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Muzzle devices intended for use on large guns and artillery were investigated experimentally at reduced scale (40 mm). These muzzle devices reduce gun muzzle blast overpressure behind and to the side of the gun muzzle, at the expense of increased overpressure in front of the muzzle near the line of fire and increased recoil impulse. Detailed data are presented for blast field and recoil parameters for several device shapes. Overpressure reductions behind the muzzle exceeded 50 percent, with increases in recoil impulse ranging up to

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10 percent. The results are applicable to a wide variety of gun sizes and types.

FOREWORD

A number of muzzle devices were tested to determine effect on near-field overpressure distribution and recoil impulse. The work was carried out using scaling principles; the results should be applicable to a wide variety of sizes and types of guns.

This report has been reviewed and approved by J. J. Yagla, Head, Ship Safety Engineering Branch, and P. D. Malcolm, Head, Systems Safety Division.

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CONTENTS

NOMENCLATURE

B	Momentum index
c	Caliber (gun bore diameter)
D	Muzzle device inside diameter at exit
E	Energy of recoiling mass, bare muzzle
E'	Recoil energy with muzzle device
E_E	Gross energy efficiency
E_{EC}	Intrinsic energy efficiency
E_M	Gross momentum efficiency
G	Gas ejection impulse
I	Recoil impulse, bare muzzle
I'	Recoil impulse with muzzle device
l	In-bore shot travel
L	Muzzle device inside length
m	Mass
m_c	Mass of propellant
m_d	Mass of muzzle device
m_p	Mass of projectile
m_r	Mass of recoiling parts
M	In-bore impulse
P_c	Peak chamber pressure
P_m	Peak muzzle pressure
V_f	Final recoil velocity
V_p	Projectile velocity at the gun muzzle

INTRODUCTION

There is a class of gun muzzle devices that yields substantial reduction of blast overpressure behind the muzzle as compared to the bare muzzle gun. These devices also generally yield increased recoil impulse and increased overpressure in some portion of the blast field forward of the muzzle. A conical "flash hider" is an example of such a muzzle device. These muzzle devices have potential use for control of overpressure levels in selected regions of the gun blast field. They can also be of use for hiding muzzle flash and for controlling trajectories of frangible rotating band fragments.

Previous work[1,2,3*] has documented the effect of a conical muzzle device on the blast field, but presented no information regarding the effect on recoil impulse and very little information regarding the effect of changes in the size or shape of the muzzle device. This report presents results of experimental tests of a variety of such muzzle devices. The objective was to determine the effect on recoil impulse and the extent to which blast overpressure could be changed.

DESIGN OF EXPERIMENT

The experimental program was carried out using a 40-mm free-recoil gun mount apparatus. The free-recoil gun mount was used to facilitate accurate measurement of recoil impulse, as described in detail in previous reports.[4,5] The 40-mm gun is small enough to permit extensive testing for a reasonable cost, yet large enough and similar enough in design so that detailed results can be scaled to large guns without excessive scale-effect errors.

The design of the experiment was guided by previous successful experience in reduced-scale muzzle device testing.[1,4,5,6] This previous experience has demonstrated techniques for performing reduced-scale muzzle device tests to maximize the applicability of the resulting data for a wide spectrum of gun sizes and performances. This use is facilitated by appropriate nondimensional presentation of the data.

The dependent parameters in this study are the muzzle device blast field overpressure and a measure of change in recoil momentum. Definitions and discussion of these parameters may be found in Appendix A. The parameters used are conceptually very similar to those used and exhaustively discussed in previous similar work.[4,5]

Independent parameters that were systematically and purposely varied in this study were the muzzle device size and shape. Considerable effort was devoted to holding all other independent parameters,[4,5] particularly basic

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* Raised numerials refer to identically numbered references listed at the end of the text.

gun performance parameters, constant throughout the test. The gun performance parameter values used were selected to closely simulate scaled performance typical of modern artillery and large naval guns. These specific gun performance parameters were achieved through barrel length, bullet weight, and propelling charge configuration.

EXPERIMENTAL APPARATUS AND PROCEDURES

GUN

The 40-mm free-recoil gun mount used in this study was identical to that of previous muzzle brake studies.[4,5] Briefly, the mount consisted of a 40-mm naval saluting gun breech assembly fitted with a standard Mk 1 water-cooled shortened barrel with the cooling jacket removed. The gun was mounted in a carriage support by linear recirculating-ball bushings on 4-in. diameter precision-steel shafts. Figure 1 shows the free-recoil gun mount.

AMMUNITION

The round configuration used, shown schematically in Figure 2, was identical to that used in the muzzle brake study[5] except for propellant type and charge weight. Specifications and resulting gun performance are given in Table 1.

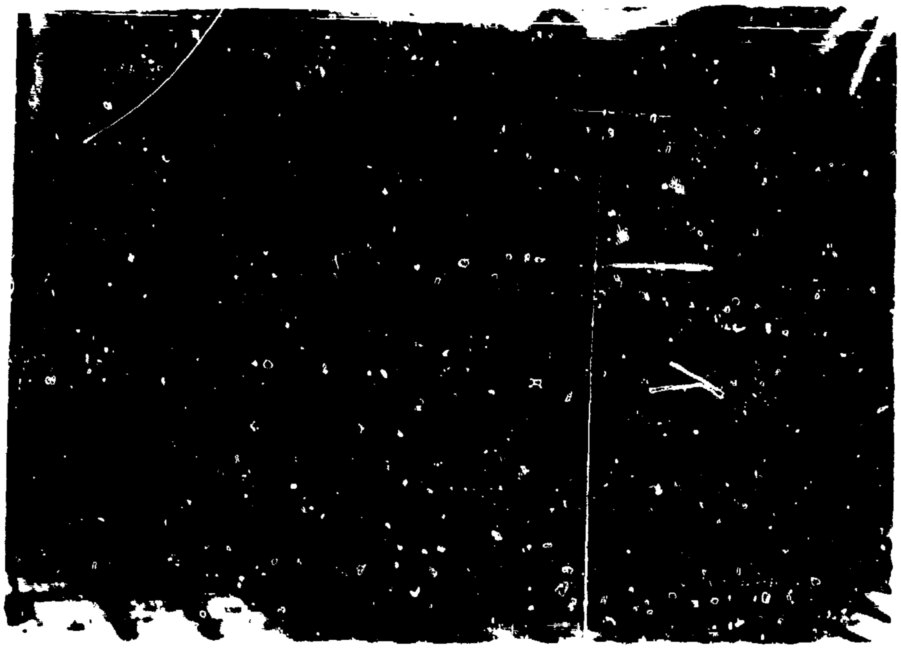

Figure 1. 40-mm Free-Recoil Gun Mount

Table 1. Gun Performance Parameters

Caliber (bore diameter), c	40 mm (1.575 in.)
In-bore shot travel, l	27.4 cal
Overall barrel length	34.3 cal
Total internal volume (including chamber volume of special ammunition)	1800 cc. (110 cu. in.)
Chamber volume	374 cc. (22.8 cu. in.)
Propellant type	40 mm, SPDN 8366
Mass of propellant, m_c	295 gm (0.65 lb)
Mass of projectile, m_p	692.2 gm (1.526 lb)
Projectile velocity, V_p	818 m/s (2685 ft/sec)
Muzzle pressure, P_m	82,000 kPa (11,900 psi)
Chamber pressure, P_c	261,000 kPa (37,900 psi)
Recoil impulse, I	970 N-s (218 lb-sec)
Gas ejection impulse, G	284 N-s (63.8 lb-sec)
Energy of recoiling mass, E	1571 N-m (1159 lb-ft)

DATA ACQUISITION EQUIPMENT

Instrumentation was provided to measure elapsed time, projectile velocity, muzzle pressure, chamber pressure, displacement of the recoiling mass, and blast overpressure at various locations around the gun. The instrumentation was identical to that used in the muzzle brake study.[5]

MUZZLE DEVICES

Appendix B gives a description of the construction and geometric forms of the muzzle devices tested.

PROCEDURES

The data acquisition and data reduction procedures used and a detailed uncertainty analysis are presented in Reference 4.

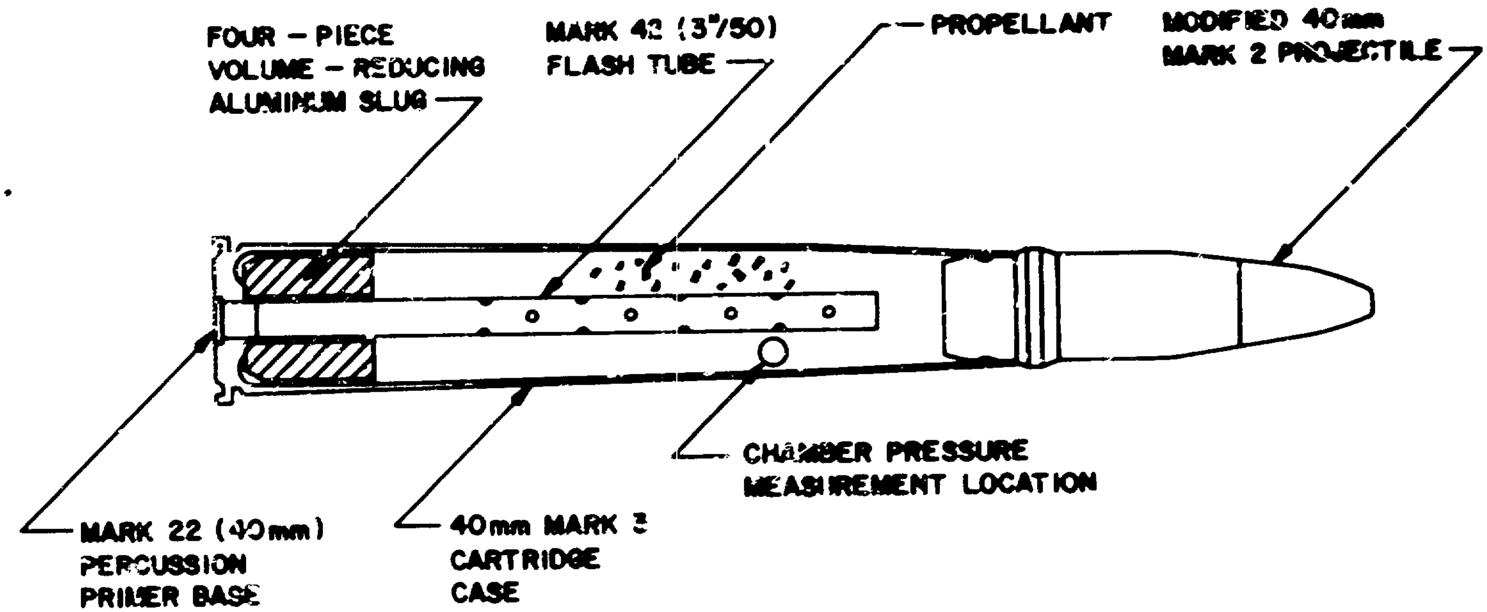

Figure 2. Round Configuration

DISCUSSION OF RESULTS

The experimental data obtained during this study are contained in Appendix C. Bare muzzle baseline data are shown in Tables C-1 and C-2 and Figures C-1 and C-2. Table C-1 lists measured bare muzzle gun performance parameters in detail, round by round, to demonstrate that these gun performance parameters, particularly muzzle pressure, projectile velocity, and free recoil velocity, were indeed held relatively constant. Table C-2 lists calculated parameters, mean values of which were used as "bare muzzle" values in calculating performance parameter values of the muzzle devices. The consistency of these data is evident and was typical of such data throughout the study. Figures C-1 and C-2 are two presentations of the bare muzzle blast field data. Each blast overpressure value shown in Figure C-1 is the mean value of data from at least three test rounds.

The effects of the various muzzle devices on recoil impulse are shown in Table C-3* in terms of the performance parameters defined in Appendix A. Each datum shown is the mean value of at least six test rounds. Effects of each device on the blast field are shown in Figures C-3 through C-9 in terms of relative blast overpressure (Appendix A). Each overpressure datum is the mean value of two or more rounds.

Configuration No. 7, the flat disk at the muzzle plane, was tested primarily to determine if a shielding effect might reduce overpressures behind the muzzle, e.g., in the crew area of an artillery fieldpiece. Even though this disk was fairly large at 3.80-cal diameter, the data presented in Figure C-9 clearly show (within the limits of experimental uncertainty for the overpressure data) that the disk had no significant effect on the blast field. The slight decrease in recoil impulse is insignificant.

Examination of the data for the rest of the muzzle devices (Figures C-3 through C-8) leads to some general conclusions. All of the devices result in potentially significant increases in recoil impulse and recoil energy that must be dissipated by the recoil system of the gun. It also appears that all of the devices yield increased overpressure in a region roughly within 45° of the line of fire and decreased overpressure in the remainder of the blast field. The greatest overpressure reductions generally occurred in the region behind the muzzle. In general, the devices that produced larger change in the blast field also produced larger increase in recoil impulse.

In addition to the above general conclusions, specific conclusions can be drawn regarding relative performance of the various muzzle device configurations. For example, comparing Configuration Nos. 1 and 2 shows that, for a given length and diameter and thus similar device weight, the cone yielded greater blast focusing and also greater recoil impulse than a cylinder. Comparison of Con-

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* Detailed voluminous round-by-round data for the muzzle devices were not included to minimize publication costs and to maximize ease of utilization of the data.

figuration Nos. 3 and 4 again shows that the cone produces a larger effect than the cylinder. Comparison of Configuration Nos. 4 and 5 shows that the parabola yields only a small increase in recoil impulse over the cone, but results in considerably more blast focusing effect. Many other such comparisons that can be made by examining the data presented in Appendix C will provide useful guidance to the designer of such devices.

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5. Pater, L. L., *Muzzle Brake Parameter Study*, NSWC/DL TR-3531, Naval Surface Weapons Center, Dahlgren, Virginia, October 1976.

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APPENDIX A

PERFORMANCE PARAMETERS

The muzzle device performance parameters of interest in this study are blast overpressure and some measure of change in recoil impulse relative to the bare muzzle gun. Blast overpressure data presented in this report consist of the peak overpressures measured at particular locations. For the bare muzzle gun, these data are reported simply as the peak overpressure values. For the muzzle devices, the overpressure is reported as "relative blast pressure," a dimensionless parameter defined as the ratio of the peak overpressure experienced with the muzzle device to the peak overpressure of the bare muzzle gun, both measured at the same point in the blast field. A discussion of blast wave duration may be found in NSWC/DL TR-3531.*

The type of muzzle device investigated in this study generally yields an increase in recoil impulse. This increase is usually not the desired effect, but it must be taken into account because of the potential effect on the recoil system. There are a number of dimensionless parameters in use to characterize change in recoil impulse. For the convenience of the user, the values of several of these parameters are presented in Appendix C for each muzzle device tested. These parameters, adapted from parameters used to characterize muzzle brake performance, are defined below.

Momentum index, B, is defined as the change in recoil impulse due to the muzzle device normalized by the gas ejection impulse, G, of the bare muzzle gun

$$B = \frac{I' - I}{G}$$

Here, "impulse" has the strict meaning "time integral of force." The change in recoil impulse can be determined simply as the difference in the total recoil impulse (or, equivalently, final recoil momentum of the free-recoil gun) for shots with and without the muzzle device, I' - I. The gas ejection impulse, G, is defined as that portion of the total recoil impulse which occurs after projectile ejection, i.e., the impulse due to the exhaust of the high-pressure propellant gas from the gun barrel (typically 10 to 40 percent of the total recoil impulse). An advantage of this parameter is that experience with muzzle brakes has shown the value of momentum index, B, to be relatively constant for a given muzzle device design, even when the device is used on different guns or on the same gun with different propelling charges. A disadvantage of this parameter is that the value of gas ejection impulse, G, is not easy to accurately determine.

Another momentum-based parameter is the gross momentum efficiency, E_M, defined as the increase in recoil impulse due to the muzzle device normalized by the total recoil impulse of the bare muzzle gun

$$E_M = \frac{I' - I}{I}$$

* Pater, L. L., *Muzzle Brake Parameter Study*, NSWC/DL TR-3531, Naval Surface Weapons Center, Dahlgren, Virginia, October 1976.

An energy-based parameter that has been used is the gross energy efficiency, E_E, defined as the change in recoil energy due to the muzzle device normalized by the total recoil energy of the bare muzzle gun,

$$E_E = \frac{E' - E}{E}$$

Here, "recoil energy" is the kinetic energy imparted to the recoiling mass during firing. A disadvantage of this parameter is that the mass of the muzzle device causes some change in recoil energy, since for a given recoil impulse a larger mass will have a smaller final velocity in free recoil.

The intrinsic energy efficiency, E_{EC}, is a modified energy-based parameter that is corrected for the effect of the mass of the muzzle device. It is defined as

$$E_{EC} = \frac{\frac{m_r + m_d}{m_r} E' - E}{E}$$

where m_r is the recoiling mass of the bare muzzle gun and m_d is the mass of the muzzle device.

A more exhaustive discussion of these parameters, including advantages and disadvantages of each, may be found in NSWC/DL TR-3531.*

* Pater, L. L., *Muzzle Brake Parameter Study*, NSWC/DL TR-3531, Naval Surface Weapons Center, Dahlgren, Virginia, October 1976.

APPENDIX B

MUZZLE DEVICES

Seven different muzzle device configurations were tested. The relative shape and size of these devices are shown in Figure B-1, which is a line-drawing cross-section schematic of the inner surfaces of the devices. Configuration No. 1 was a cylinder of 2-cal (inside) diameter and 6-cal (inside) length. Configuration No. 2 was a cone of the same length and exit diameter as Configuration No. 1, with an initial diameter at the muzzle plane of 1.05 cal (as were all the cones and paraboloids), and a cone half-angle of 4.5°. Configuration No. 3 was a shorter, larger diameter cylinder, with D = 3.80 cal and L = 3.17 cal. Configuration No. 4 was a cone of the same length and final diameter as No. 3 and a half-angle of 23.5°. Configuration No. 5 was a paraboloid, also of the same length and final diameter as Configuration No. 3, with a geometric focal point at the muzzle plane. Configuration No. 6 was a paraboloid with a geometric focal point 0.5 cal downrange from the muzzle plane, also 3.17 cal long, which resulted in a final diameter of 5.68 cal. Configuration No. 7 was simply a flat circular disk, of the same diameter as Configuration No. 3, located at the muzzle plane.

All of the muzzle devices were constructed of 4340 steel with a wall thickness of 6.35 mm (0.25 in.).

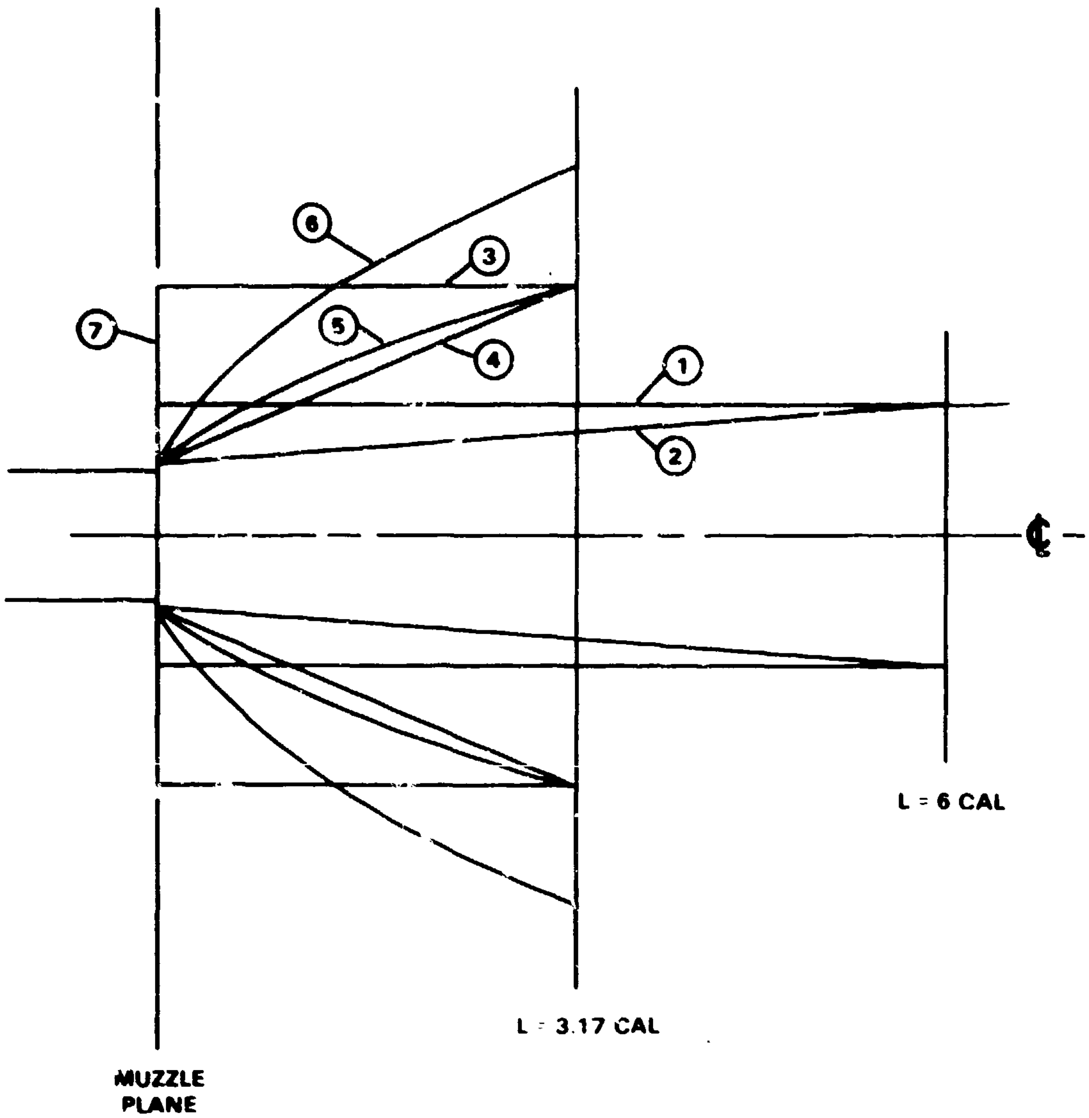

Figure B-1. Muzzle Device Configurations

APPENDIX C

EXPERIMENTAL DATA

Table C-1. Bare Muzzle Measured Parameters

Date	Round	P_c (psi)	P_m (psi)	V_p (ft/sec)	V_f (ft/sec)	M_r (lb)
5-7-74	6	37,000	11,500	2679	10.61	660.6
5-7-74	7	38,900	11,600	2696	10.68	660.6
5-7-74	8	39,600	11,100	2688	10.66	660.6
5-8-74	6	38,500	11,800	2700	10.71	660.6
5-8-74	7	37,400	11,500	2682	10.65	660.6
5-8-74	8	39,300	12,100	2717	10.66	660.6
5-8-74	9	37,100	11,900	2690	10.66	660.6
5-8-74	14	37,900	12,100	2680	10.63	660.6
5-8-74	15	38,800	12,200	2716	10.70	660.6
5-8-74	16	37,600	11,900	2696	10.66	660.6
5-10-74	6	36,800	11,800	2658	10.53	660.6
5-10-74	7	37,200	11,800	---	10.49	660.6
5-10-74	8	38,900	13,700	2690	10.64	659.7
5-10-74	9	38,500	12,000	2688	10.62	659.7
5-10-74	13	37,200	11,800	2661	10.60	659.7
5-10-74	14	37,200	11,700	2676	10.60	659.7
5-10-74	15	36,100	11,700	2669	10.60	659.7
5-10-74	19	37,100	11,800	2667	10.62	659.7
5-10-74	20	38,800	11,900	2702	10.66	659.7
5-10-74	21	37,300	12,100	2662	10.58	659.7
Mean Value		37,900	11,900	2685	10.62	
Std. Dev.		970	500	17.3	0.05	

Table C-2. Bare Muzzle Calculated Parameters

Date	Round	M (lb-sec)	I (lb-sec)	G (lb-sec)	E (lb-ft)
5-7-74	6	154.1	217.9	63.8	1157
5-7-74	7	155.1	218.7	63.6	1164
5-7-74	8	154.7	218.9	64.2	1167
5-8-74	6	155.4	219.9	64.5	1178
5-8-74	7	154.3	218.6	64.3	1164
5-8-74	8	156.3	219.0	64.7	1168
5-8-74	9	154.8	218.9	64.1	1166
5-9-74	14	154.2	218.3	64.1	1160
5-8-74	15	156.3	219.5	63.2	1174
5-8-74	16	155.1	219.0	63.9	1168
5-10-74	6	152.9	216.3	63.4	1139
5-10-74	7	---	215.4	---	1130
5-10-74	8	154.8	218.2	63.4	1160
5-10-74	9	154.7	217.7	63.0	1156
5-10-74	13	153.1	217.2	64.1	1150
5-10-74	14	154.0	217.4	63.4	1152
5-10-74	15	153.6	217.4	63.8	1153
5-10-74	19	153.5	217.6	64.1	1155
5-10-74	20	155.5	218.7	63.2	1166
5-10-74	21	153.2	217.0	63.8	1148
Mean Value		154.5	218.0	63.8	1159
Std. Dev.		1.0	1.1	0.47	11.5

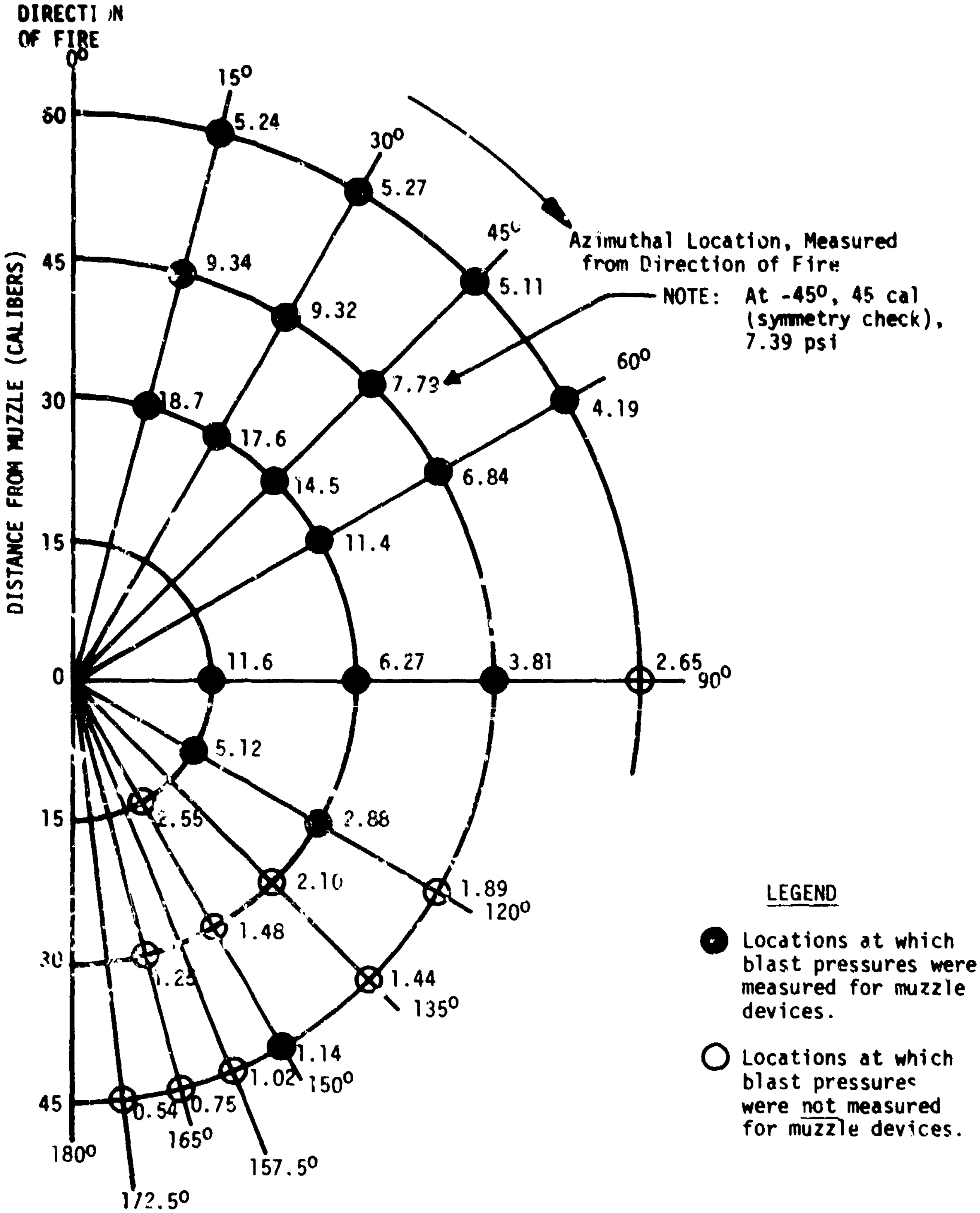

Figure C-1. Bare Muzzle Blast Overpressures (psi) at Various Locations

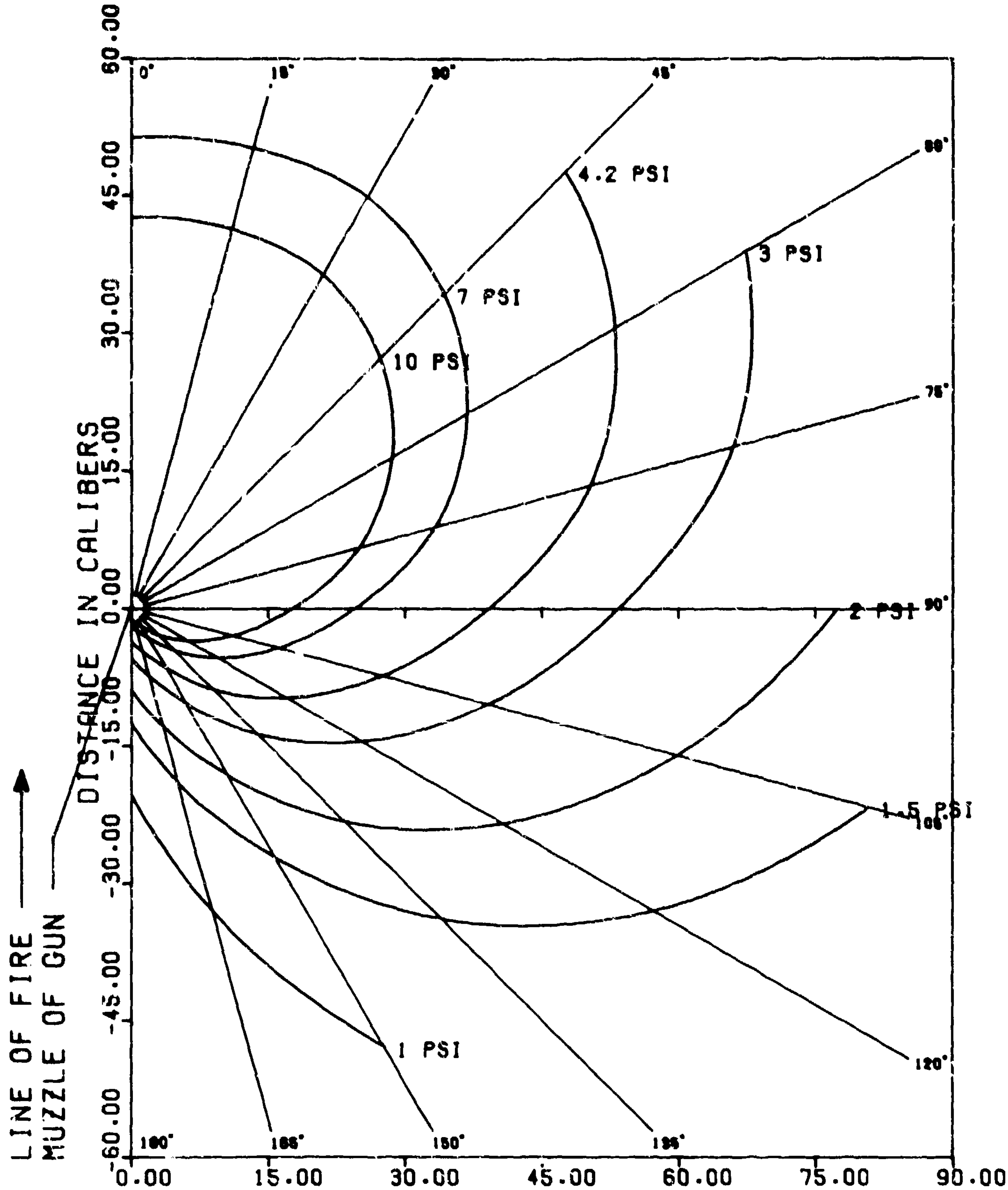

Figure C-2. Free-Air Overpressures for 40-mm Free-Recoil Gun (SPDN 8366 Propellant)

Table C-3. Muzzle Device Performance Parameters

Muzzle Device Configuration	B	E_M	E_E	E_{EC}
1. Cylinder, L = 6 cal, D = 2 cal (Figure C-3)	0.12	0.033	0.058	0.066
2. Cone, L = 6 cal, D = 2 cal , 4.5° half-angle (Figure C-4)	0.31	0.090	0.176	0.187
3. Cylinder, L = 3.17 cal, D = 3.80 cal (Figure C-5)	0.13	0.039	0.066	0.079
4. Cone, L = 3.17 cal, D = 3.80 cal, 23.5° half-angle (Figure C-6)	0.34	0.096	0.189	0.201
5. Paraboloid, L = 3.17 cal, D = 3.80 cal, geometric focal point at muzzle plane (Figure C-7)	0.35	0.102	0.205	0.215
6. Paraboloid, L = 3.17 cal, D = 5.68 cal, geometric focal point located 0.5 cal down-range of muzzle plane (Figure C-8)	0.23	0.066	0.123	0.135
7. Flat circular disk at muzzle plane, D = 3.80 cal (Figure C-9)	-0.02	-0.008	-0.015	-0.015

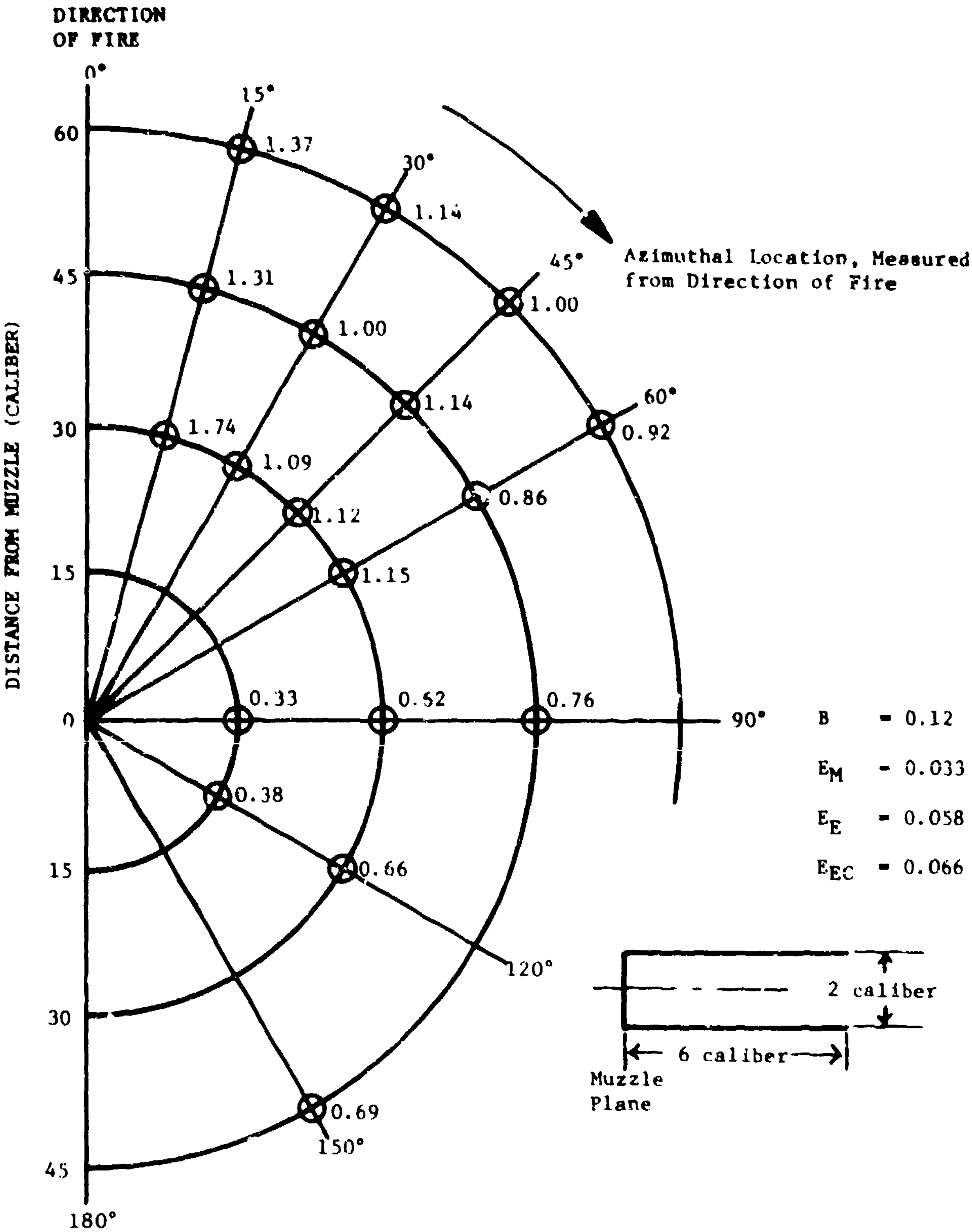

Figure C-3. Relative Blast Pressures for Cylindrical Muzzle Device, L = 6 cal, D = 2 cal

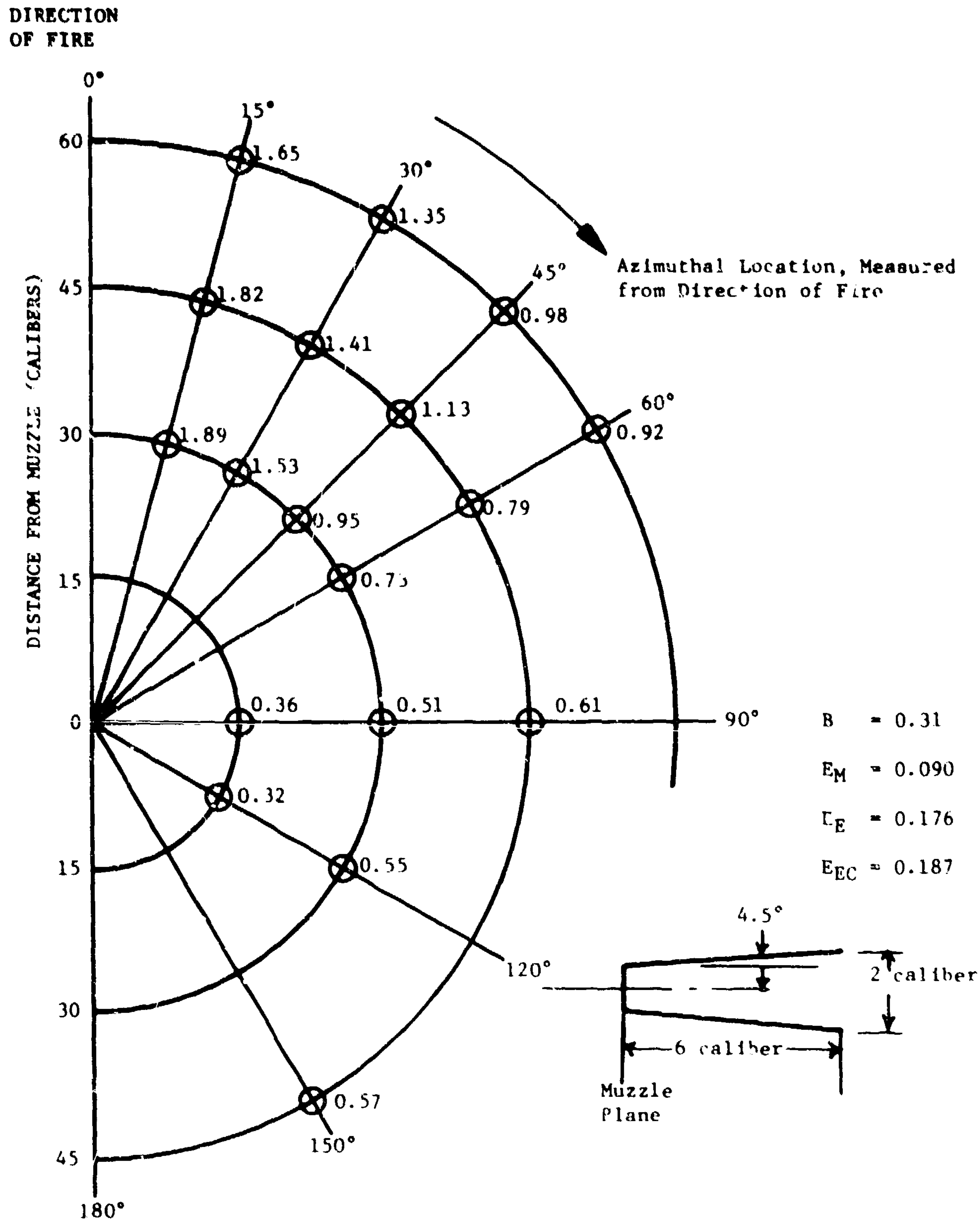

Figure C-4. Relative Blast Pressures for Conical Muzzle Device, L = 6 cal, D = 2 cal, 4.5° Half-Angle

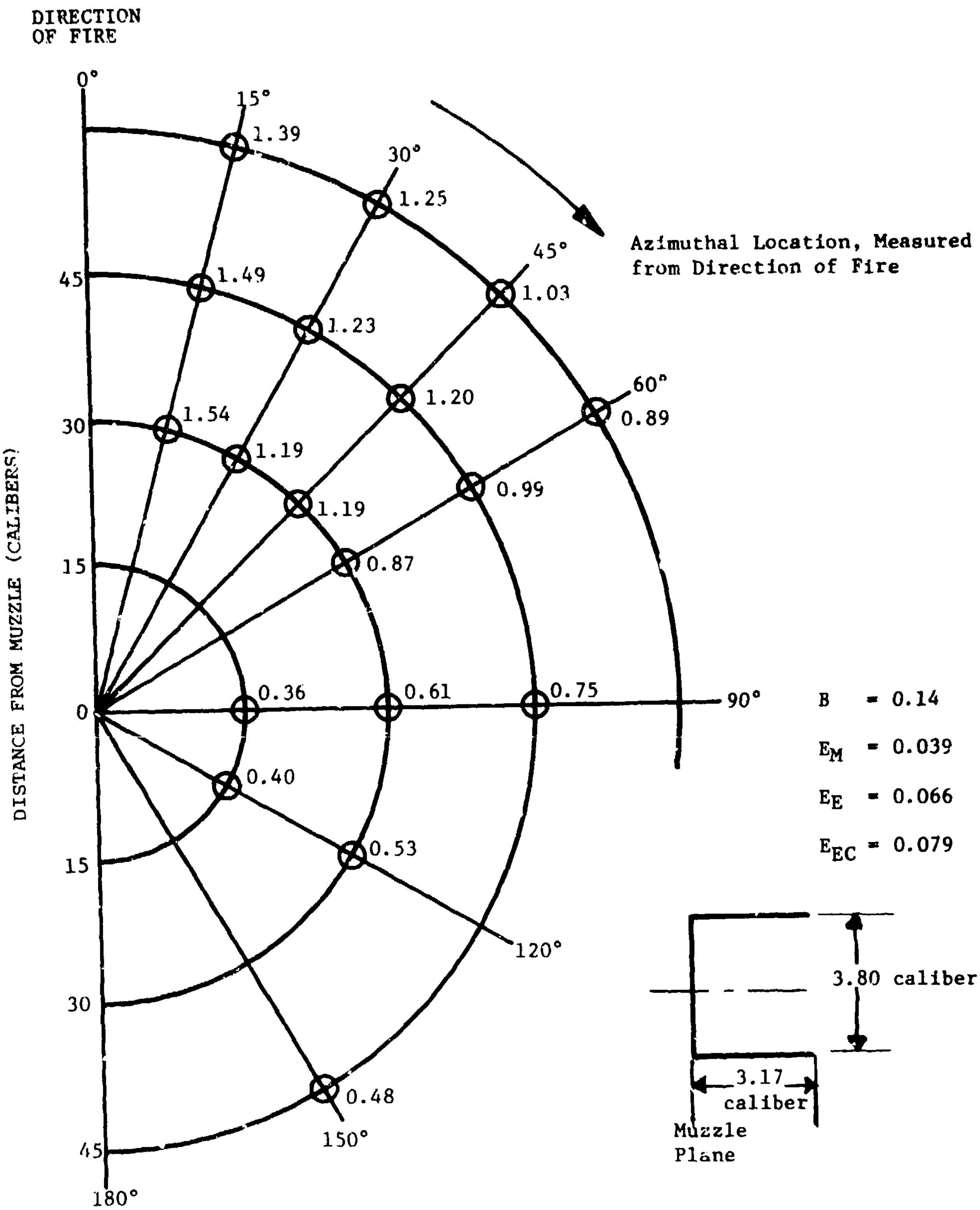

Figure C-5. Relative Blast Pressures for Cylindrical Muzzle Device, L = 3.17 cal, D = 3.80 cal

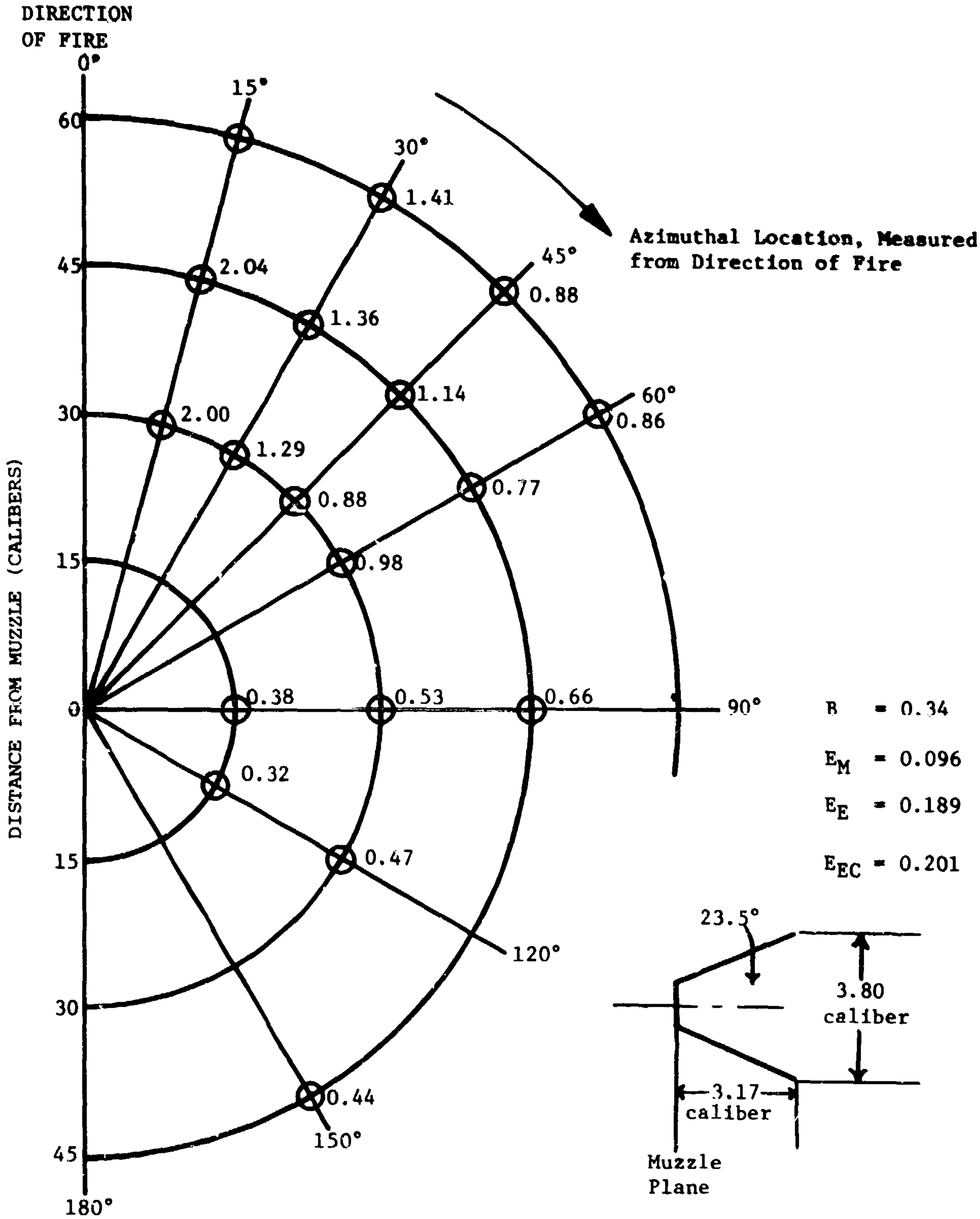

Figure C-6. Relative Blast Pressures for Conical Muzzle Device, L = 3.17 cal, D = 3.80 cal, 23.5° Half-Angle

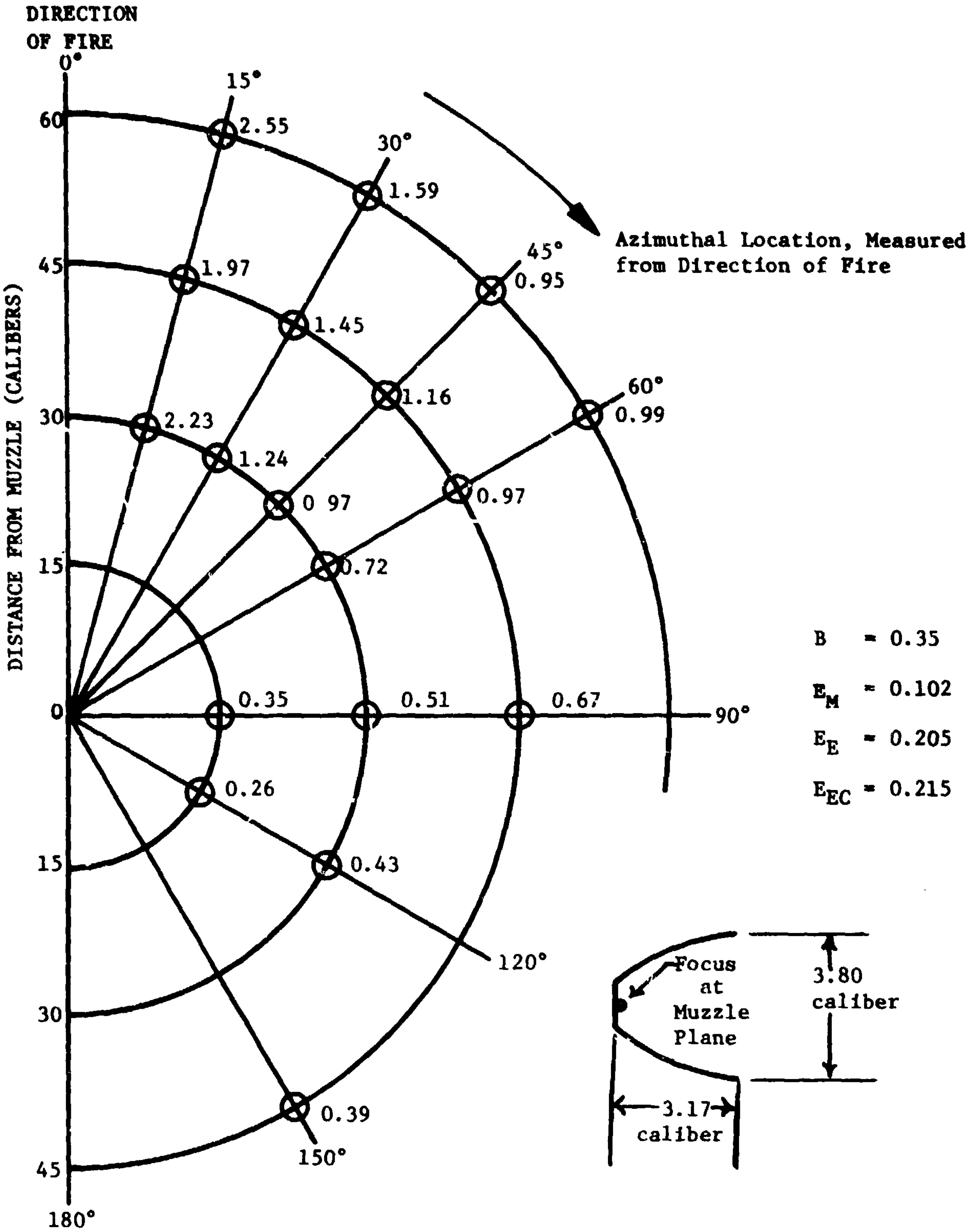

Figure C-7. Relative Blast Pressures for Parabolic Muzzle Device,
L = 3.17 cal, D = 3.80 cal, Focus at Muzzle Plane

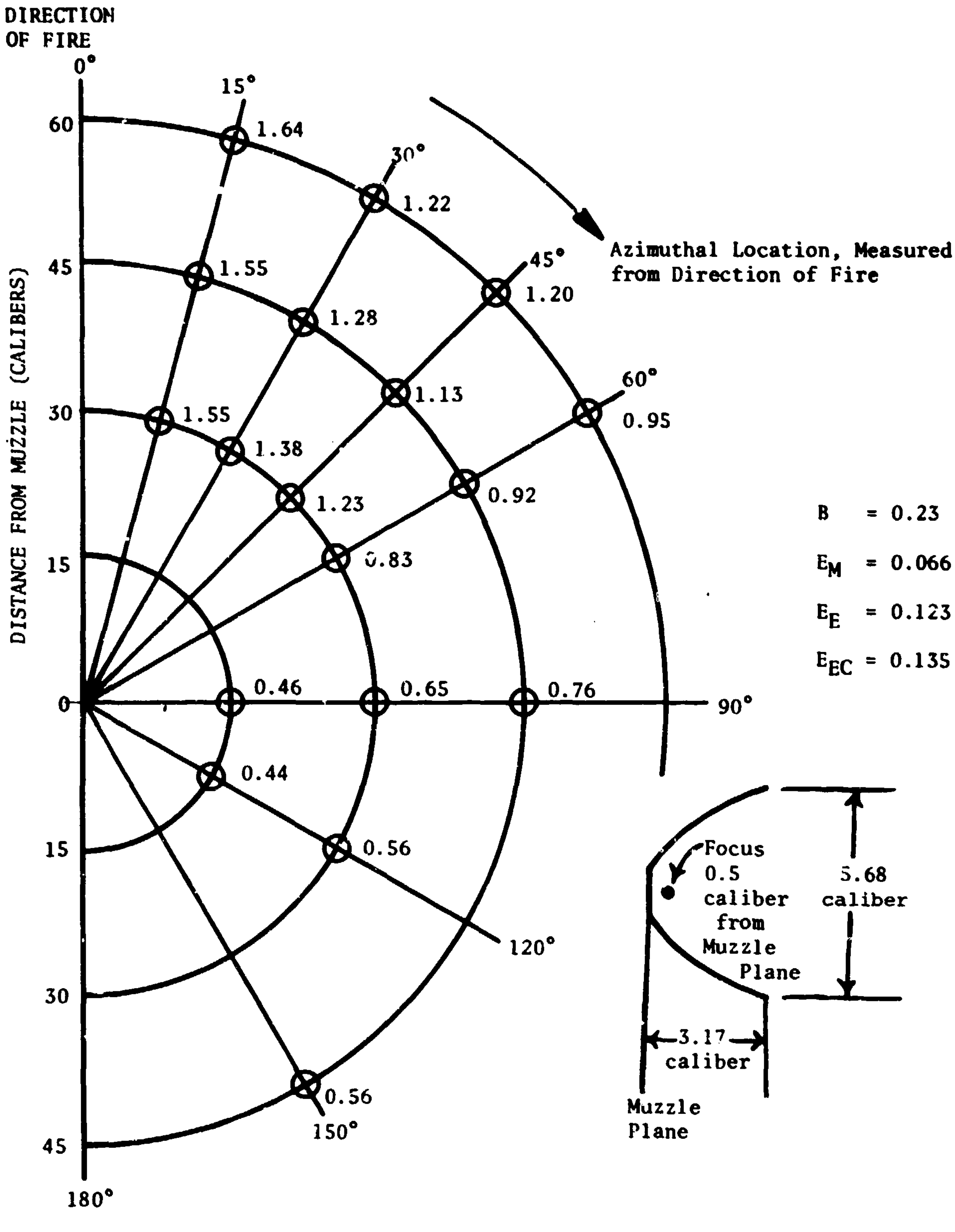

Figure C-8. Relative Blast Pressures for Parabolic Muzzle Device, L = 3.17 cal, D = 5.68 cal, Focus Located 0.5 cal Ahead of Muzzle Plane

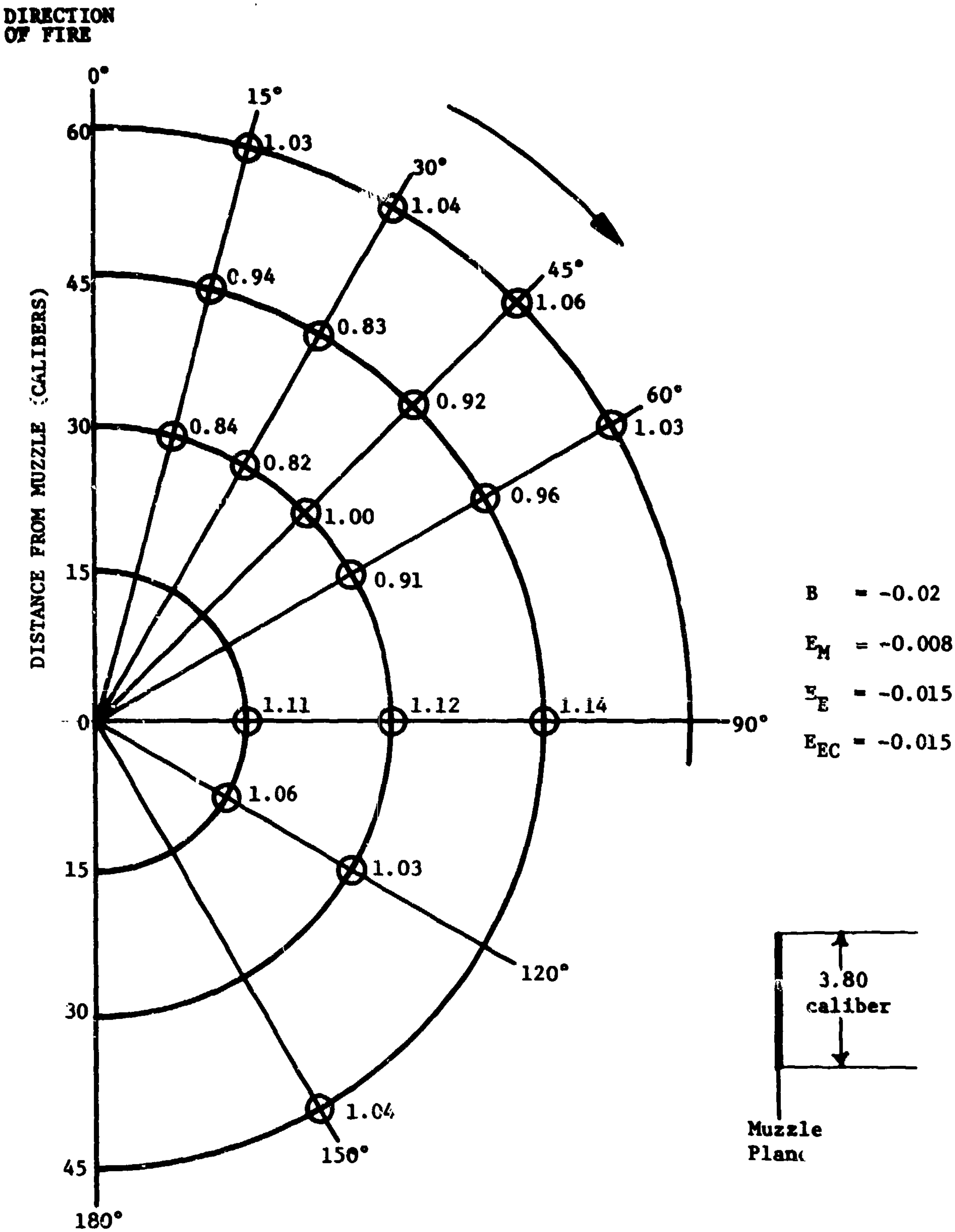

Figure C-9. Relative Blast Pressures for Flat Circular Disk at Muzzle Plane, D = 3.80 cal