this appendix.

I. Example 1, Configuration per Figure 2 for L < Lm

The actual explosive length (L) is less than the theoretical maximum length (Lm) for a right circular cone as shown in Figure 2.

A. Given: (Reference 9, Test MC3644 of Table I)

1. Do = 0.5"
2. d = Di = 0.128"
3. RHOn = 7.86 g/cc
4. RHOc = 1.60 g/cc
5. D = 0.621 cm/μs
6. Gamma = 2.8
7. L = 0.128", L/d = 1.0, d/L = 1.0
8. RHOf = 7.86 g/cc
9. t = 0.005", L/t = 25.6

B. From Figure 3, for Do/Di = 3.9 and RHOn/RHOc = 4.91

1. Obtain: N/C = 70

C. From Figure 4, for N/C = 70

1. Obtain: THETA $\approx$ 3 degrees

D. From Figure 5, for THETA = 3 DEGREES

1. Obtain: Lm/d = 9.8

a. Lm = 1.25"
b. L = 0.128"

2. Therefore: L < Lm

a. Obtain ALFA from Figure 7.

E. From Figure 7, for THETA = 3 degrees and L/d = 1.0

1. Obtain: ALFA = 0.90

F. From Figure 8, for L/t = 25.6 and RHOc/RHOf = 0.20

1. Obtain: C/M = 5.1

G. From Figure 9, for C/M = 5.1 and ALFA = 0.9

1. Obtain: Ce/M = 4.9

H. From Figure 10, for Ce/M = 4.9 and Gamma = 2.8

1. Obtain: Vf/D = 0.48

I. Maximum flyer velocity, given D = .621 cm/μs

Vf = 0.3 cm/μs

II. Example 2, configuration per Figure 1 for L > Lm

The actual explosive length (L) is greater than the theoretical maximum length (Lm) for a right circular cone as shown in Figure 1.

A. Given: (Reference 1, Test 26 of Table I)

1. N/C = 0.06"

2. L = 2.0"

3. d = Di = 2.0"

4. t = 0.267"

5. RHOc = 1.6 g/cc

6. RHOf = 2.7 g/cc

B. Skip Figure 3 since N/C is already known.

C. From Figure 4, for N/C = 0.06

1. Obtain: THETA = 28.0 degrees

D. From Figure 5, for THETA = 28.0 degrees

1. Obtain: Lm/d = 0.97

a. Lm = 1.94"
b. L = 2.0"

2. Therefore: L > Lm

a. Obtain ALFA from Figure 6.

E. From Figure 6, for d/L = 1.0 and THETA - 28.0 degrees,

1. Obtain: ALFA = 0.295

F. From Figure 8, for L/t = 7.5 and RHOc/RHOf = 0.59

1. Obtain: C/M = 4.6

G. From Figure 9, for C/M = 4.6 and ALFA = .295

1. Obtain: Ce/M = 1.5

H. From Figure 10, for Ce/M = 1.5 and Gamma = 3.0

1. Obtain: Vf/D = 0.28

I. Maximum flyer velocity given D = 0.804 cm/μs.

<u>Vf = 0.225 cm/μs</u>

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	9122	R. H. Braasch
	9122	R. O. Nellums
	9122	M. M. Hightower