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PREDICTION OF STANDOFF DISTANCES TO  
PREVENT LOSS OF HEARING FROM MUZZLE  
BLAST

Peter S. Westine, et al

Southwest Research Institute

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) THE RECENTLY ISSUED MIL-STD-1474(MI) SPECIFIES WHAT MAXIMUM SIDE-ON SOUND PRESSURE LEVELS ARE TOLERABLE FOR DIFFERENT DURATIONS OF INCIDENT WAVES IF PERSONNEL AROUND HAZARDOUS NOISE SOURCES ARE TO BE PROTECTED FROM HEARING LOSS. IN THE CASE OF GUN CREW HEARING LOSS FROM MUZZLE BLAST, THE CODE EITHER PRESUMES THAT BLAST PRESSURES AND DURATIONS ARE KNOWN, EXPECTS BLAST PRESSURES AND DURATION TO BE CALCULATED, AND/OR DEMANDS THAT BLAST PRESSURES AND DURATIONS BE MEASURED AROUND ALL GUNS. IN RESPONSE TO MIL-STD-1474, THIS REPORT PRESENTS EMPIRICALLY DERIVED EQUATIONS FOR ESTIMATING PRESSURE, DURATION, AND		

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TIME OF ARRIVAL FOR REFLECTED SHOCKS RELATIVE TO INCIDENT SHOCKS IN THE BLAST FIELD AROUND THE MUZZLE OF GUNS.

EXPERIMENTAL TEST DATA FROM DIFFERENT 105MM HOWITZER AS WELL AS NAVAL GUN FIRINGS WERE USED TO CURVE FIT PI TERMS FROM A MODEL ANALYSIS TO OVERPRESSURE, DURATION, AND TIME OF ARRIVAL TEST DATA. THE RESULTS CAN BE APPLIED FOR ANY OF THREE ANGLES OF GUN TUBE ELEVATION TO ANY CLOSED BREECH WEAPON WITHOUT A MUZZLE BRAKE OR FLASH SUPPRESSOR.

BECAUSE GUN CREWS AND WEAPON DESIGNERS WISH TO ESTABLISH LIMITING SAFE STANDOFF POSITIONS WITHOUT THE USE OF COMPLEX SECONDARY ANALYSIS PROCEDURES, DESIGN NOMOGRAPHS ARE ALSO PRESENTED WHICH GRAPHICALLY PERMIT PREDICTIONS OF STANDOFF LOCATIONS WHETHER EARS ARE UNPROTECTED, PROTECTED WITH PLUGS, PROTECTED WITH MUFFS, OR PROTECTED WITH BOTH PLUGS AND MUFFS. EXPERIMENTAL TEST DATA FROM 105MM HOWITZER FIRINGS DEMONSTRATE THAT MIL-STD-1474 IS MET WHEN THESE GRAPHICAL PROCEDURES FOR PREDICTING SAFE STANDOFF ARE APPLIED. FUTURE RECOMMENDATIONS SUGGEST HOW TO EXTEND THIS EFFORT FOR GUNS WITH MUZZLE BRAKES, FLASH SUPPRESSORS, AND/OR OPEN BREECHES.

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## I. INTRODUCTION

Whenever a gun is fired, a very intense blast wave is emitted from the muzzle with such severity that hearing loss is common in gun crews. Presently the U. S. government makes annual payments of over several million dollars to citizens with damaged hearing from muzzle blast. In response to this and other hazardous noise problems, the Surgeon General's Office recently issued MIL-STD-1474 (MI)<sup>(1)</sup> based on work performed by Mr. Georges Garinther at the Human Engineering Laboratories. This standard specifies what maximum side-on sound pressure levels are tolerable for different durations of incident waves.

To apply the hearing loss standard to field artillery muzzle blast problems, one must be able to calculate peak pressures and durations around guns. Such a calculation using computer codes is a very complicated procedure. In fact, whenever ground reflections are significant, as in reality, computer calculations are impossible unless one of the three geometric coordinates can be ignored. On the other hand, gun designers and field personnel must be able to establish safe locations to prevent hearing loss in gun crews. They need simple design charts that permit accurate estimates after only a few multiplications or additions. The fundamental question to gun designers and field personnel is where can crew members safely stand for a particular gun at an arbitrary angle of elevation, propelling charge, length of barrel, etc. ? These people do not wish to deal with indirect quantities such as pressure and duration, because the basic quantity to them is distance. For these reasons, the primary purpose of this report is the creation of graphical procedures for estimating safe standoff distances around artillery.

Unfortunately, before results can be presented, the code and its influence must be discussed so results and all derivations are placed into perspective. This discussion is presented in Section II of this report. A very serious problem arises when durations must be measured for artillery muzzle blast as specified in the code. We are of the opinion that what the code requires and what instrumentation is capable of measuring are not compatible with one another. This conflict must be understood; otherwise, subsequent results presented throughout this report will be confusing.

Section III of this report contains design nomographs which can be used to establish minimum safe standoff distances around any closed breech gun. This section is the heart of this report for those wishing to obtain numerical results. The nomographs which are presented can be used on guns of any caliber, barrel length, with any size propelling charge, and fired at any gun tube elevation angle. Until further work is performed,

these nomographs are limited to closed breech guns without muzzle brake, flash suppressor, or other device to divert the flow of gases from a gun muzzle. In addition to presenting the nomographs in Section III, we also show how to apply them and demonstrate that they work by comparing predictions to test data from actual gun firings.

The basis for all relationships shown in Section III is dimensional analysis and then a subsequent curve fit to test data. These derivations are presented in Section IV for readers with more fundamental questions such as how well are pressures, durations, and times of arrival for reflected shocks predicted? The vast bulk of the test data comes from 105-mm howitzer test firings performed by Mr. Mark Salsbury of Rock Island Arsenal on the M102 with a zone 7 charge, XM204 with a zone 5 charge, XM204 with a zone 7 charge, and XM204 with a zone 8 charge. These data together with a Naval gun test data compilation by Mr. M. F. Walther<sup>(2)</sup> are the basis for all curve fits, especially those on pressure. The range of weapons examined is extensive. In addition to the four different howitzers, the guns include 8"/55, 6"/47, 5"/54, 5"/38, 3"/50, 40 mm, 20 mm M3, 20 mm XM197, and 20 mm Mark 12.

The last section of this report, Section V, is a recommendation for future work. Included is a short discussion on how solutions for guns with muzzle brakes can be developed. The report concludes with a list of references.

## II. HEARING LOSS MIL STANDARD

The mil standard presented in Reference 1 specifies what maximum side-on sound pressure levels are tolerable for different durations of incident waves. Figure 1 shows the limits for hearing loss from gun blast as presented in MIL-STD-1474. Notice that three different curves exist in Figure 1. As applied to the gun blast problem, the  $\bar{W}$ -curve is the threshold for no ear protection, the  $\bar{Y}$  curve is the threshold whenever either plugs or muffs are being worn, and the  $\bar{Z}$  curve is the threshold if both plugs and muffs are worn. These curves, based on a noise exposure rate of 100 per day, were obtained at HEL from various investigators' test data on monkeys, themselves, and soldiers until temporary but recoverable loss in hearing was experienced by 25% of the personnel subjected to a grazing or incident blast pressure wave. It is assumed in the standard that repeated exposure to a temporary hearing loss would result in some permanent nonrecoverable loss in hearing. The  $\bar{W}$  curve is a continuation of requirements from earlier criteria, TB MED 251. Both HEL and the writers of this report feel that for short duration pressures, the  $\bar{W}$  pressure

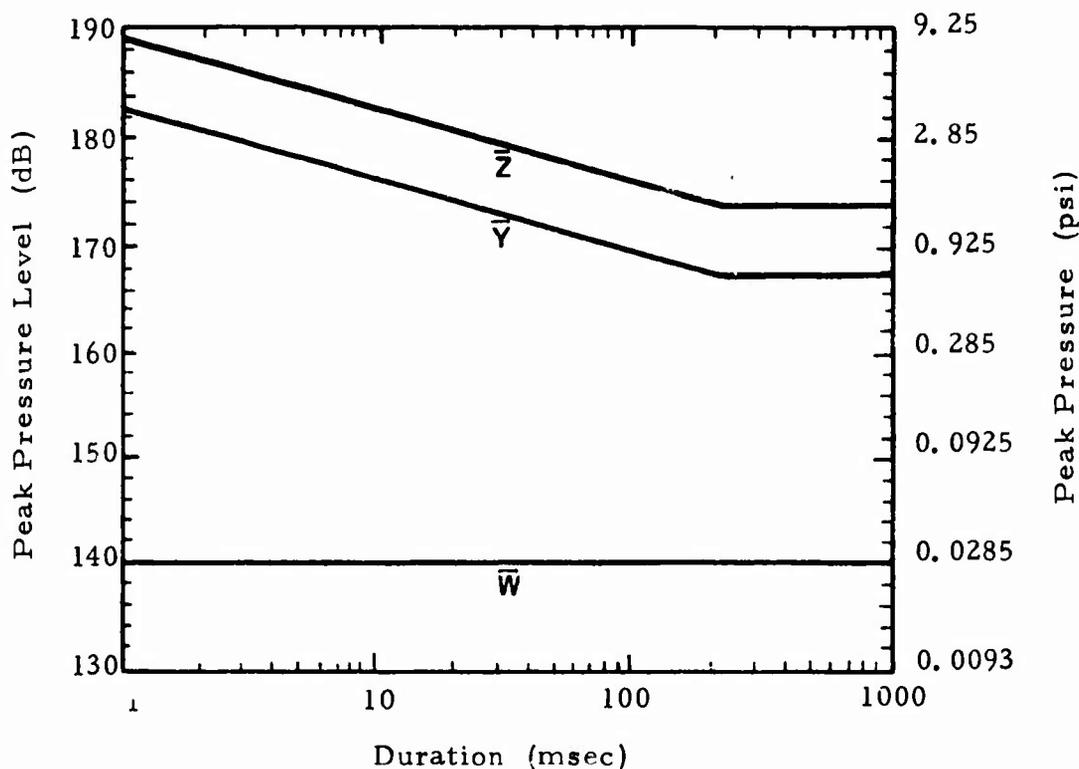


FIGURE 1. PEAK PRESSURE LEVEL AND DURATION LIMITS

levels should also increase with decreased durations; however, insufficient data exist to offer a modified  $\bar{W}$ -curve at this time.

Because the hazardous noise standard was developed for other sources as well as guns, we must discuss the developer's thoughts on how to interpret the time axis for an impulsive muzzle blast noise source. In general, a blast wave emitted from a gun must diffract and reflect from obstacles such as the gun carriage and ground. The obstructions cause reflected blast pressure waves to interact with the incident air blast wave emitted from the muzzle of a gun. For field artillery in particular, the ground becomes a very significant reflecting surface. If other reflecting surfaces are assumed to be insignificant, as they are relative to the ground, idealized transient blast pressure histories can be obtained as seen in Figure 2. Three different pressure histories are shown in Figure 2, because the character of the pressure history at a point in space above a reflecting plane differs depending upon the duration of the incident air blast wave and the time lag between the incident and reflected air blast fronts. In Figure 2a, the reflected wave arrives after the incident wave is fully

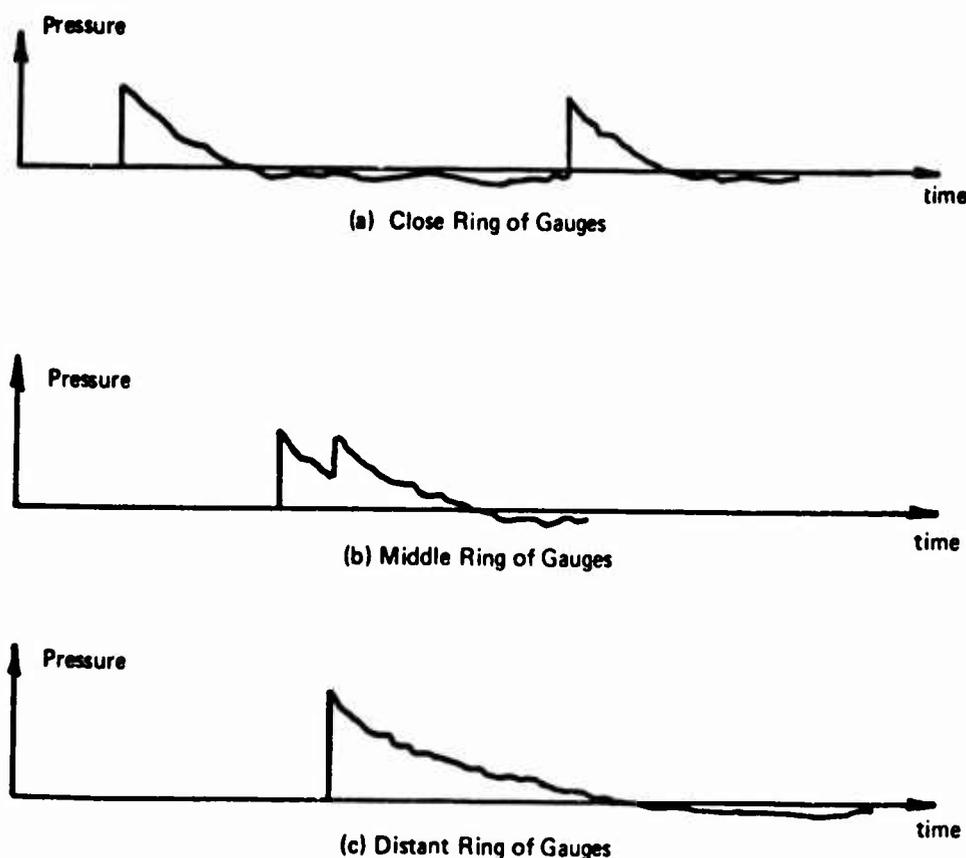


FIGURE 2. INCIDENT AND REFLECTED GUN BLAST WAVES

dissipated. Figure 2b shows an air blast wave in which the reflected wave arrives before the incident wave is fully dissipated. Figure 2c illustrates an air blast wave in which the reflection has overtaken the incident wave to form a new blast wave in the Mach stem. Because HEL, as developers of the code, wished to avoid confusion as to how durations could be defined when decaying waves asymptotically approach a baseline, they specified that peak pressures should be measured and then envelopes established on both sides of the baseline at 10% of the peak pressure level or 20 dB from the peak as in Figure 3. Figure 3 from the code is the illustrative example of how the durations are to be established for use in Figure 1. The duration according to the code is the sum of the times from A to D and from E to F. If no reflection existed, the time would be that associated with the incident wave whenever all pressure fluctuations positive and negative are between 10% and 100% of the peak pressure level. Unfortunately, this illustrative example from the code looks nothing like an air blast wave.

Figure 4 shows five different air blast waves measured at various positions around the muzzle of an XM204, 105-mm howitzer with LC-33 piezoelectric, pencil gauges. Notice that noise exists on all the records; nevertheless, these traces would usually be thought of as recordings of excellent quality. To follow the code quite literally, and this is what is expected, requires the user to carry the duration to point C in Figure 4a, point D in Figure 4c, point F in Figure 4d, point H in Figure 4e, and beyond recorded time in Figure 4b. Quite frankly, these deviations are not

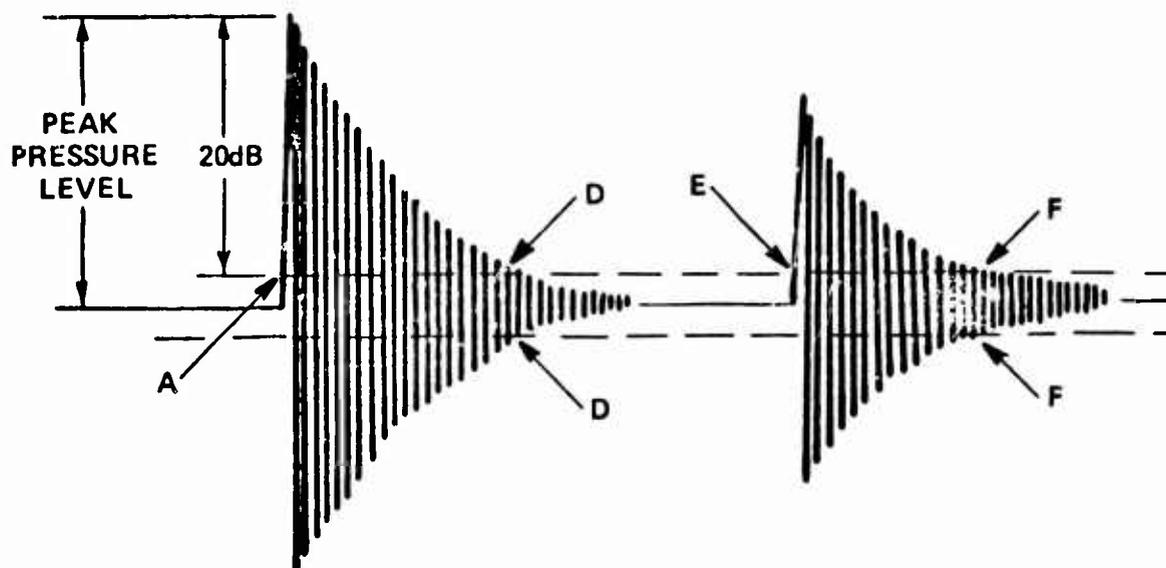


FIGURE 3. IDEALIZED HEL PRESSURE-TIME HISTORY OF AN IMPULSE NOISE

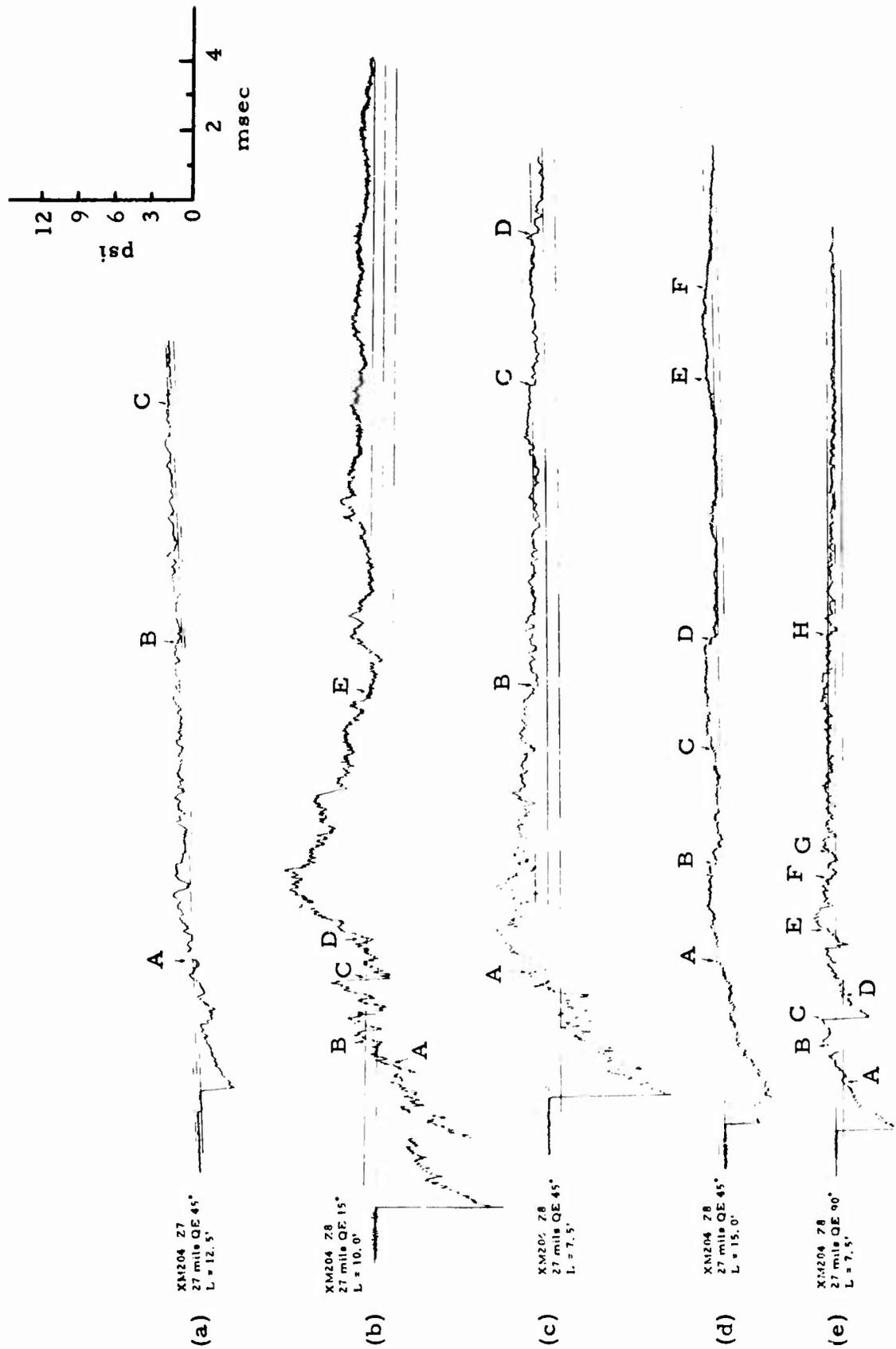


FIGURE 4. EXAMPLES OF FIELD TRACES FOR XM204 HOWITZER MUZZLE BLAST

associated with the rarefaction wave from a muzzle blast; they are associated with instrumentation noise and the RC time constant of the recording system. Perfect recordings cannot be made; instrumentation noise is always present. Piezoelectric elements are subject to thermal drift from such phenomena as the sun passing behind clouds and radiation from the gun's fireball. Usually thermal drift is slow relative to positive duration from a compressive wave, but not slow relative to durations 10 times longer than the positive wave with a low frequency instrumentation discharge asymptotically approaching a limit. Figure 4b is probably an example of thermal heating from the howitzer's fireball. Other sources of noise include cable whip, shocks through the gauge, flutter in the tape recorder, dampness in connectors, and noise on power lines. Because the frequency response is in the AM radio band, cables even when shielded act as antennae and present radio broadcasts as extraneous noise sources. The durations BC and DE that could be subtracted from the overall duration F in Figure 4d are probably examples of one of the aforementioned extraneous noise sources. These instrumentation problems are not unique to this program; everyone measuring blast around large weapons has these difficulties. In telephone conversations with HEL, they implied that test records could be repeated, even where measured with different instrumentation systems. Unfortunately, all instrumentation systems used to piezoelectrically record blast pressure signals have low frequency responses in the area of 2 cps. This argument simply means that systematic errors can be repeated. Whenever we applied the code to Rock Island 105-mm muzzle blast records, we obtained negative envelope durations of  $20 \pm 7$  m. s. except for a wave such as Figure 4b with thermal energy introduced into the recording system. This result is probably a consequence of the low frequency response for the instrumentation and has nothing to do with negative blast wave durations. Based on our analysis of hundreds of records, we believe that the rarefaction durations cannot be measured around artillery, and that observed results are measures of the instrumentation RC time constant and extraneous instrumentation noise sources which exaggerate the total pulse duration.

To circumvent this instrumentation limitation, procedures were developed for predicting peak pressures, times of arrival for reflected waves, and total duration of all wave fronts using only the positive or compressive wave durations. This procedure is not in strict compliance with the code, but we believe these to be the only times which can be accurately measured, and are representative of blast pressure durations. Then, so that negative times may be included to approximate the observed total duration as defined by the HEL code (an observation that we believe measures instrumentation noise and time constants) a factor N was introduced into the solution for the  $\bar{Y}$  and  $\bar{Z}$  criteria.

If  $N$  equals 1.0, the duration is that associated with a decay intersecting only the positive 20 dB or positive 10% envelope line. No negative durations are considered when  $N$  equals 1.0. An  $N$  of 5.0 closely approximates the total instrumentation times (positive + negative) for 105-mm howitzer firings whenever incident and reflected waves are separated as in Figure 2a. An  $N$  value of 10 more closely approximates the recorded total durations for the 105-mm howitzer firings whenever waves are in the Mach stem as in Figure 2c. Although these values are given as guidelines, we leave it up to the individual to decide what value of  $N$  is most appropriate for his weapon system.

### III. SAFE STANDOFF POSITIONS

#### General

Two procedures are discussed in this section, one for computing the safe standoff position whenever no ear protection is offered, and the other for computing safe standoff position with protection such as plugs and/or muffs. No derivations of these relationships are presented in this section of the report; all derivations are presented in Section IV for those interested in an in-depth understanding of this approach and in a fundamental review of scaling muzzle blast pressures, durations, and times of arrival. Two separate solutions must be presented because the  $W$  no-ear-protection threshold is independent of muzzle blast duration, whereas the  $Y$  and  $Z$  protected-ear thresholds are functions of duration (see Figure 1).

#### Solution for $\bar{W}$ Criterion

The maximum free field overpressure around a gun muzzle over a reflecting plane such as the ground is given by:

$$\frac{P c^2 \ell}{W} = e^{\xi + \epsilon \cos \left( \frac{\theta}{\gamma} - \delta \right)} \left( \frac{c}{L} \right)^{\beta + \psi \cos \left( \frac{\theta}{\gamma} - \delta \right)} \quad (1)$$

where

- $P$  = peak side-on overpressure
- $c$  = caliber of gun
- $\ell$  = barrel length
- $W$  = effective energy release in propellant
- $\theta$  = angular position of observer in radians from line of fire
- $L$  = standoff distance of observer from muzzle
- $\xi, \epsilon, \gamma, \delta, \beta, \psi$  = coefficients given by Table A which are functions of gun tube angle  $\alpha$

Several quantities in Eq. (1) require further explanation. The coordinate system for the observer's position relative to the muzzle of a closed-breech gun is a radial coordinate system with its origin as the perpendicular projection of the muzzle onto the ground under the gun, and its reference line, the projection of the line of fire onto the ground. In other words,  $\theta$  equal to zero is the line of fire,  $\theta$  equal to  $\pi$  radius is directly aft, and  $L$  is the standoff distance from the muzzle when measured parallel to the ground. No slant distances are involved from the ear of the observer to the gun muzzle.

Equation (1) for pressure is not a strong function in the region measured of either the height of the muzzle  $h$  off of the ground or the height of the observer  $H$  off of the ground. These parameters are therefore not included. The angle of the gun barrel  $\alpha$  relative to the ground does make a significant difference; hence, its influence is included in the numerical values for the six Greek letter coefficients ( $\xi$ ,  $\epsilon$ ,  $\gamma$ ,  $\delta$ ,  $\beta$ , and  $\Psi$ ). Table A presents these nondimensional coefficients as functions of  $\alpha$  for three different gun tube elevations. Because these coefficients come from an empirical curve fit to experimental test data, one standard deviation  $\sigma$  for using these coefficients to predict pressure is also presented in Table A. As can be seen, one standard deviation for predicting pressure is essentially 25% over the range of test results described in Section IV.

TABLE A. COEFFICIENTS FOR PRESSURE EQUATION

$\alpha$ (radius)	$\sigma$	$\xi$	$\epsilon$	$\gamma$	$\delta$	$\beta$	$\Psi$
0	28.2%	-6.652	3.502	1.80	0.0	0.9352	0.3551
0.293	18.3%	-6.484	2.468	1.00	0.7854	0.7843	0.3601
1.197	12.9%	-8.635	0.365	0.457	1.454	0.2737	0.8618

The final quantity requiring considerable discussion is the effective energy release  $W$ . For use in Eq. (1) and throughout this report,  $W$  will be given by Eq. (2).

$$W = \eta \left[ E - \frac{1}{2} m V^2 \right] \quad (2)$$

where

W = effective energy entering blast

E = energy in propellant

$\frac{1}{2}mV^2$  = kinetic energy of projectile at ejection

$\eta$  = nondimensional coefficient dependent upon chemistry and heat of a propellant

Essentially, Eq. (2) is an energy balance. It states that the energy in the propellant that does not enter the kinetic energy of the projectile goes into muzzle blast. Actually, other forms of energy dissipation do exist, particularly thermal losses; however, provided these losses are directly proportional to  $E - \frac{1}{2}mV^2$ , Eq. (2) will be valid. The quantity E is determined by multiplying the weight of propellant times the heat of explosion for the propellant. The proportionality coefficient  $\eta$  is both a correction factor for thermal losses and a coefficient that depends upon the chemistry of propellants. It does appear to be a nonlinear function of heat of explosion. Table B presents values of  $\eta$  for propellants that we have encountered in experimental tests.

TABLE B. NUMERICAL VALUES OF  $\eta$  FOR ENERGY RELEASES

<u>Type of Propellant</u>	<u>Heat of Explosion (ft-lb/lb)</u>	<u><math>\eta</math></u>
Navy NACO	$0.92 \times 10^{+6}$	1.00
Army M1	$0.98 \times 10^{+6}$	1.00
Navy PYRO	$1.05 \times 10^{+6}$	1.00
Unknown (20 mm)	$1.16 \times 10^{+6}$	1.06
Dupont IMR	$1.21 \times 10^{+6}$	0.693
Army M30A1	$1.36 \times 10^{+6}$	0.716
Hercules Unique	$1.69 \times 10^{+6}$	0.511

Because the  $\bar{W}$  threshold of hearing loss criterion is a constant pressure criterion (see Figure 1), we have only to substitute the amplitude  $Z$  for  $P$  in Eq. (1). Whenever this substitution is made, the solution for threshold of hearing loss becomes a four-parameter space of nondimensional numbers that can be written in functional format as:

$$F \left[ \frac{Z c^2 \ell}{W}, \alpha, \theta, \frac{L}{c} \right] = 0 \quad (3)$$

The value for  $Z$  is 0.0285 psi or 4.104 psf if  $\bar{W}$  from Figure 1 is considered to be the appropriate threshold. Equation (3) can also be used for the  $\bar{Y}$  and  $\bar{Z}$  thresholds if durations are greater than 200 milliseconds. Such a computation is an academic rather than practical consideration because a 40-in. gun would be required for a duration around 200 milliseconds. If one believed that durations are a function of the instrumentation system, as has already been discussed, and wanted to use a constant  $Y$  or  $Z$  pressure for a constant duration from a given gun, Figure 1 could be used to obtain  $Z$  and Eq. (3) with the appropriate  $Z$  would still apply.

A four-parameter solution has the advantage that it can be displayed graphically. Figures 5 are this graphical representation of Eq. (3), only rectangular rather than polar coordinates are being used. The parameter  $L_{\perp}$  is the standoff distance from the muzzle perpendicular to the line of fire, and  $L_{\parallel}$  is the distance parallel to the line of fire. Negative values for  $L_{\parallel}$  are aft of the gun muzzle. Each of the successive Figures 5 is for a different gun tube elevation  $\alpha$ . Any self-consistent set of units can be used when applying Figures 5, as the parameters are all nondimensional.

The isoclines throughout each figure are for constant values of  $\frac{Z c^2 \ell}{W}$ .

For a particular gun and propelling charge,  $c$ ,  $\ell$ , and  $W$  will be constants. Select the appropriate value for  $Z$  from Figure 1 ( $Z = 4.104$  psi if the  $W$  criterion is being applied) and compute the numerical value of the isocline  $\frac{Z c^2 \ell}{W}$ . Figures 5 show in gun tube calibers where the pressure will be greater or less than the constant pressure hearing loss threshold. Inside the limiting isocline of  $\frac{Z c^2 \ell}{W}$ , we would predict hearing loss, whereas outside this same isocline, we would predict no hearing loss.

The 100-caliber square region aft of the muzzle has been enlarged and inserted in Figures 5a and 5b as this domain covers the area where gun crews stand. Notice that the most severe muzzle blast occurs whenever the gun is fully depressed to 0 degrees. For artillery this condition may be too severe a restriction in the field, as essentially all rounds are

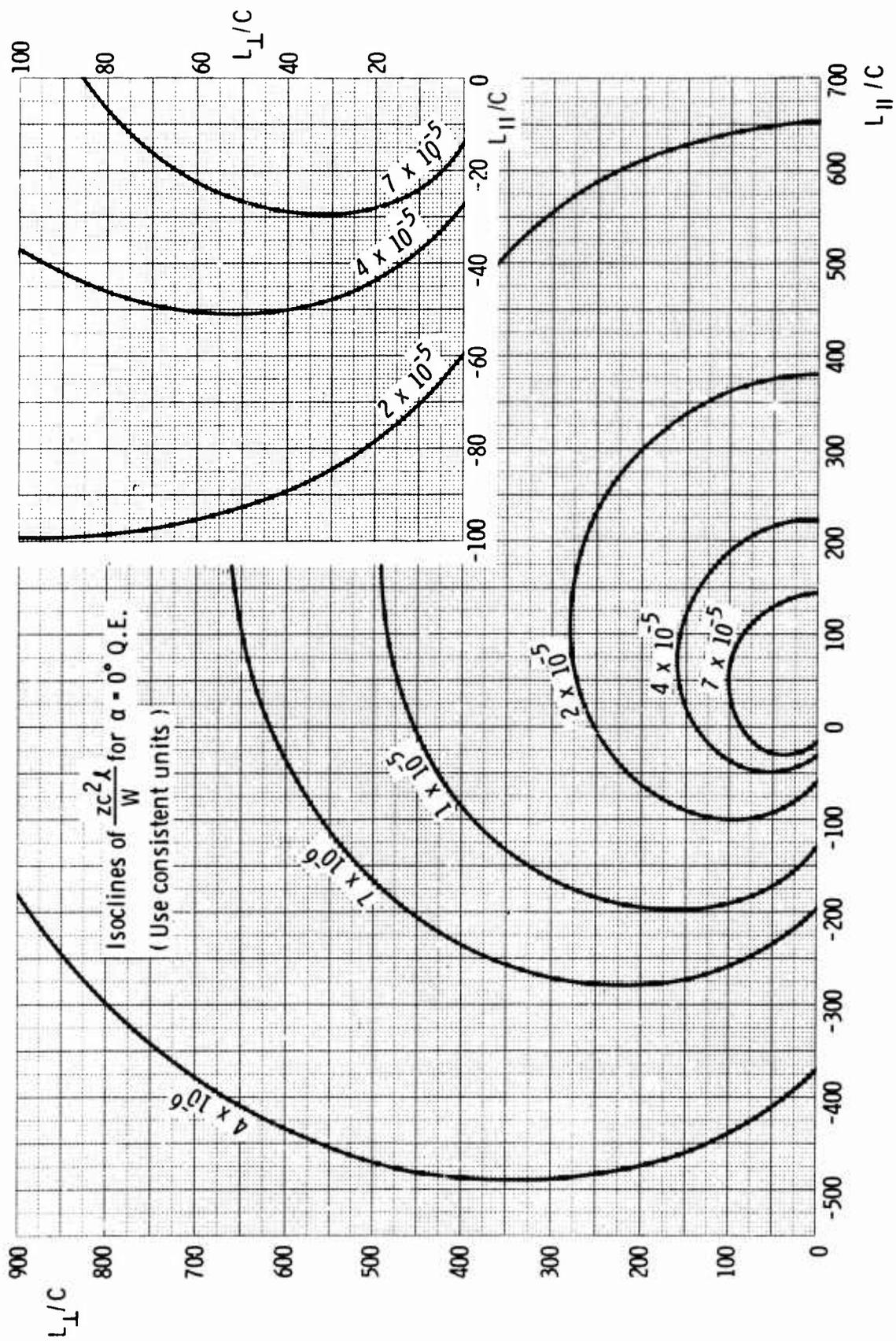


FIGURE 5. SAFE STANDOFF DISTANCES FOR NO EAR PROTECTION ( $\bar{W}$  CRITERION)

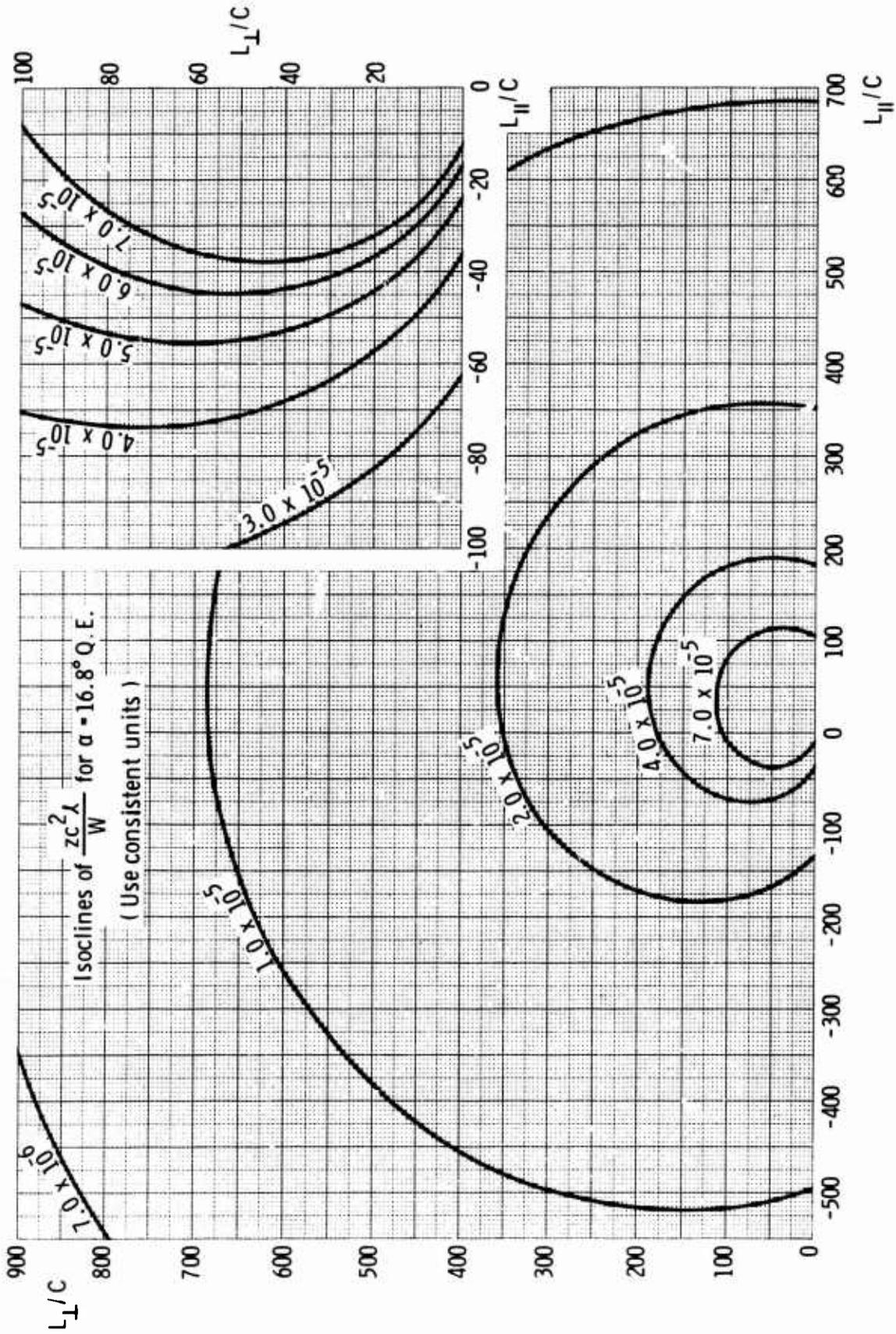


FIGURE 5 (CONT'D)

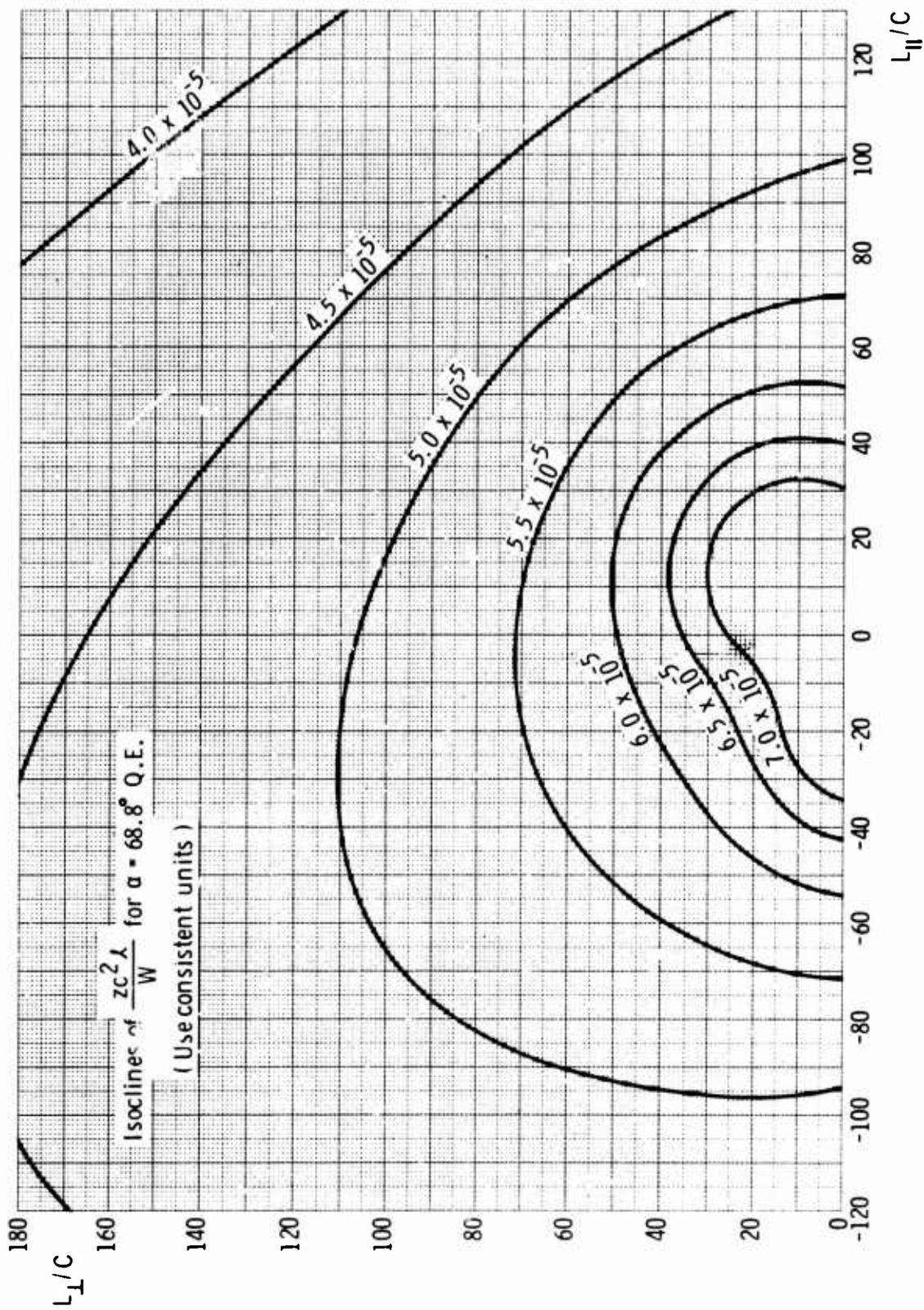


FIGURE 5 (CONT'D)

fired with a gun tube elevation of at least 300 mils (16.8 degrees), the second graph. The only time an artillery piece is fired at 0 degrees is whenever a position is being overrun, a time for kill or be killed with no concern for hearing loss and the positioning of people. The code<sup>(1)</sup> incidentally does recognize and accept the existence of such circumstances. Figure 5c for a gun tube elevation of 68.6° does not cover as large a field as the other two figures because the data being curve fitted did not cover as large a domain. Ideally, the contours should be normal to the  $L/c$  axis at  $L/c = 0$  as is the case in Figure 5a. The bulges aft of the muzzle in Figure 5c are primarily due to the limited number of measurements at large standoffs for a gun tube elevation of 68.6°

To illustrate the use of Figures 5, consider a 105-mm, XM204 howitzer firing a zone 5 round. We will presume that the propellant is M-1 type; hence,  $\eta = 1.0$ . For this particular system, the heat of explosion would equal  $0.980 \times 10^{+6}$  ft-lb/lb, the weight of propellant is 1.38 lb, the weight of the projectile is 33.0 lb, the muzzle velocity is 1090 fps, the length of the gun is 140 in., and the caliber of the gun is 4.133 inches. Substitution into Eq. (2) indicates that the effective energy release  $W = 7.439 \times 10^{+5}$  ft-lb. With  $Z = 4.104$  psf for the  $W$  criterion, the isocline  $\frac{Z c^2 \ell}{W}$  equals in nondimensional units  $7.625 \times 10^{-6}$ . Figure 5a shows that within a region 200 calibers (68.9 ft) aft of the muzzle, 655 calibers (225.6 ft) forward of the muzzle, and 615 calibers (211.9 ft) perpendicular to the muzzle, hearing loss can be expected unless ear protection is worn. The region encompassing hearing loss with no ear protection extends out even further for guns with larger propelling charges such as zones 7 and 8. Because the gunner and assistant gunner positions are essentially 55 calibers aft of a 105-mm howitzer, hearing loss should be anticipated unless these individuals wear ear protection.

Mr. Mark Salsbury at Rock Island Arsenal has supplied muzzle blast test data on zone 5, 7, and 8 firings from 105-mm howitzers. All of his gauges at 0 degrees gun elevation were located at various positions up to maximums of approximately 100 calibers along radial lines spaced 15 degrees apart. Every one of these gauges measured pressures greater than 0.0285 psi; that is, the blast pressure recorded by all gauges was, according to the  $W$  criterion, sufficient to cause threshold hearing loss at each gauge position. This result is consistent with the predictions stated in the previous paragraph.

#### Solution for $\bar{Y}$ and $\bar{Z}$ Criteria

For muzzle blast durations of less than 200 milliseconds (which is true for all known guns) and ear protection in the form of either plugs

and/or muffs, the hearing loss thresholds as seen in Figure 1 are functions of both pressure and time. Because the  $\bar{Y}$  and  $\bar{Z}$  criteria from Figure 1 are parallel straight lines on a log-log plot of maximum pressure  $P$  versus duration  $T$ , the equation for these lines can be written as:

$$P T^{0.345} = Z(\text{prot}) \quad (4)$$

The exponent 0.345 is the slope of the  $\bar{Y}$  and  $\bar{Z}$  lines seen in Figure 1. The parameter  $Z(\text{prot})$  for level of ear protection has units of  $\text{lb-ms}^{0.345}/\text{ft}^2$  and is a constant dependent only upon the type of ear protection. For the  $\bar{Y}$  level of ear protection  $Z(\text{prot})$  equals  $562.0 \text{ lb-ms}^{0.345}/\text{ft}^2$ , and for the  $\bar{Z}$  level of ear protection it equals  $1180.0 \text{ lb-ms}^{0.345}/\text{ft}^2$ .

Both pressure and duration equations are needed to substitute into Eq. (4) and develop a functional relationship. Equation (1) for maximum side-on overpressure is still valid as the blast pressure field is independent of the type or lack of ear protection. The total free field duration for muzzle blast around a gun muzzle over a reflecting plane such as the ground is given by:

$$\frac{T \ell^{5/12}}{NW^{1/3} c^{5/12}} = \frac{(a + b\theta) \frac{L}{c}}{\left(d + \frac{L}{c}\right)} + (e - f\theta^2) \quad (5)$$

where

- $T$  = total duration of all compressive waves
- $N$  = nondimensional factor to account for negative durations as well as positive durations
- $a, b, d,$   
 $e, f$  = coefficients given by Table C which are functions of gun tube angle  $\alpha$
- $W, \ell, c,$   
 $L, \theta$  = parameters already defined in Eq. (1)

Just as Eq. (1) for pressure was not a strong function in the region tested of either the height of the muzzle  $h$  off of the ground or the height of the observer  $H$ , so, too, duration is treated as being independent of these two parameters. The angle of the gun barrel  $\alpha$  relative to the ground does make a significant difference; hence, its influence is included in the

numerical value for the five coefficients (a, b, d, e, and f). Table C presents these nondimensional coefficients as functions of  $\alpha$  for three different gun tube elevations. Because these duration coefficients come from an empirical curve fit to experimental test data, one standard deviation  $\sigma$  for using these coefficients to predict duration is also presented in Table C. As can be seen, one standard deviation for predicting duration is essentially 25% over the range of test results described in Section IV.

TABLE C. COEFFICIENTS FOR DURATION EQUATION

$\alpha$ (radians)	$\sigma$	a	b	d	e	f
0	23.0%	0.1192	-0.02346	0.03224	-0.001215	28.0
0.293	26.0%	0.1971	-0.04871	0.04200	0.0	42.0
1.197	22.7%	0.05603	-0.02280	0.05617	+0.004501	42.0

Whenever the coefficients from Table C are substituted into Eq. (5), the scaled duration  $\frac{T l^{5/12}}{N W^{1/3} c^{5/12}}$  will have units of  $\frac{ms}{ft^{1/3} b^{1/3}}$ . After the effective energy release as defined by Eq. (2) has been substituted into the scaled duration, the duration T is obtained in units of milliseconds. The duration T, as has already been discussed in Section II, is the sum of all the positive durations associated with compressive blast wave pressure decays intersecting only the positive 20 dB or positive 10% envelope line. No negative or rarefaction durations are considered unless N equals a number greater than 1.0. The parameter N is a nondimensional factor for approximately estimating the sum of all positive and negative durations as defined in the code. We have already discussed that for the muzzle blast field around artillery, measured results reflect the low frequency RC time constant and instrumentation noise rather than the reality of an accurately measured duration associated with a rarefaction. The choice of an appropriate value for N is left up to the individual. For blast fields measured around 105-mm howitzers, we have indicated that an N of 5.0 approximates negative instrumentation times whenever incident and reflected waves are separated, and an N of 10.0 approximates negative and positive durations for waves in the Mach stem.

If waves are to be in or out of the Mach stem and have different values of N assigned, one must be able to predict where the triple point

passes when guns are fired at different angles over a reflecting plane. For gun tubes at angles of  $16.8^\circ$  and  $68.6^\circ$ , the gauges were not located over a sufficiently extended region to predict passage of the triple point. All of these higher gun tube angles had transducers measuring separate incident and reflected waves. For a gun at  $0^\circ$  QE, we were able to develop from time of arrival curves described in Section IV the standoff distance  $\frac{L}{c}$  along various radial lines  $\theta$  for which the triple point passes essentially at ear level. An algebraic expression from these  $\alpha = 0^\circ$  curve fits is given by:

$$\left(\frac{L}{c}\right)_{\text{triple point}} = 70.46 + 2.216\theta^2 \quad (6)$$

Equation (6) indicates that at  $\theta = 0.262$  radians ( $15^\circ$ ),  $\frac{L}{c} = 70.6$  calibers; at  $\theta = 1.571$  radians ( $90^\circ$ ),  $\frac{L}{c} = 75.9$  calibers; and at  $\theta = 2.880$  radians ( $165^\circ$ ),  $\frac{L}{c} = 88.3$  calibers for the passage of the triple point at ear level.

For distances beyond these values, an observer would be in the Mach stem and an N of 10 is more appropriate. Inside these values, N is closer to 5 provided you accept the instrumentation as being adequate.

A graphical solution for the  $\bar{Y}$  and  $\bar{Z}$  criteria can now be developed similar to that already presented for the W criterion. To develop this solution, the pressure equation (Eq. (1)), the duration equation (Eq. (5)), and the equation for the hearing loss threshold (Eq. (4)) must be combined. Unfortunately, the resulting expression is not an explicit one in either  $\frac{L}{c}$  or  $\theta$ . In functional format, the result is another four-parameter space given by:

$$F \left[ \frac{Z(\text{prot})c^{1.855} l^{1.14}}{N^{0.345} W^{1.115}}, \alpha, \theta, \frac{L}{c} \right] = 0 \quad (7)$$

This four-parameter solution can also be presented graphically on three different plots for the different  $\alpha$  values. Figures 6 are then graphical representations of Eq. (7) with polar coordinates  $\theta$  and  $\frac{L}{c}$  having been transformed into rectangular coordinates  $\frac{L_{\perp}}{c}$  and  $\frac{L_{\parallel}}{c}$ . Because the iso-clines in Figures 6 are for  $\frac{Zc^{1.855} l^{1.14}}{N^{0.345} W^{1.115}}$ , a quantity that has not been

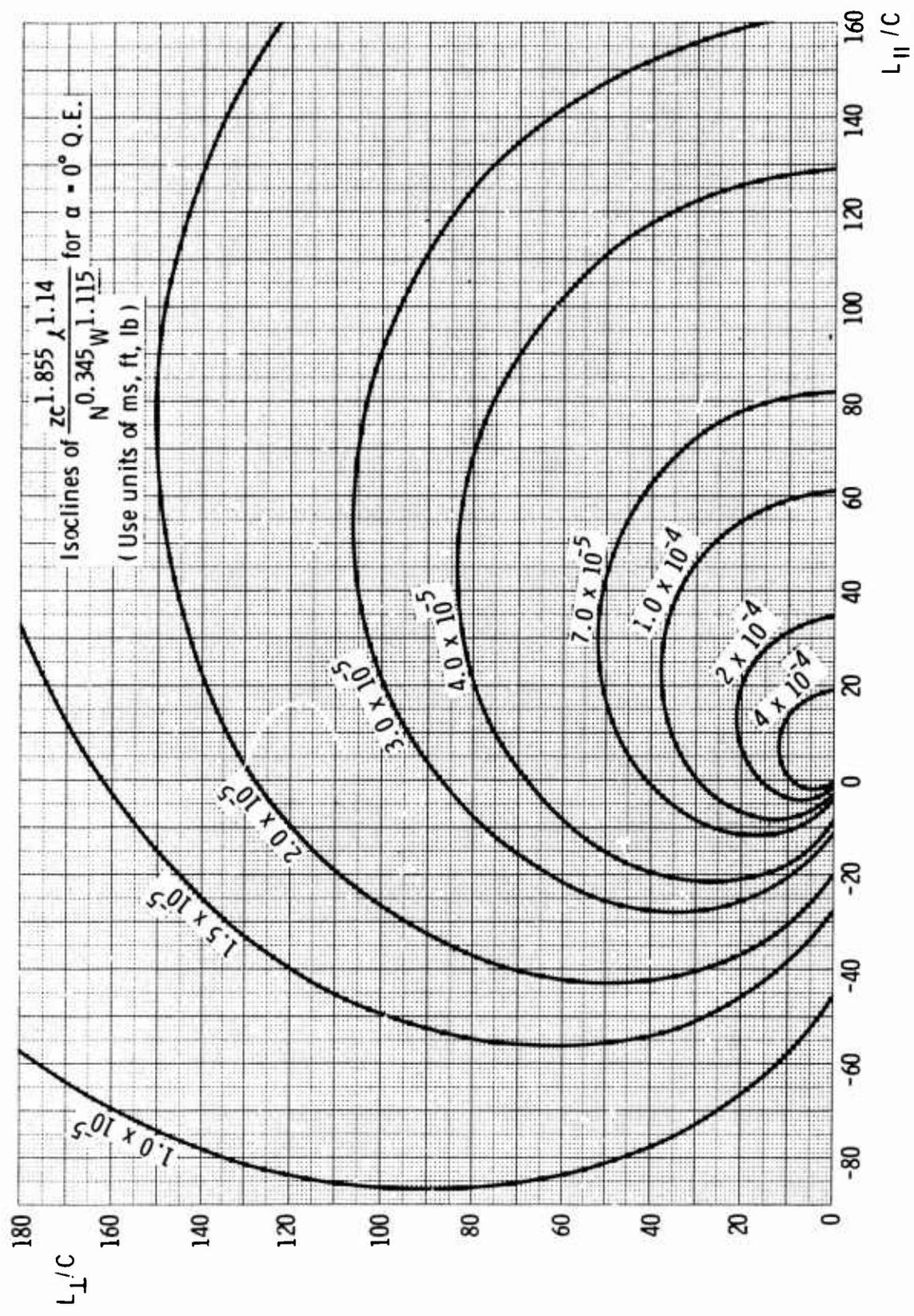


FIGURE 6. SAFE STANDOFF DISTANCES FOR Y AND Z EAR PROTECTION LEVELS

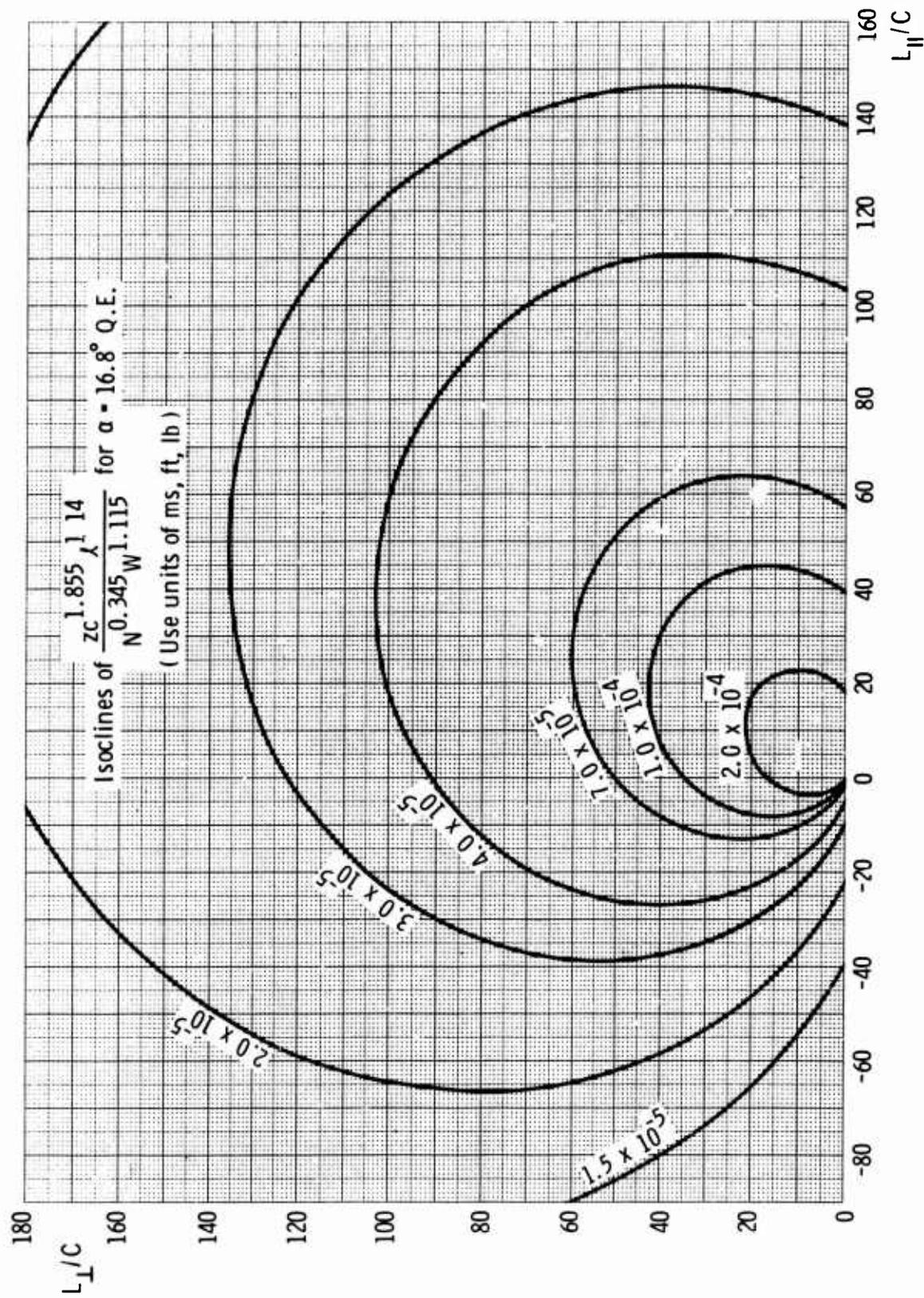


FIGURE 6 (CONT'D)

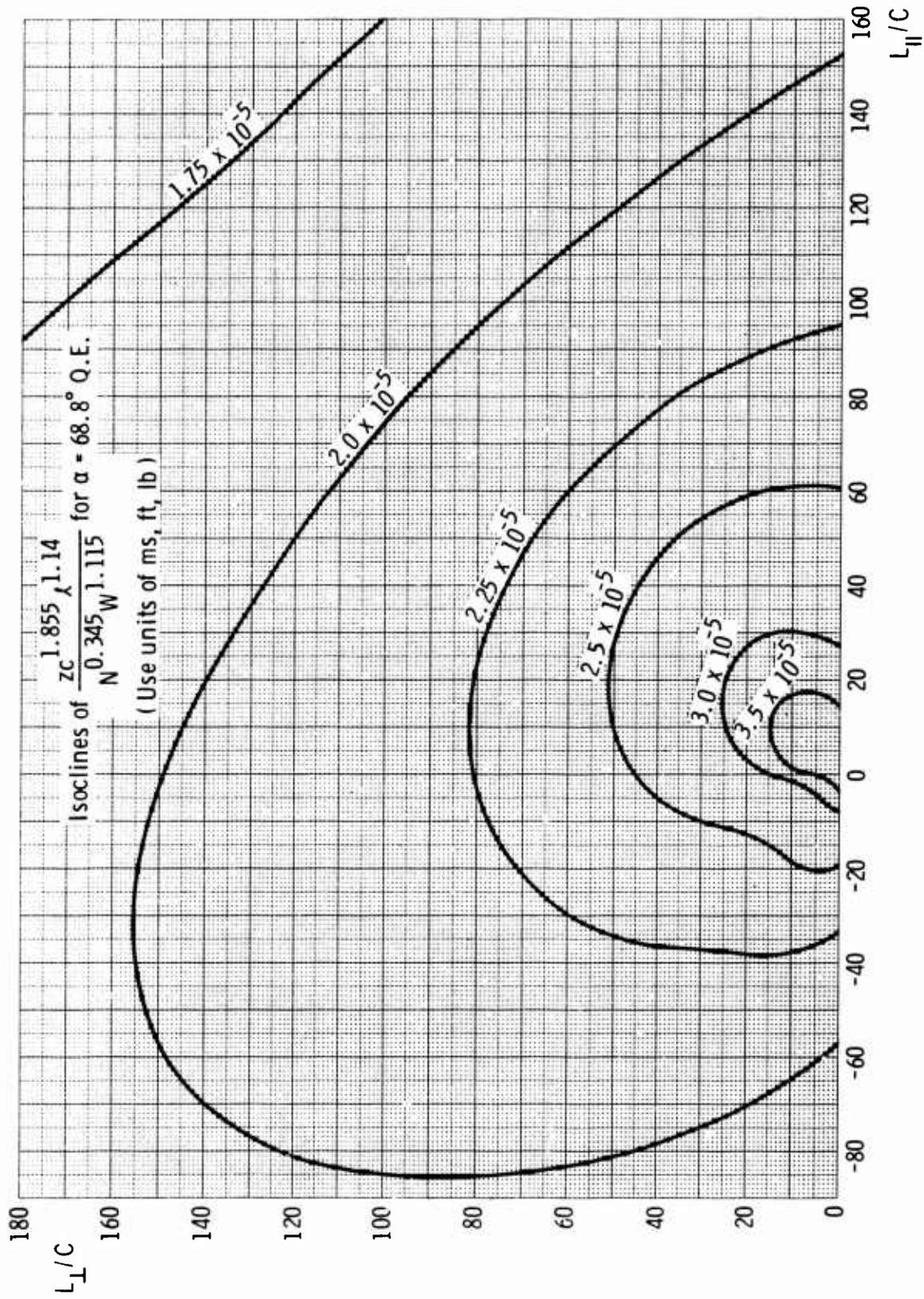


FIGURE 6 (CONT'D)

made nondimensional by using constants such as the speed of sound in air and ambient atmospheric pressure, units of measure for these charts must be in milliseconds, feet, and pounds.

As can be seen in Figures 6, the most severe case occurs when the gun tube is fully depressed to 0 degrees. Once again as in the discussion with the *W* criterion, designers would probably be justified in using the 16.8° gun tube curve.

To illustrate the use of Figures 6, consider a 105-mm, XM204 howitzer firing a zone 8 round. We will presume that the propellant is the hot M30A1 type; hence,  $\eta = 0.719$ . For such a system, the heat of explosion equals  $1.36 \times 10^{+6}$  ft-lb/lb, the weight of propellant is 4.419 lb, the weight of the projectile is 33.0 lb, the muzzle velocity is 2133 fps, the length of the gun is 140 in., and the caliber of the gun is 4.133 inches. Substitution into Eq. (2) indicates that the effective energy release *W* equals  $2.629 \times 10^{+6}$  ft-lb. If we assume  $N = 5.0$  and wish to determine safe standoff positions for gun crews with ear plugs (the *Y* criterion with

$$Z = 562.0 \text{ lb-ms}^{0.345} / \text{ft}^2, \text{ then the isocline } \frac{Z_c^{1.855} l^{1.14}}{N^{0.345} W^{1.115}} = 5.10 \times 10^{-5}.$$

Figure 6a is then entered and by extrapolating between the  $4.0 \times 10^{-5}$  and  $7.0 \times 10^{-5}$  isoclines, the threshold for safe standoff distance is established. The continuous line in Figure 7a is this analytical result.

It is interesting to compare predicted safe standoff distances with experimentally measured results. As has already been indicated, test data on the XM204 firing a zone 8 has been obtained by placing blast pressure transducers at various locations around gun muzzles. The different dots in Figure 7a represent transducer locations. Both the maximum pressure and the sum of all positive durations were recorded outside the 20 dB envelope. These average recorded durations were multiplied by 5 to obtain an average estimated positive and negative duration. Figure 1 from the noise standard was then entered using average pressure and duration to assess whether or not hearing is damaged. Blackened-in dots indicate that Figure 1 predicts a definite hearing loss, whereas the white or open dots indicate no hearing loss. All partially shaded points in Figure 7a indicate that this location was within one standard deviation for pressure (within 25%) of the *Y* threshold from Figure 1. Scatter does occur in pressure measurements, and such a procedure is a method of denoting uncertainty caused by this scatter. If the location showed that the threshold was exceeded by less than 25%, the dot has its lower half colored. If the location on the average was close to the threshold but under it, the dot has its right hand side colored. As can be seen in Figure 7a, the predicted threshold appears to separate hearing loss and no loss of hearing domains appropriately.

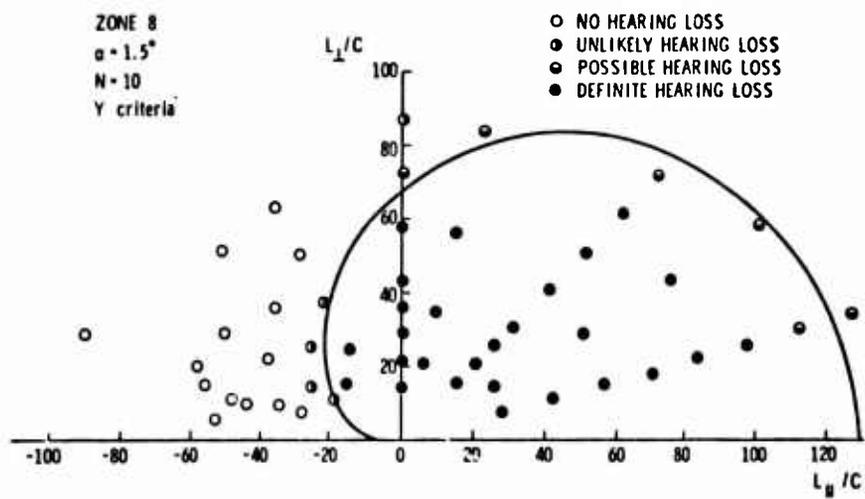
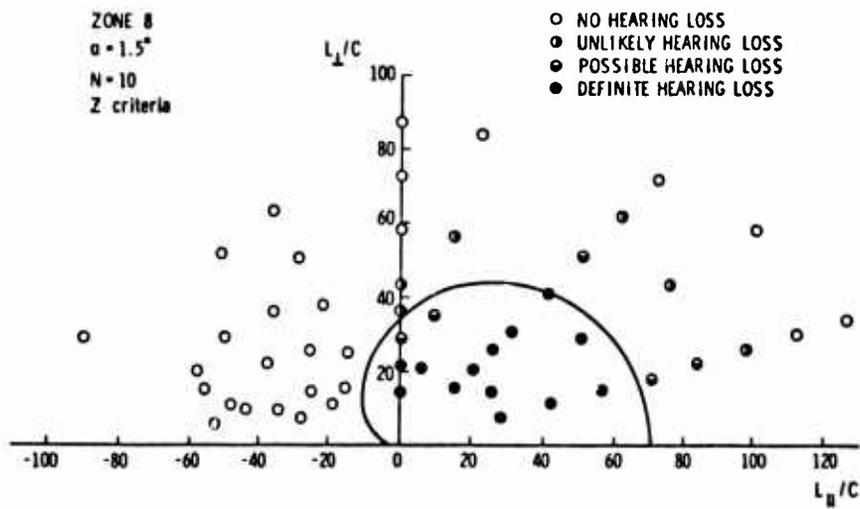
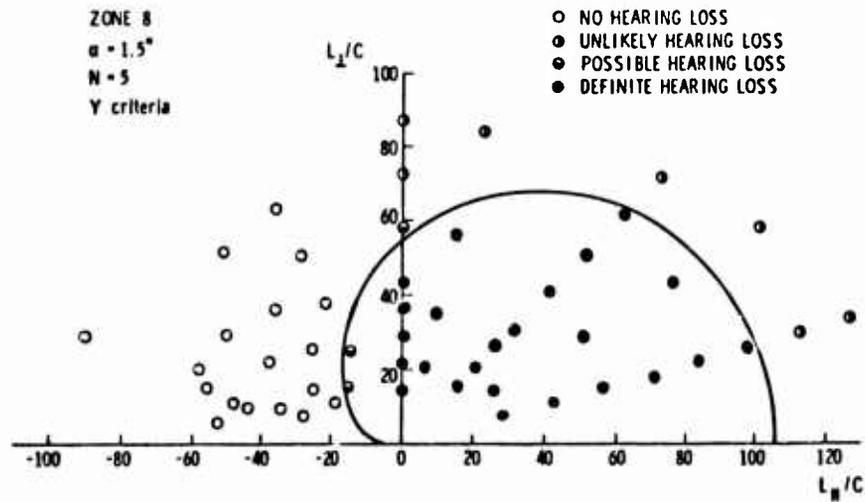


FIGURE 7. COMPARISON BETWEEN PREDICTED AND MEASURED SAFE STANDOFFS FOR XM204 HOWITZER

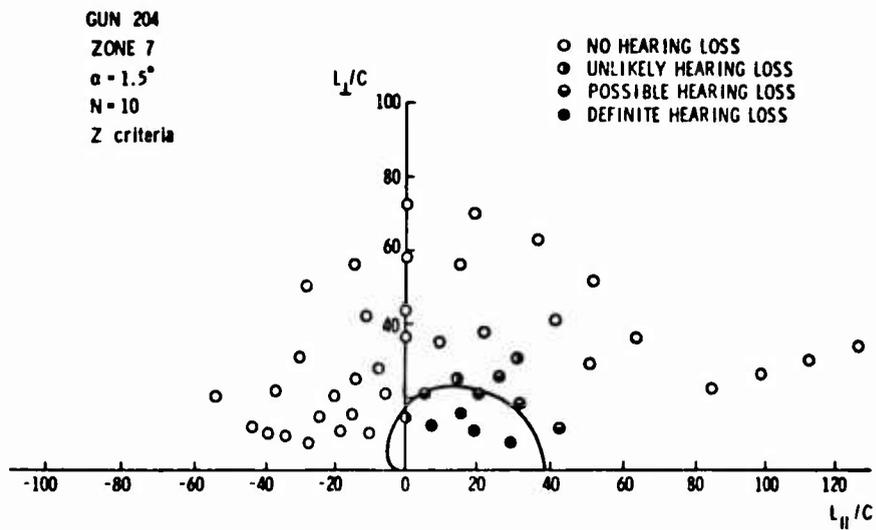
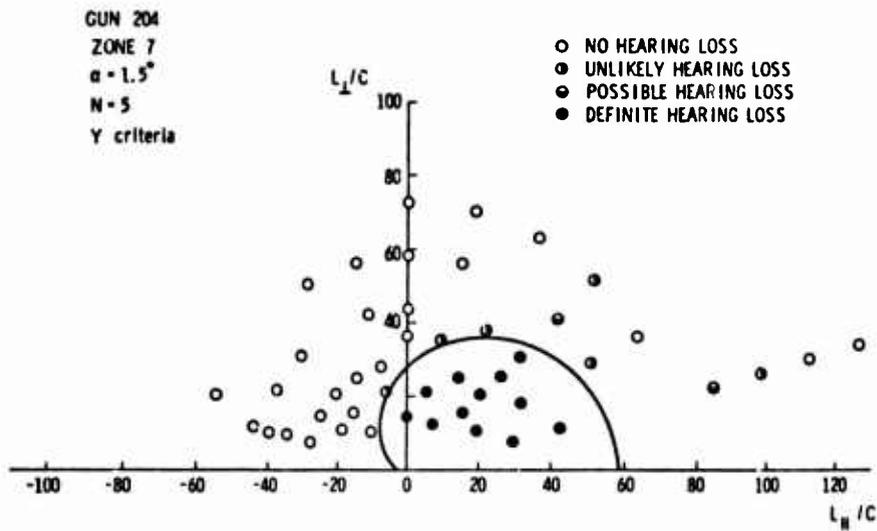
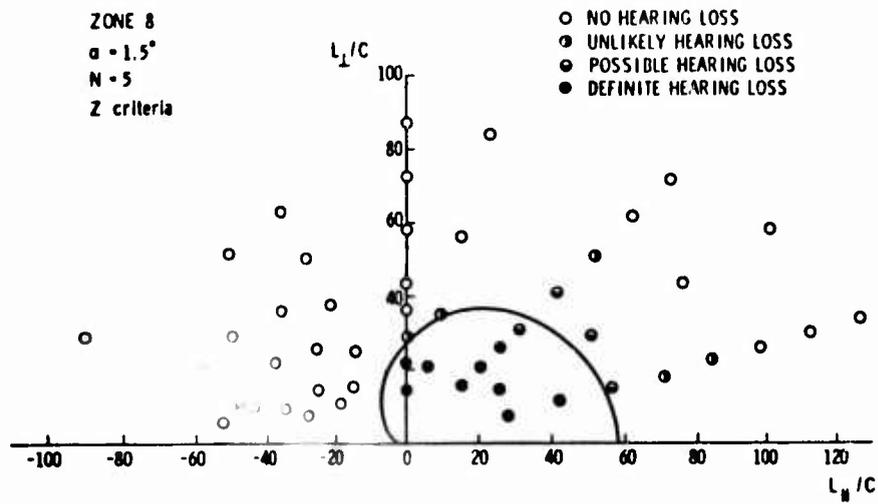


FIGURE 7 (CONT'D)

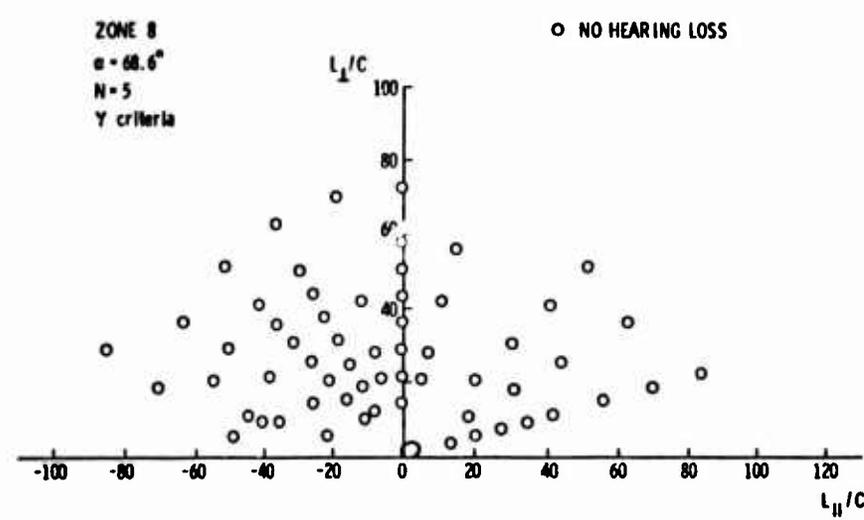
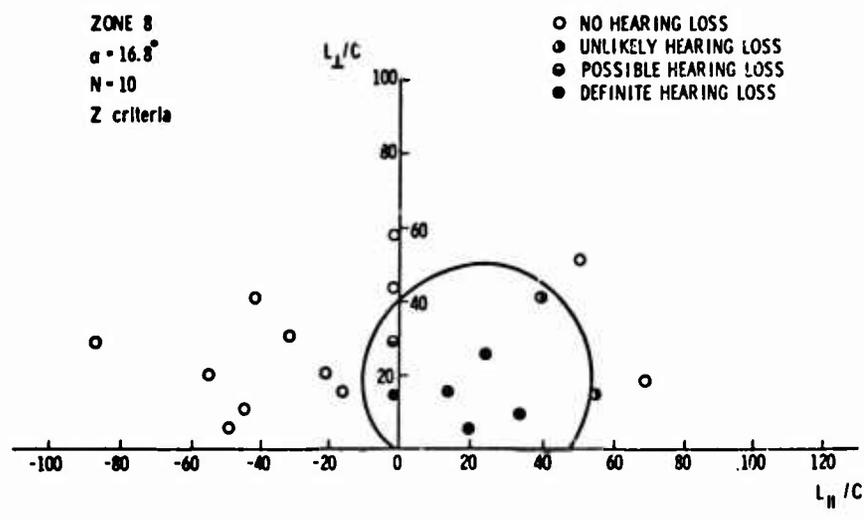
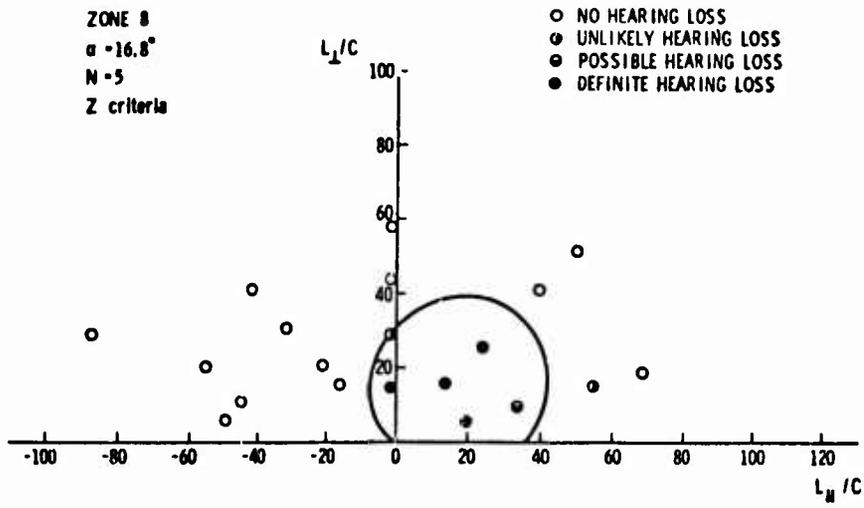


FIGURE 7 (CONT'D)

Eight other Figures 7 are also presented to show that hearing loss and no loss of hearing domains are predicted accurately for the  $\bar{Z}$  criterion as well as  $\bar{Y}$  criterion, various values of N, other angles of gun tube elevation, and zone 7 as well as zone 8 charges. In all these figures, all blackened and open dots appear in the appropriate region and only occasionally do partially shaded dots appear in the wrong domain. Whenever a partially shaded dot is incorrect, it is close to the predicted threshold, and any errors are random. The fact that none of the partially colored dots are incorrect aft of the muzzle is probably good fortune rather than well conditioned physical behavior. By comparing the various Figures 7 with each other, readers can obtain a feel for how changes in gun tube elevation, propelling charge, N factor, and level of ear protection influence safe standoff position.

For a 105-mm howitzer gun crew, gunner and assistant gunner positions are essentially 55 calibers aft. Figures 7 imply that no hearing loss should result provided crew members wear either ear plugs or muffs. Earlier predictions for the  $\bar{W}$  criterion with no ear protection have demonstrated that loss of hearing should be expected whenever 105-mm howitzer crews wear no ear protection.

## IV. DERIVATIONS

### General

The safe standoff thresholds presented in the previous section required explicit expressions for the maximum pressure, duration of an event, and (of less importance) time of arrival for a reflected wave relative to an incident muzzle blast wave. All three of these relationships have been developed empirically by first conducting a model analysis so results can be nondimensionalized for application to all weapons and then curve fitting the nondimensionalized parameters or pi terms to experimental test data.

The test data used in all curve fits come from one of two sources. Reference 2 by Mark Walther is a compilation of all Naval Weapons Laboratory muzzle blast test data. Included in this compilation are data obtained by both NWL and its contractors (such as by the senior author of this report). Unfortunately, most of the information is peak pressure for various locations around the muzzle of many guns, including 20 mm, 40 mm, 3"/50, 5"/38, 5"/54, 6"/47, and 8"/55 guns. No angle of gun tube elevation  $\alpha$  is reported although the writers know from personal conversations that the angles are near  $0^\circ$ . The height of guns, heights of gauges, durations, and arrival times are unreported; hence, these data are largely limited to peak pressure fits for an  $\alpha$  of zero. The second source of data comes from 105-mm howitzer test firings conducted by Mark Salsbury of Rock Island Arsenal. Tests on an M102 howitzer firing zone 7 propelling charges are reported in Reference 3; however, the vast bulk of the data is as yet unreported XM204 tests firing zone 5, zone 7, and zone 8 charges at gun tube angles of  $1.5^\circ$ ,  $16.8^\circ$ , and  $68.6^\circ$ . All parameters are known in these experiments, including height of gun, height of gauges, pressures, durations, and times of arrival for reflected shocks. Gauges were usually placed along radial lines every  $15^\circ$  from  $15^\circ$  to  $165^\circ$ . A diagram showing gauge locations is represented by the dots or gauge locations on Figures 7. Atlantic Research LC-33 pencil gauges and a magnetic tape recorder with a frequency response of from 2 cps to 20,000 cps were used on all tests. In the appendix to this report, we present compilations of average maximum pressures, average total positive durations from all peaks to the positive 20 dB envelope, and average times of arrival for reflected waves from the ground relative to incident muzzle blast waves.

### Model Analysis

Various investigators have previously used model analyses to evaluate the blast field around the muzzle guns. Probably Westine<sup>(4)</sup> presents the most complete review of these programs. The earliest

efforts at Princeton<sup>(5)</sup> under BRL sponsorship and at David Taylor Model Basin<sup>(6)</sup> for the Navy lead to an accurate, but awkward-to-apply replica modeling law. Provided rigorous geometric similarity was maintained, projectile masses and propellant energy scaled as the cube of the geometric scale factor, and projectile velocities were invariant, the Princeton and DTMB efforts correctly stated that at homologous locations, pressures would be identical and times would scale as the geometric scale factor. These statements are a direct extension of Hopkinson's Law<sup>(7)</sup> of 1915 for scaling air blast around H. E. charges. The major limitation to this early replica modeling law is that changes in some key parameters such as barrel length, amount of energy in the propellant, mass of projectile, and/or projectile velocity prevented new predictions of the muzzle blast field until new experiments had been conducted.

The next effort to overcome replica modeling limitations and scale pressures only was at Armour Research Institute<sup>(8)</sup> where an equivalent spherical explosive charge was located on the bore axis at a distance from the muzzle. To create an approximation to the peak pressures, Armour created a "reduced energy" using Eq. (2). Creation of this equivalent energy release simplified future model analysis by using an equation instead of independently modeling projectile mass, projectile velocity, and total energy in the propellant. Three weaknesses existed in the Armour approach. First, all contours were spherically symmetric instead of being elongated as in nature because a stationary point charge was envisioned as an equivalent muzzle blast source. Second, the same equivalent energy release used to predict pressures would not predict durations, and third, the scaled barrel length  $\frac{\ell}{c}$  was not included in the analysis because all weapons tested at that time possessed virtually the same scaled barrel length.

Finally, Westine in 1968<sup>(9)</sup> and 1969<sup>(10)</sup> modified the Armour approach and developed the procedures in use today. In these reports, Westine recognized that the Armour concept of an equivalent energy release greatly simplified any analysis, and that it could be applied without using the concept of a point charge provided a model analysis is conducted. The most detailed of these model analyses by Westine appears in Reference 4. We will follow the procedure used in Reference 4 to briefly reconstruct that model analysis for this study.

Any model analysis begins by defining the problem so parameters can be listed. Our problem is to determine the pressure-time history at some arbitrary point in space above a rigid reflecting plane, the ground. The blast pressures are created by a closed-breech gun with no muzzle

brake or flash suppressor also located above this same reflecting surface and having an equivalent energy release  $W$ . A polar coordinate system will be used with its origin directly below the gun muzzle but in the plane under the weapons. The  $\theta = 0$  axis will be the projection of the line of fire upon the reflecting surface, and the standoff distance  $L$  will be the distance in the reflecting plane of an arbitrary location of interest from the projection of the gun muzzle onto the plane. The gun itself will be of caliber  $c$ , barrel length  $l$ , and have an equivalent energy release  $W$  based upon Eq. (2). Its muzzle height above the reflecting plane is  $h$ , and it has a gun tube angle  $\alpha$  relative to the horizon. A point or location of interest in space is specified by  $\theta$  and  $L$  and the height  $H$  over the surface. This location in space will experience peak overpressure  $P$ , duration  $T$ , and time of arrival  $\tau$  of a reflected wave relative to an incident wave.

Three ambient atmospheric conditions are needed to complete this model analysis and permit the blast wave to propagate through space. Although the choice of these parameters is somewhat arbitrary, we will use atmospheric pressure  $P_0$ , sonic velocity  $a_0$ , and the ratio of specific heats  $\gamma_0$ . Table D lists the significant parameters presented in this model analysis together with their fundamental units of measurement in an engineering system of force  $p$ , length  $x$ , and time  $t$ .

Several different procedures exist for obtaining pi terms from a list of parameters, several of which are demonstrated in various texts or the reader can follow the procedure presented in Reference 4. Because these procedures involve only tedious algebra and no new assumptions, we will present only the results. If pi terms are obtained by solving in terms of the exponents on  $c$ ,  $W$ , and  $a_0$ , the 11 nondimensional ratios presented in Table E will result from the 14 parameters listed in Table D.

The first seven pi terms are statements of geometric similarity, pi terms 7 and 8 place environmental restraints on the system, and the last three pi terms are the responses which are of interest. This analysis shows that scaled response for a muzzle blast wave is a function of geometric similarity and two environmental restraints. In functional analytical format the response for either scaled pressure, or scaled duration, or scaled time of arrival may be written as:

TABLE D. LIST OF SIGNIFICANT  
MUZZLE BLAST PARAMETERS

<u>Symbol</u>	<u>Quantity</u>	<u>Fundamental Dimensions</u>
<u>Geometry</u>		
$\theta$	reference angle in polar coordinate system	--
L	standoff distance in polar coordinate system	x
h	height of muzzle	x
c	caliber of gun	x
$l$	length of gun barrel	x
H	height for location of interest	x
$\alpha$	angle of gun barrel with the horizon	--
<u>Ambient Atmospheric Environment</u>		
$P_o$	atmospheric pressure	$p/x^2$
$a_o$	sonic velocity	$x/t$
$\gamma_o$	ratio of specific heats	--
<u>Energy Release</u>		
W	equivalent energy release $n(E - \frac{1}{2} MV^2)$	px
<u>Response Parameters</u>		
P	maximum overpressure	$p/x^2$
T	duration	t
$\tau$	time of arrival for reflected waves relative to incident waves	t

$$\begin{bmatrix} \frac{P_c^3}{W} \\ \frac{Ta_o}{c} \\ \frac{\tau a_o}{c} \end{bmatrix} = F\left(\frac{\ell}{c}, \frac{L}{c}, \frac{h}{c}, \frac{H}{c}, \theta, \alpha, \frac{P_o c^3}{W}, \gamma_o\right) \quad (8)$$

TABLE E. PI TERMS FOR MUZZLE BLAST

$\pi_1 = \frac{\ell}{c}$	}	Geometric similarity
$\pi_2 = \frac{L}{c}$		
$\pi_3 = \frac{h}{c}$		
$\pi_4 = \frac{H}{c}$		
$\pi_5 = \theta$		
$\pi_6 = \alpha$		
$\pi_7 = \frac{P_o c^3}{W}$	}	Environmental restraints
$\pi_8 = \gamma_o$		
$\pi_9 = \frac{P_c^3}{W}$	}	Response pi terms
$\pi_{10} = \frac{Ta_o}{c}$		
$\pi_{11} = \frac{\tau a_o}{c}$		

Equation (8) can be simplified further by deleting constants. For all practical purposes,  $a_0$ ,  $\gamma_0$ , and  $P_0$  are constants, provided we restrict ourselves to muzzle blast under sea level ambient conditions and weak shocks without ionization or disassociation of the air. Neither of these conditions creates an invalid analysis when we delete  $a_0$ ,  $P_0$ , and  $\gamma_0$  from Eq. (8) and obtain:

$$\begin{bmatrix} \frac{Pc^3}{W} \\ \frac{T}{c} \\ \frac{\tau}{c} \end{bmatrix} = F\left(\frac{\ell}{c}, \frac{L}{c}, \frac{h}{c}, \frac{H}{c}, \theta, \alpha, \frac{c^3}{W}\right) \quad (9)$$

Equation (9) is the most general solution. It does present an eight-parameter space for curve fitting to experimental results. Further reductions in this experimental space and the development of curve fits must now be evaluated in separate discussions for pressure, duration, and time of arrival.

### Predicting Pressure

To predict maximum overpressure, we apply Eq. (9) in the format of:

$$\frac{Pc^2 \ell}{W} = F\left(\frac{L}{c}, \theta, \alpha\right) \quad (10)$$

Equation (1) requires four empirical observations before this approximate format can be substituted for Eq. (9). The first of these observations is that  $\frac{c^3}{W}$  is insignificant, the second is that  $\frac{Pc^3}{W}$  and  $\frac{\ell}{c}$  may be combined to form  $\frac{Pc^2 \ell}{W}$ , the third is that  $\frac{h}{c}$  is insignificant, and the fourth is that  $\frac{H}{c}$  is insignificant.

In 1970, Westine<sup>(4)</sup> demonstrated that  $\frac{c^3}{W}$  was insignificant for predicting pressure by plotting scaled pressure versus scaled position in space for a wide variety of weapons with different values of  $\frac{c^3}{W}$ . Because scaled pressure as a function of scaled position plotted as a single unique function, the results showed that  $\frac{c^3}{W}$  was unimportant. This observation

was made using 12 different weapon systems and included a range in  $\frac{c^3}{W}$  of from  $2.5 \times 10^{-7}$  to  $3,490 \times 10^{-7}$  in<sup>2</sup>/lb, a range of over three orders of magnitude. If the term  $\frac{c^3}{W}$  is rewritten as  $\frac{c}{W^{1/3}}$ , it can be interpreted as a statement of geometric similarity, and an analogy can be noted between it and  $\frac{r}{W^{1/3}}$  in Hopkinson's scaling law<sup>(7)</sup> for the blast field around an explosive charge. An alternate method of rewriting Hopkinson's law is to write  $\frac{r}{d}$ , where d is a charge diameter. Similarly,  $\frac{c}{W^{1/3}}$  can be thought of as  $\frac{c}{d}$  where d is a linear dimension associated with the energy release. Physically, the insignificance of this parameter implies that positions of interest in space are large relative to weapon caliber or relative to d. No contradictions for this empirical observation are to be found in Rock Island howitzer firings when the only change in XM204 tests is the energy release W because of a zone 5, zone 7, or zone 8 experiment.

Westine<sup>(9,10)</sup> also made the second empirical observation that scaled barrel length could be combined with the dependent normalized pressure term to form one term  $\frac{P c^2 l}{W}$ . Experimental tests on very short barrel weapons such as a 0.45 pistol and several 40-mm grenade launchers agreed with more conventional long barrel weapons only when these terms were combined. The difference in barrel length expressed in calibers for a 0.45 pistol and a 22 caliber long rifle is one order of magnitude of from approximately 8.8 to 92. Physically this second observation implies that  $\frac{P c^2 l}{W}$  can be thought of as pressure relative to an effective chamber pressure  $\frac{W}{c^2 l}$ , not actual chamber pressure but rather an effective one for an adiabatic process. No contradiction to this empirical observation exists from the Rock Island 105-mm howitzer firing with zone 7 propelling charges in the 26.6 caliber long M102 or the 33.9 caliber long XM204 guns.

The last two empirical observations concerning the insignificance of scaled muzzle height  $\frac{h}{c}$  and scaled location  $\frac{H}{c}$  on predicted pressure are somewhat harder to substantiate. All observations on the influence of these two parameters come from this study. Rock Island does report the muzzle height on their howitzer firings; however, the variation in this parameter is very limited. For 0° to 1.5° gun tube elevations, howitzer muzzle heights  $\frac{h}{c}$  only varied from 7.26 calibers to 9.86 calibers above the deck. In these same experiments, gauge locations  $\frac{H}{c}$  ranged from

7.26 to 13.07 to 18.87 calibers for the M102 tests, and 10.65 to 14.52 calibers for the XM102 experiments. Within such a limited range, no trend could be noted. In the Navy gun resume, Walther<sup>(2)</sup> does not report either muzzle locations or gauge heights. For the 3"/50 and 8"/55 Naval gun experiments, we know that these weapons were 17.4 calibers above the ground, as the senior author of this report witnessed these tests. With a wide variation in weapons of from 20 mm up through 8"/55 Naval guns, we can probably presume with some degree of assurance that muzzle heights and gauge positions varied. All comparison of scaled pressures for different weapon systems proceeded based upon the assumption that  $\frac{h}{c}$  and  $\frac{H}{c}$  were not highly significant.

An empirical curve fit for predicting peak pressure was developed based upon the validity of Eq. (10). Many plots of  $\frac{P c^2 \ell}{W}$  versus  $\frac{L}{c}$  for constant values of  $\theta$  and  $\alpha$  were made for many different weapon systems. Included in these plots were three different  $\alpha$  gun tube elevations of  $0^\circ$ ,  $16.8^\circ$ , and  $68.6^\circ$ . Scaled pressures were plotted along radial lines for  $15^\circ$  increments from  $\theta = 15$  to  $165$  degrees. Eight of these plots may be seen in Figures 8 as examples of this effort.

The first four graphs in Figure 8 are for  $\alpha = 0^\circ$ . If more than one gauge were on a pole in a howitzer experiment, the maximum pressures were averaged and plotted in these figures together with guns from Reference 2. The scatter is very little, especially when one considers the range of weapons which are involved. These results help to imply that  $\frac{h}{c}$  and  $\frac{H}{c}$  were relatively insignificant for this variation in test conditions.

The last four graphs in Figure 8 are for  $\alpha$ 's of  $16.8$  and  $68.6$  degrees. Many less data points are on these graphs because only the XM204 with zone 7 and 8 propelling charges were fired at these higher angles. No averaging of pressures for two gauges on a pole was performed in these tests, as we wished to emphasize that sometimes the lowest gauge recorded the highest pressure, whereas on other occasions the highest gauge recorded the highest pressure. In all the  $16.8$  and  $68.6$  gun tube experiments, gauge heights were either  $10.65$  calibers or  $14.52$  calibers off the ground; hence, the variation in  $\frac{h}{c}$  is small. As can be seen in Figures 8, scaled pressures also correlate for the higher gun tube elevations, but peak pressure is a strong function of  $\alpha$ .

The straight lines through the data points in Figures 8 are the curve fits to these data given by Eq. (1) in Section III. Equation (1) and

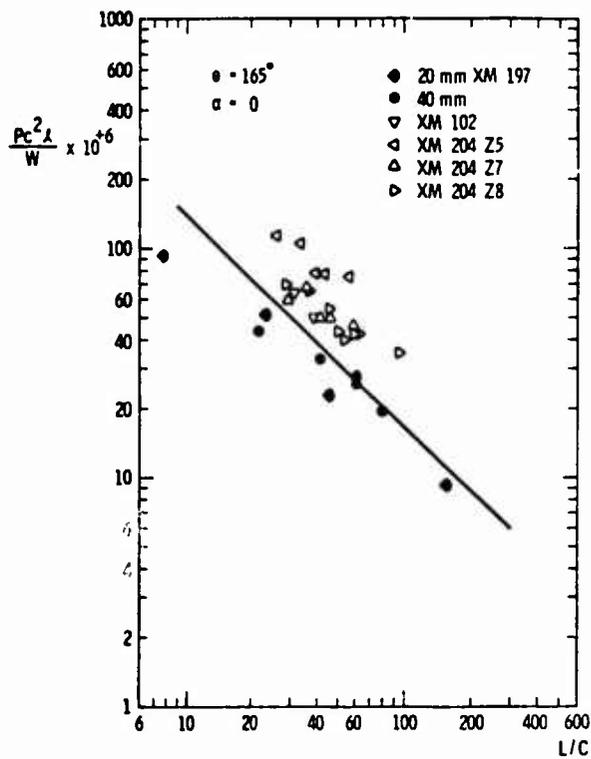
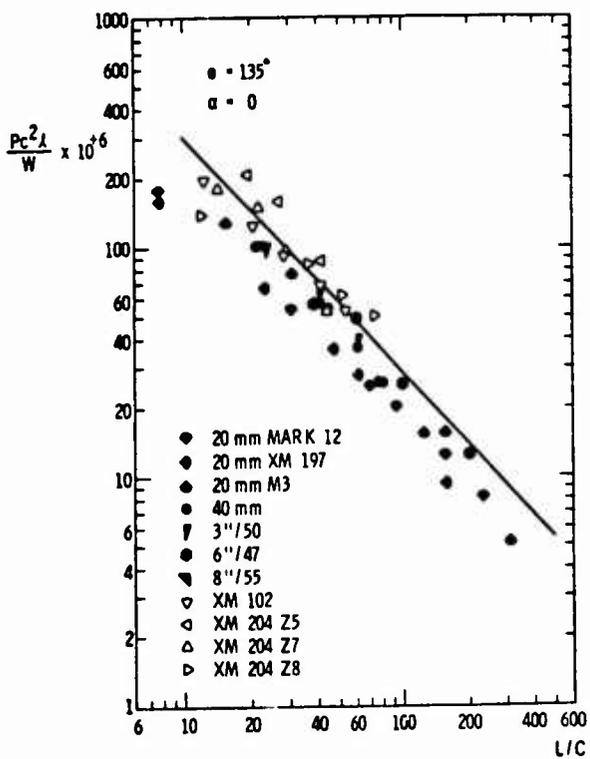
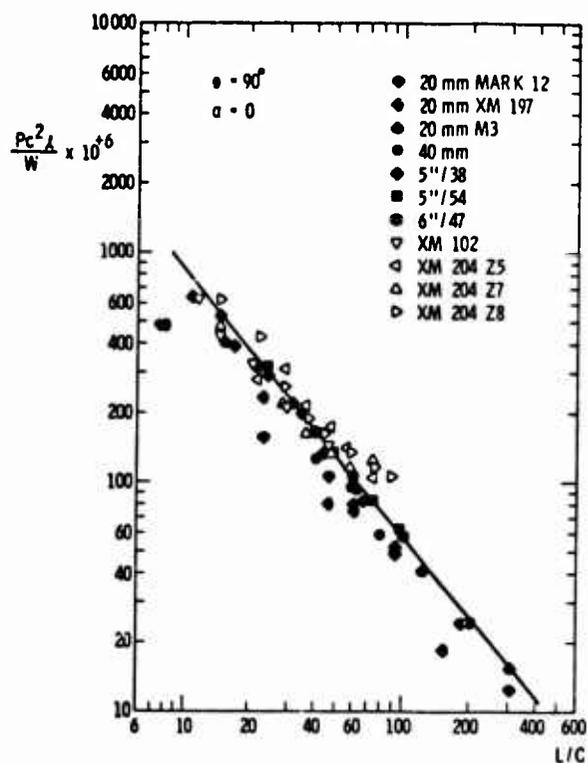
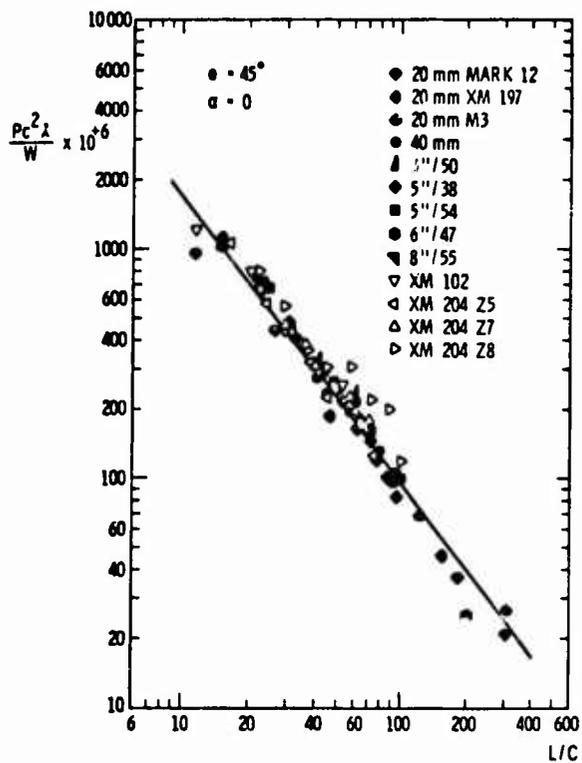


FIGURE 8. SCALED PRESSURE VS SCALED STANDOFF DISTANCE

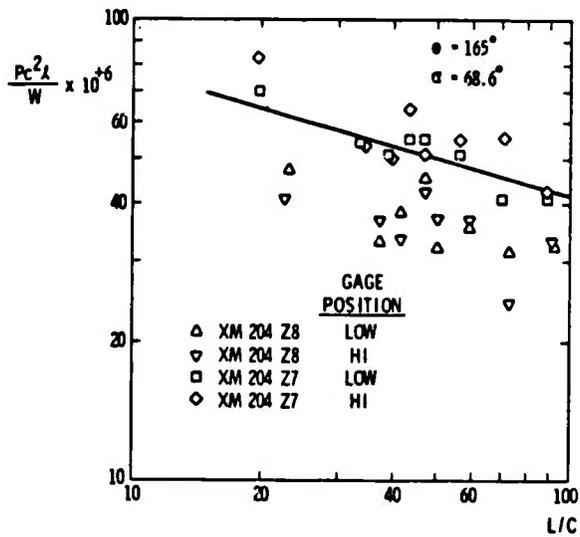
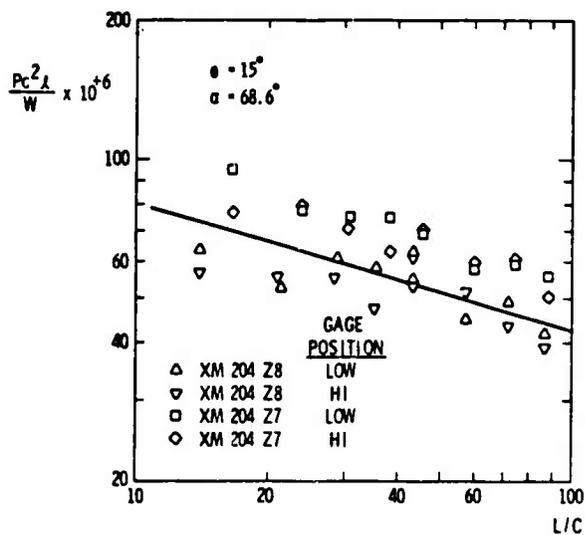
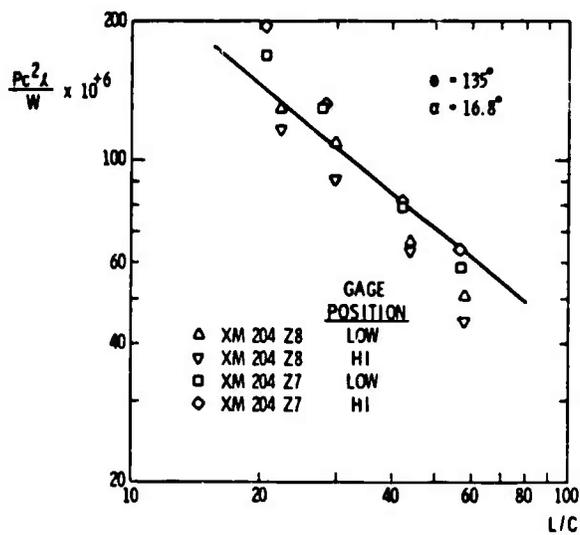
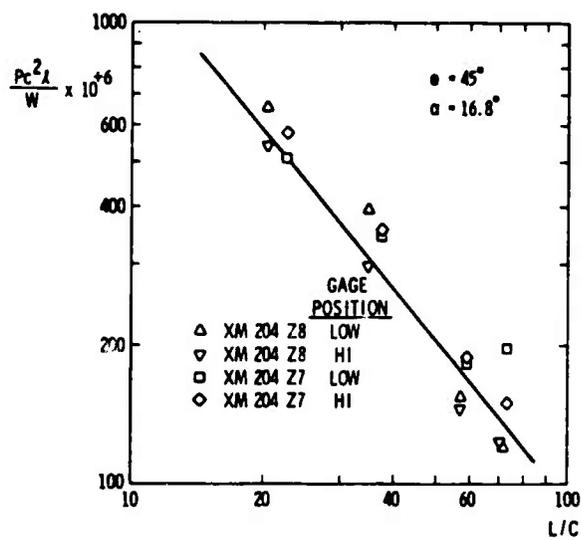


FIGURE 8 (CONT'D)

its numerical coefficients given in Table A constitute an explicit expression for Eq. (10). As can be seen, results are fairly accurate. One standard deviation for these data points about the curve fit can be found in Table A. A higher standard deviation exists for  $\alpha = 0$  than for  $\alpha = 16.8$  or  $68.6$  degrees because the curve fit is over a larger variation in  $\frac{L}{c}$  for the lowest angle and because some uncertainty exists in some results from Reference 2. Scatter may appear to be larger in Figures 8 for larger angles, but this result is deceiving, as  $\frac{P c^2 \ell}{W}$  covers three rather than one order of magnitude for gun tube elevations of 0 degrees.

The method used to determine the coefficients of Eq. (1) is known as the method of successive linearizations.<sup>(11)</sup> To simplify the procedure, the pressure equation was transformed by taking the natural logarithm of both sides of the equation. The resulting Eq. (11) is nonlinear, as long as the parameters  $\gamma$  and  $\delta$  are unknown. Careful observation of the pressure plots in Figures 8 resulted in approximate values of these two parameters. Substituting the initial

$$\ln \left( \frac{P c^2 \ell}{W} \right) = \xi + \epsilon \cos \left( \frac{\theta}{\gamma} - \delta \right) + \left[ \beta + \psi \cos \left( \frac{\theta}{\gamma} - \delta \right) \right] \ln \frac{c}{L} \quad (11)$$

guesses for  $\gamma$  and  $\delta$  into Eq. (11) along with experimentally measured values of  $\frac{c}{L}$ ,  $\frac{P c^2 \ell}{W}$  and  $\theta$  allows the following matrix equation to be written:

$$\begin{bmatrix} \ln(\bar{P}_1) \\ \ln(\bar{P}_2) \\ \vdots \\ \ln(\bar{P}_N) \end{bmatrix} = \begin{bmatrix} 1.0 & , & \ln\left(\frac{c}{L_1}\right) & , & \cos\left(\frac{\theta_1}{\gamma^\circ} - \delta^\circ\right) & , & \ln\left(\frac{c}{L_1}\right) & \cos\left(\frac{\theta_1}{\gamma^\circ} - \delta^\circ\right) \\ 1.0 & , & \ln\left(\frac{c}{L_2}\right) & , & \cos\left(\frac{\theta_2}{\gamma^\circ} - \delta^\circ\right) & , & \ln\left(\frac{c}{L_2}\right) & \cos\left(\frac{\theta_2}{\gamma^\circ} - \delta^\circ\right) \\ \vdots & & \vdots & & \vdots & & \vdots & \vdots \\ 1.0 & , & \ln\left(\frac{c}{L_N}\right) & , & \cos\left(\frac{\theta_N}{\gamma^\circ} - \delta^\circ\right) & , & \ln\left(\frac{c}{L_N}\right) & \cos\left(\frac{\theta_N}{\gamma^\circ} - \delta^\circ\right) \end{bmatrix} \begin{bmatrix} \xi^\circ \\ \epsilon^\circ \\ \beta^\circ \\ \psi^\circ \end{bmatrix} \quad (12)$$

where

$N$  = the number of experimental observations

$$\bar{P}_1 = \left( \frac{P c^2 \ell}{W} \right)_i = \text{nondimensionalized experimental pressures}$$

and the superscripts on the Greek letters indicate that  $\gamma^\circ$ ,  $\delta^\circ$ ,  $\xi^\circ$ ,  $\epsilon^\circ$ ,  $\beta^\circ$ , and  $\Psi^\circ$  are initial estimations to the coefficients of Eq. (1). Equation (12) can be written more concisely if we let  $[\hat{P}]$

$$[\hat{P}] = [C][b^\circ] \quad (13)$$

represent the  $1 \times N$  matrix of nondimensional pressures,  $[C]$  represents the  $4 \times N$  scaled position matrix and  $[b^\circ]$  represent the  $1 \times N$  matrix of undetermined coefficients. Equation (13) can be solved by premultiplying both sides of the equation by  $\left([C]^T[C]\right)^{-1}[C]^T$ . Equation (14) is the resulting matrix equation. In order to obtain a more exact value for the

$$[b^\circ] = \left([C]^T[C]\right)^{-1}[C]^T[\hat{P}] \quad (14)$$

coefficients of the pressure equation, expand Eq. (11) in a Taylor series, about the point  $b^\circ = (\xi^\circ, \epsilon^\circ, \beta^\circ, \Psi^\circ, \gamma^\circ, \delta^\circ)$  and keep only the first order derivatives.

$$\begin{aligned} \hat{P}(b) = \hat{P}(b^\circ) &+ \left. \frac{\partial \hat{P}}{\partial \xi} \right|_{\xi^\circ} (\xi - \xi^\circ) + \left. \frac{\partial \hat{P}}{\partial \epsilon} \right|_{\epsilon^\circ} (\epsilon - \epsilon^\circ) + \left. \frac{\partial \hat{P}}{\partial \beta} \right|_{\beta^\circ} (\beta - \beta^\circ) + \left. \frac{\partial \hat{P}}{\partial \Psi} \right|_{\Psi^\circ} (\Psi - \Psi^\circ) \\ &+ \left. \frac{\partial \hat{P}}{\partial \gamma} \right|_{\gamma^\circ} (\gamma - \gamma^\circ) + \left. \frac{\partial \hat{P}}{\partial \delta} \right|_{\delta^\circ} (\delta - \delta^\circ) \end{aligned} \quad (15)$$

Expanding the derivatives and collecting like terms results in Eq. (16):

$$\begin{aligned} \hat{P}(b) - \hat{P}(b^\circ) &= (\xi - \xi^\circ) + (\epsilon - \epsilon^\circ) \cos \left( \frac{\theta}{\gamma} - \delta \right) + \ln \left( \frac{c}{L} \right) (\beta - \beta^\circ) + (\Psi - \Psi^\circ) \ln \\ &\cdot \left[ \frac{c}{L} \right] \cos \left( \frac{\theta}{\gamma} - \delta \right) + \frac{\theta}{(\gamma^\circ)^2} \left[ \beta^\circ + \Psi^\circ \ln \left( \frac{c}{L} \right) \right] \sin \left( \frac{\theta}{\gamma^\circ} - \delta^\circ \right) (\gamma - \gamma^\circ) \\ &+ \left[ \beta^\circ + \Psi^\circ \ln \left( \frac{c}{L} \right) \right] \sin \left( \frac{\theta}{\gamma^\circ} - \delta^\circ \right) (\delta - \delta^\circ) \end{aligned} \quad (16)$$

Again, this can be written in matrix notation as

$$\begin{bmatrix} \hat{P}_1(b) - \hat{P}_1(b^0) \\ \vdots \\ \hat{P}_N(b) - \hat{P}_N(b^0) \end{bmatrix} = \begin{bmatrix} 1.0, \ln\left(\frac{c}{L}\right)_1, \cos \eta_1^0, \ln\left(\frac{c}{L}\right)_1 \cos \eta_1^0, \\ \vdots \\ 1.0, \ln\left(\frac{c}{L}\right)_N, \cos \eta_N^0, \ln\left(\frac{c}{L}\right)_N \cos \eta_N^0, \end{bmatrix} \begin{bmatrix} \frac{\theta_1}{(\gamma^0)^2} \left[ \beta^0 + \psi^0 \ln\left(\frac{c}{L}\right)_1 \right] \sin \eta_1^0, & \left[ \beta^0 + \psi^0 \ln\left(\frac{c}{L}\right)_1 \right] \sin \eta_1^0 \\ \vdots \\ \frac{\theta_N}{(\gamma^0)^2} \left[ \beta^0 + \psi^0 \ln\left(\frac{c}{L}\right)_1 \right] \sin \eta_N^0, & \left[ \beta^0 + \psi^0 \ln\left(\frac{c}{L}\right)_N \right] \sin \eta_N^0 \end{bmatrix} \begin{bmatrix} \epsilon - \epsilon^0 \\ \beta - \beta^0 \\ \psi - \psi^0 \\ \gamma - \gamma^0 \\ \delta - \delta^0 \end{bmatrix} \quad (17)$$

Equation (17) can now be solved in the same manner as Eq. (14). The new approximations to the pressure coefficients are determined by adding the solution of Eq. (17) to the previous guess:

$$b_i^1 = b_i^0 + (b_i - b_i^0) \quad (18)$$

Finally, if the difference  $\left| \frac{b_i^1 - b_i^0}{b_i^0} \right|$  is not arbitrarily small, replace  $b_i^0$

by  $b_i^1$  and begin another linearization with Eq. (17). By using the method briefly described in this paragraph the coefficients summarized in Table A were obtained. The standard deviation reported for each gun tube elevation was obtained by ratioing the experimentally observed nondimensionalized pressures with the calculated scaled pressures.

The Appendix to this report contains computer printouts of all measured average pressures for Rock Island M102 and XM204 experiments. All pressures for other weapon systems used in this curve fit are found in tables from Reference 2.

### Predicting Duration

To predict total positive duration ( $N = 1.0$ ), we apply Eq. (9) in the format of:

$$\frac{T \ell^{5/12}}{W^{1/3} c^{5/12}} = F\left(\frac{L}{c}, \theta, \alpha\right) \quad (19)$$

Equation (19) requires three empirical observations before this approximate format can be substituted for Eq. (9). The first of these observations is that  $\frac{T}{c}$ ,  $\frac{c^3}{W}$ , and  $\frac{\ell}{c}$  combine to form  $\frac{T \ell^{5/12}}{W^{1/3} c^{5/12}}$ , the second is that  $\frac{h}{c}$  is insignificant, and the third is that  $\frac{H}{c}$  is insignificant. All three of these observations were made in this study using data from Rock Island howitzer test firings. Although some durations were reported in a few Naval gun firings, these times could not be used, as they are not measured on the same bases as the howitzer records. For all howitzer blast records, the 10% or 20 dB positive envelope was established, and durations were the sum of all times for compressive incident and reflected waves whose amplitude exceeded that limit.

Figures 9 show eight plots of scaled duration  $\frac{T \ell^{5/12}}{W^{1/3} c^{5/12}}$  versus scaled standoff  $\frac{L}{c}$  for various constant values of  $\theta$  and  $\alpha$ . For gun tube elevations of 0 degrees, test results include data for the M102 firing a zone 7, XM204 firing a zone 5, XM204 firing a zone 7, and XM204 firing a zone 8 propelling charge. At the two higher gun tube elevation angles, 16.8° and 68.6°, data only exist for the XM204 firing either a zone 7 or zone 8 round. Different orientations of the symbols in Figures 8 do note whether the gauge measuring the blast wave was on the lowest, middle, or highest pole position. The details of gauge height and muzzle height locations have already been presented in the blast overpressure discussion. As can be seen in Figures 9, no systematic trend appears to indicate that scaled time should be a function of scaled gauge height  $\frac{H}{c}$ . We also presume that scaled muzzle height  $\frac{h}{c}$  will have a similar negligible influence.

The terms  $\frac{T}{c}$ ,  $\frac{c^3}{W}$ , and  $\frac{\ell}{c}$  were combined to form  $\left(\frac{T}{c}\right) \cdot \left(\frac{c^3}{W}\right)^{1/3} \cdot \left(\frac{\ell}{c}\right)^{5/12}$  because of observations made with the zero degree howitzer firings. The only change in all zero degree, zone 5, zone 7, or zone 8,

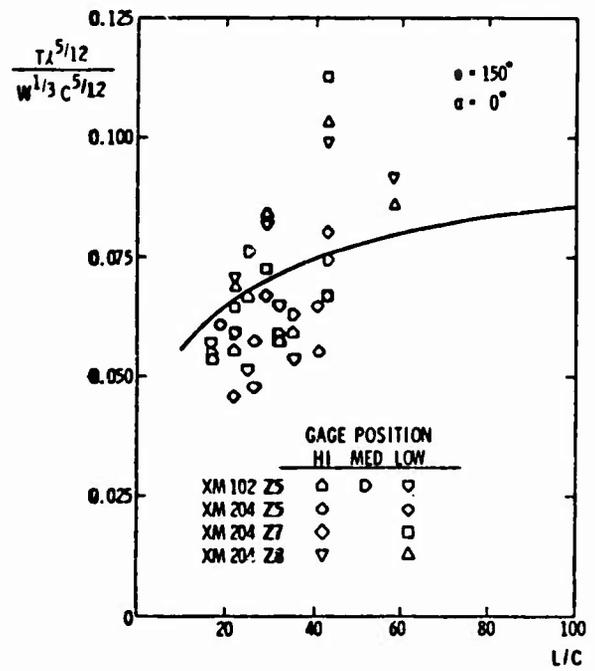
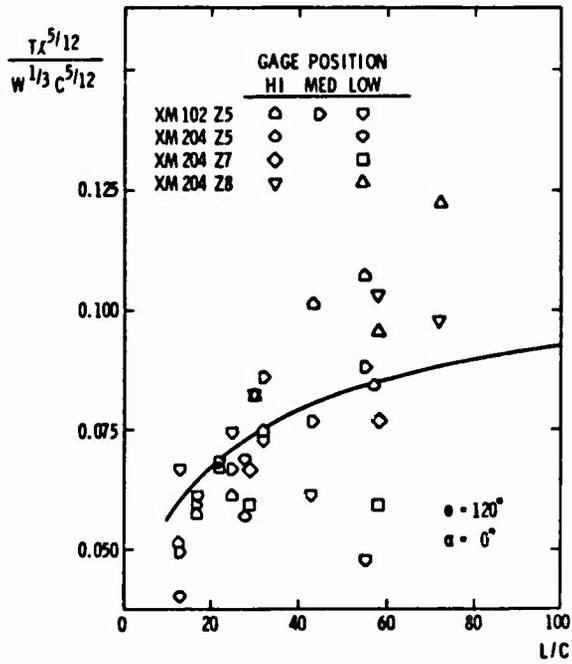
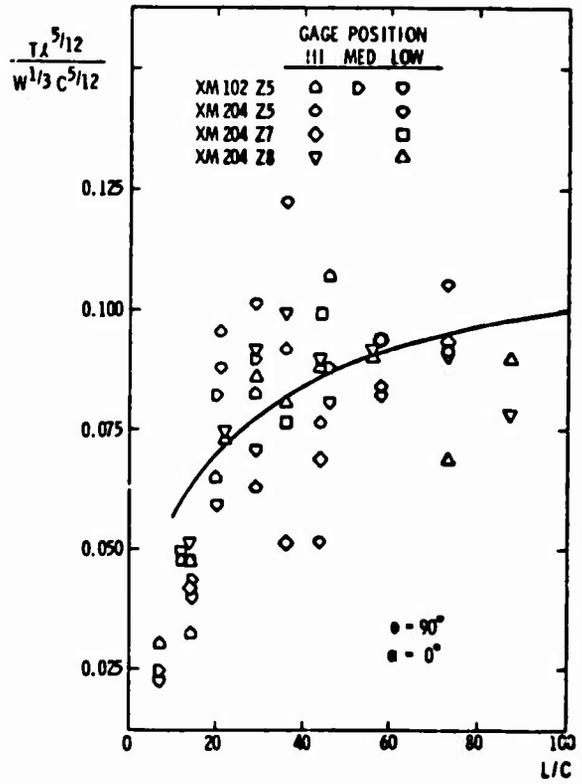
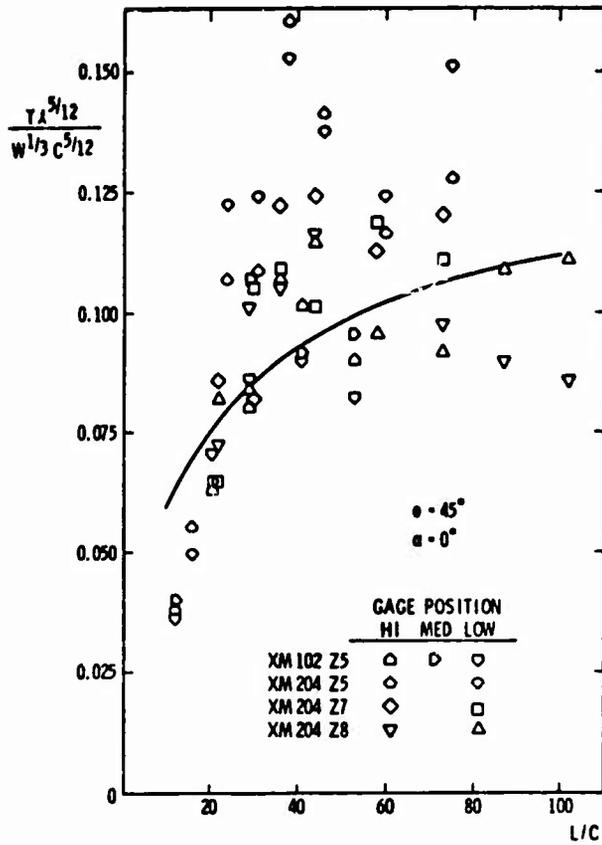


FIGURE 9. SCALED DURATION VS SCALED STANDOFF DISTANCE

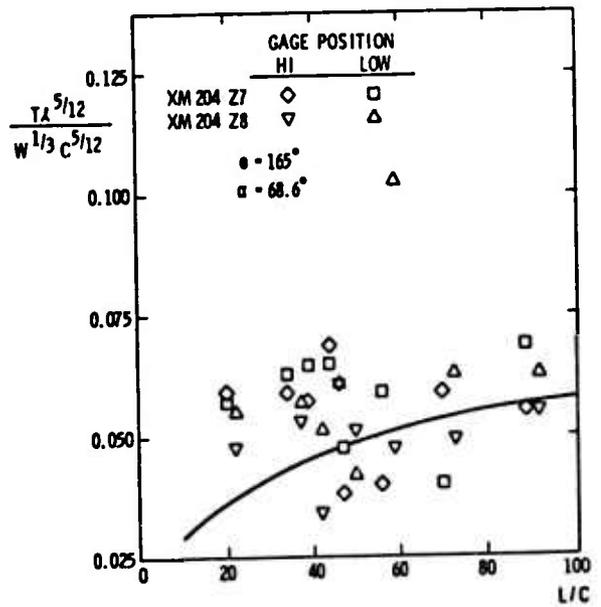
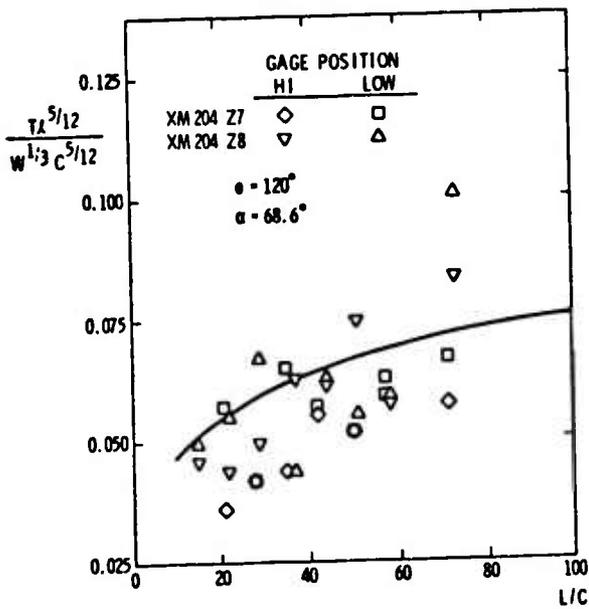
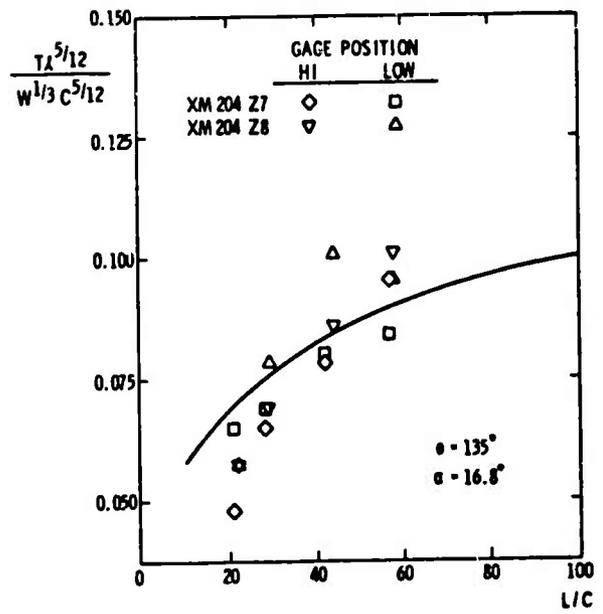
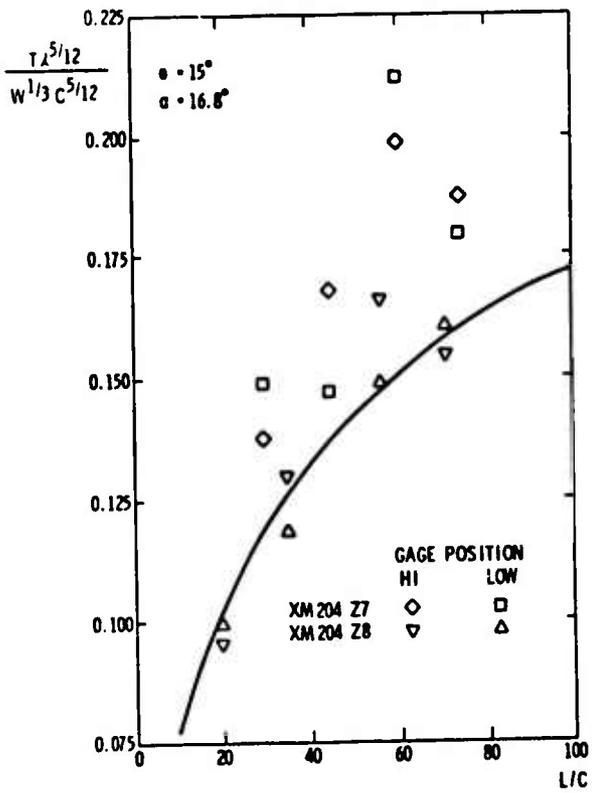


FIGURE 9 (CONT'D)

XM204 howitzer firings was the  $W$  parameters in the  $\frac{c^3}{W}$  term. Duration data points from tests on these three weapon systems appeared to correlate best when  $\frac{T}{c}$  and  $\frac{c^3}{W}$  were empirically combined to form  $\frac{T}{W^{1/3}}$ . Similarly, the major change in zone 7 firings with the XM204 and zone 7 firings with the M102, 105-mm howitzer was in the term  $\frac{\ell}{c}$ . The M102 has a barrel 110 in. long, whereas the XM204 has a barrel 140 in. long. This is not a large change in  $\frac{\ell}{c}$ , but considering that observations were made on eleven different  $\alpha = 0$  radial lines, the data were sufficient to imply that  $\frac{T}{W^{1/3}}$  and  $\frac{\ell}{c}$  should be combined into  $\frac{T \ell^{5/12}}{W^{1/3} c^{5/12}}$ . The result of these empirical observations is that Eq. (9) becomes Eq. (19).

The scatter seen in Figures 9 does appear to be very large, but before drawing such a conclusion, remember that Figures 9 are plotted on very enlarged geometric scales, whereas Figures 8 for pressure were plotted on log-log paper. The continuous lines seen in the various Figures 9 are the equations obtained from the empirical curve fit to these data. Table C and Eq. (5) from Section II are the coefficients and the functional format for Eq. (19) used to predict scaled duration as a function of  $\frac{L}{c}$ ,  $\theta$ , and  $\alpha$ . We have also demonstrated that, for all practical purposes, one standard deviation for scaled duration is essentially 25%, the same as one standard deviation for predicting scaled pressure.

The method used to determine the coefficients in Eq. (5) from the duration data is similar to the curve-fitting technique used for pressure. Equation (5) was first transposed into Eq. (20) by multiplying both sides of the equation with  $N = 1.0$  by  $\left(d + \frac{L}{c}\right)$ .

$$\left(\frac{T \ell^{5/12}}{W^{1/3} c^{5/12}}\right) \left(d + \frac{L}{c}\right) = \left(a + b \theta\right) \frac{L}{c} + \left(e - f \theta^2\right) \left(d + \frac{L}{c}\right) \quad (20)$$

This equation can easily be solved for the coefficients  $a$ ,  $b$ ,  $e$ , and  $f$  providing  $d$  is known. Observation of the duration plots, Figures 9, showed that variations in the  $d$  caused no significant coefficient variations in predicted scaled durations. Once the value of the  $d$  coefficient was set, Eq. (20) was written in matrix notation as:

$$\begin{bmatrix} \bar{T}_1 \left( d + \frac{L}{c_1} \right) \\ \bar{T}_2 \left( d + \frac{L}{c_2} \right) \\ . \\ \bar{T}_N \left( d + \frac{L}{c_N} \right) \end{bmatrix} = \begin{bmatrix} \frac{L}{c_1} & \frac{L}{c_1} \theta_1 & d + \frac{L}{c_1} & - \left( d + \frac{L}{c_1} \right) \theta_1^2 \\ \frac{L}{c_2} & \frac{L}{c_2} \theta_2 & d + \frac{L}{c_2} & - \left( d + \frac{L}{c_2} \right) \theta_2^2 \\ . & . & . & . \\ \frac{L}{c_N} & \frac{L}{c_N} \theta_N & d + \frac{L}{c_N} & - \left( d + \frac{L}{c_N} \right) \theta_N^2 \end{bmatrix} \begin{bmatrix} a \\ b \\ e \\ f \end{bmatrix} \quad (21)$$

or more concisely:

$$\left[ \bar{T} \left( d + \frac{L}{c} \right) \right] = [C] [b] \quad (22)$$

where

$[\bar{T}]$  is the  $1 \times N$  matrix of experimentally observed scaled durations

$[C]$  is the  $4 \times N$  scaled position matrix

and  $[b]$  is the  $1 \times N$  matrix of undetermined coefficients.

Finally, Eq. (22) can be solved for the undetermined coefficients by pre-multiplying both sides of Eq. (22) by  $\left( [C]^T [C] \right)^{-1} [C]^T$  to obtain:

$$[b] = \left( [C]^T [C] \right)^{-1} [C]^T \left[ \bar{T} \left( d + \frac{L}{c} \right) \right] \quad (23)$$

The coefficients found in Table C were obtained from Eq. (23). Several runs were made with varying values of  $d$ ; in no case was the standard deviation more than 0.008 higher than the value reported in Table C. This result substantiates the observation that predicted scaled durations are relatively insensitive to variations in the  $d$  coefficient.

All average values for durations from Rock Island Arsenal howitzer firings and used in these curve fits can be found in the Appendix to this report.

## Predicting Time of Arrival

Time of arrival for reflected blast waves relative to incident blast waves is not of any importance to the latest hearing loss standard provided this standard is interpreted literally. Unfortunately, we needed to develop a relationship for time of arrival because of the factor  $N$  used to estimate negative blast wave durations from durations for positive or compressive waves. In Section II an  $N$  of 5.0 was used whenever the triple point associated with the formation of the Mach stem passed below the point of interest, and an  $N$  of 10.0 was used whenever the triple point passed over the point of interest.

Equation (9) as developed in the model is the complete equation in functional format for predicting time of arrival. The parameters  $\frac{h}{c}$  and  $\frac{H}{c}$  for height of gun muzzle and point of interest over the ground are significant parameters for predicting time of arrival, as the major reflecting surface is the ground. This result is unlike that used in the prediction of pressure or duration. Also unlike the results obtained for pressure and durations, the parameters  $\frac{l}{c}$  and  $\frac{c^3}{W}$  become insignificant whenever time of arrival is predicted.

After the observer has removed himself 10 or more calibers from a muzzle blast, the maximum overpressures are usually 6 psi or less. Such a domain is a region of weak shocks with fronts propagating at a velocity only slightly greater than that for the speed of sound. In this domain, the size of the energy release and rate at which it is released, phenomena associated with  $\frac{c^3}{W}$  and  $\frac{l}{c}$ , do not influence the velocity of propagation. Because standoff distances of interest to us are greater than 10 calibers, we are justified in treating  $\frac{l}{c}$  and  $\frac{c^3}{W}$  as insignificant parameters. This manipulation reduces Eq. (9) for scaled arrival time to Eq. (24).

$$\frac{\tau}{c} = F\left(\frac{h}{c}, \frac{H}{c}, \frac{L}{c}, \alpha, \theta\right) \quad (24)$$

Equation (24) can be reduced further to Eq. (25) by considering the respective lengths of the paths that incident and reflected waves travel.

$$\frac{\frac{\tau}{c}}{\left(\frac{h}{c}\right)\left(\frac{H}{c}\right)} = F\left(\frac{L}{c}, \alpha, \theta\right) \quad (25)$$

The straight line path in calibers from a gun muzzle to a transducer location is given by  $\sqrt{\left(\frac{L}{c}\right)^2 + \left(\frac{h}{c} - \frac{H}{c}\right)^2}$ . A reflected wave will strike the ground and reflect along a path such that incident and reflected angles of reflection are numerically identical. The length of the path in calibers for such a reflected wave is given by  $\sqrt{\left(\frac{L}{c}\right)^2 + \left(\frac{h}{c} + \frac{H}{c}\right)^2}$ . Because weak shocks, as have already been discussed, travel at essentially the speed of sound  $a_0$ , the scaled time of arrival  $\frac{\tau a_0}{c}$  will be equal to the difference in calibers for the lengths of these paths. On the other hand,  $a_0$  is a constant which can be treated as an abstract nondimensional coefficient; hence, we can write after dropping  $a_0$  and factoring out  $\left(\frac{L}{c}\right)$  from each expression for the length of the path.

$$\left(\frac{\tau}{c}\right) \alpha \left(\frac{L}{c}\right) \left[ \sqrt{1 + \left(\frac{h}{L} + \frac{H}{L}\right)^2} - \sqrt{1 + \left(\frac{h}{L} - \frac{H}{L}\right)^2} \right] \quad (26)$$

Usually the height of gun muzzles and gauge locations are small relative to the standoff distances. This observation permits us to use the binomial expansion for expanding the terms under both square root signs. The results of this expansion are:

$$\left(\frac{\tau}{c}\right) \alpha \left(\frac{L}{c}\right) \left[ 1 + \frac{1}{2} \frac{h^2}{L^2} + \frac{h}{L} \frac{H}{L} + \frac{1}{2} \frac{H^2}{L^2} - 1 - \frac{1}{2} \frac{h^2}{L^2} + \frac{h}{L} \frac{H}{L} - \frac{1}{2} \frac{H^2}{L^2} + \dots \right] \quad (27)$$

Dividing Eq. (27) through by  $\left(\frac{h}{c}\right) \left(\frac{H}{c}\right)$  and ignoring higher terms in the expansion gives:

$$\frac{\frac{\tau}{c}}{\left(\frac{h}{c}\right) \left(\frac{H}{c}\right)} \alpha \left[ 2 \left(\frac{c}{L}\right) + \dots \right] \quad (28)$$

Because Eq. (28) shows that the terms  $\frac{\tau}{c}$ ,  $\frac{h}{c}$ , and  $\frac{H}{c}$  combine to form

$\frac{\frac{\tau}{c}}{\left(\frac{h}{c}\right) \left(\frac{H}{c}\right)}$ , we are justified in using Eq. (25) as an approximation to Eq. (24).

The functional format given by Eq. (25) is the relationship used in developing empirical curve fits to test results from 105-mm howitzer firings.

Figures 10 show example plots of scaled time of arrival  $\frac{\tau}{c} \left( \frac{h}{c} \right) \left( \frac{H}{c} \right)$  versus scaled standoff  $\frac{L}{c}$  for various constant values of  $\theta$  and  $\alpha$ . Because all time of arrival data come from the same series of experiments as duration data, the same variations are evident in time of arrival as in durations. Once again, orientation of the symbol denotes height of gauge. The details of gauge height and muzzle height locations have already been presented in the blast overpressure discussion. Much less scatter is evident in time of arrival results than in other measurements. As can be seen in Figures 10, the data do form nearly a single relationship even on these plots with geometric scales. At standoff distances greater than 70 or 80 calibers on the  $\alpha = 0$  plots, the times of arrival are zero, as incident and reflected waves have coalesced to form a Mach wave. At the larger angles of gun tube elevation, gauges were not placed far enough away from the muzzle to record blast waves in the Mach stem. This limitation prevents us from extending curve fits to time of arrival so triple point location can be predicted for gun tube elevation angles of 16.8 and 68.6 degrees.

The equation used to curve fit a functional format for Eq. (25) to test data is:

$$\frac{\tau}{c} \left( \frac{h}{c} \right) \left( \frac{H}{c} \right) = (S_1 + S_2 \theta) + (S_3 + S_4 \theta) \left( \frac{L}{c} \right) + (S_5 + S_6 \theta) \left( \frac{L}{c} \right)^2 \quad (29)$$

where

$S_i$  = coefficients which are functions of  $\alpha$ .

Table F contains the numerical values for the time of arrival coefficients and the standard deviation which is obtained using these coefficients. In using Eq. (29), all angles must be in radians, time in milliseconds, and distance in feet. One standard deviation for using Eq. (29) is on the order of 10 to 15%. Two different values for standard deviations are presented for zero degree gun tube elevation angles, because the larger value is a misleading one based upon the technique used to determine  $\sigma$ . After obtaining coefficients from a curve fit,  $\sigma$  was computed by dividing computed values into experimentally measured values of scaled time. This procedure creates a large sample with a mean of approximately 1.0; however, large standard deviations result if many numerically small values of scaled time are in the distribution. Whenever numerically small numbers near zero are divided into observed results, the percentage error becomes

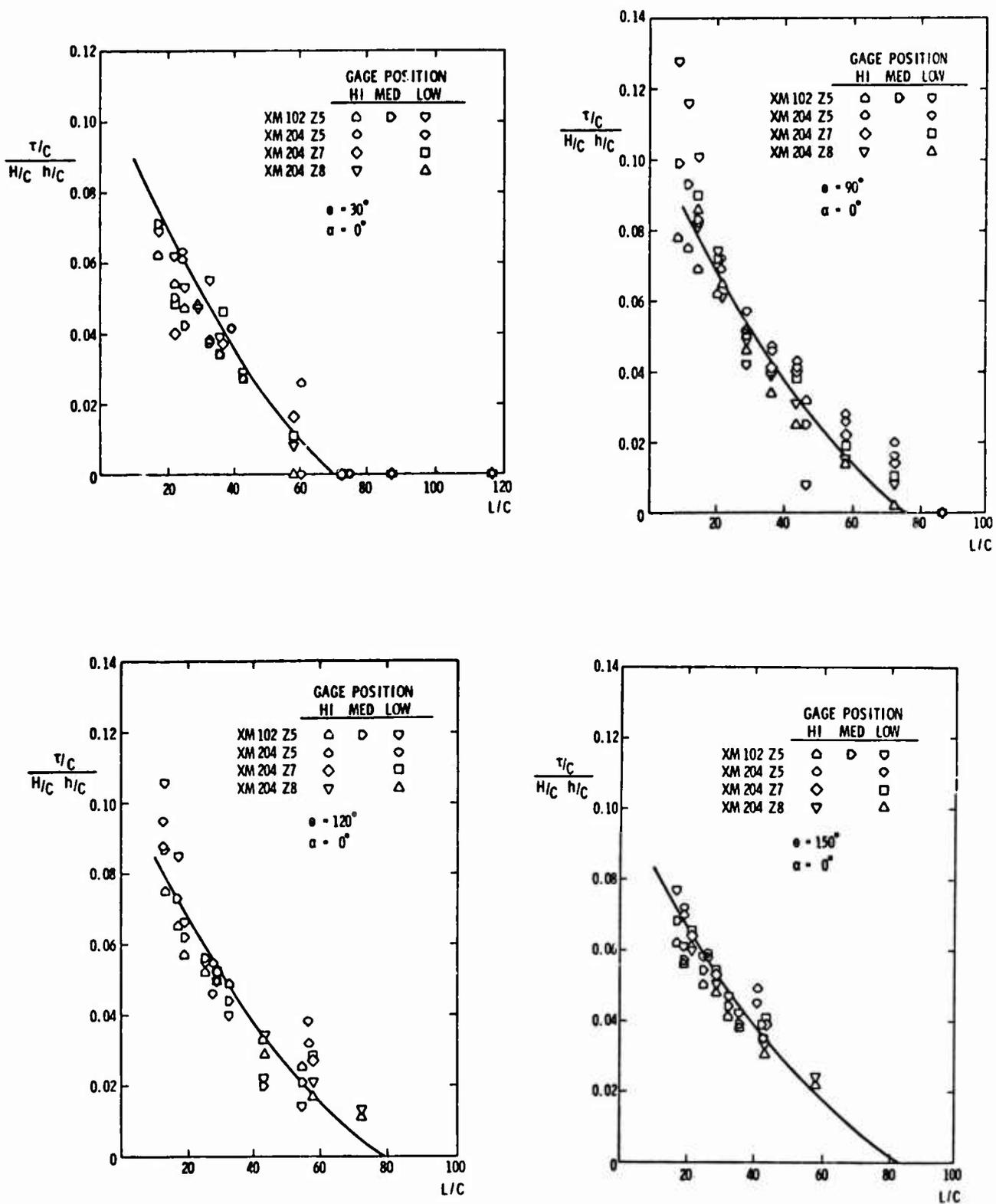


FIGURE 10. SCALED TIME OF ARRIVAL VS SCALED STANDOFF DISTANCE

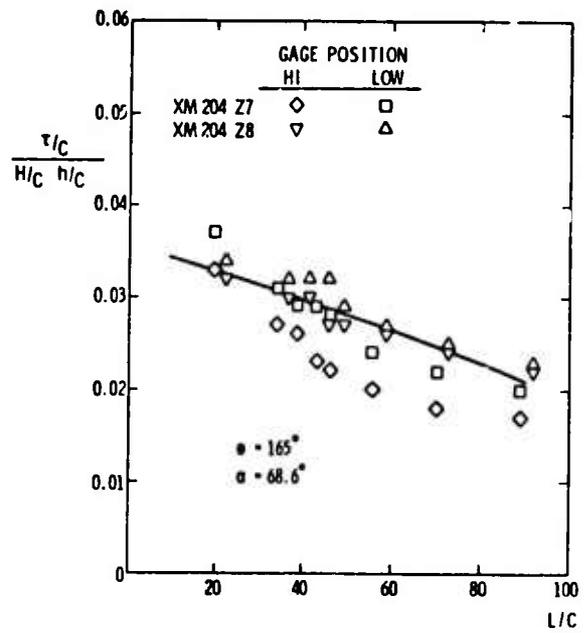
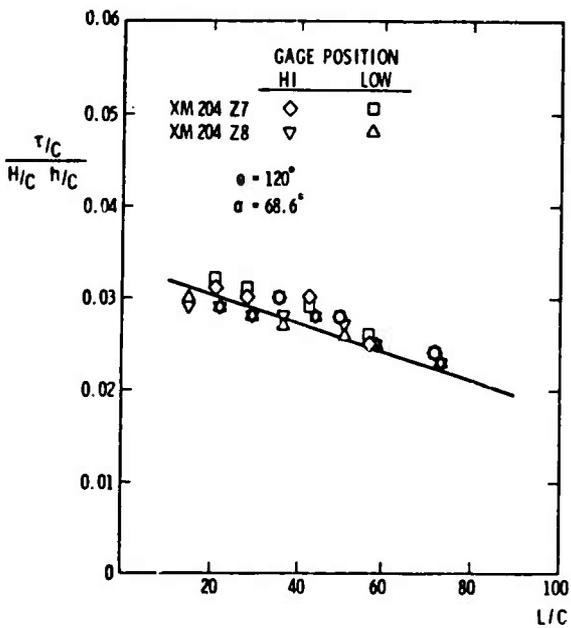
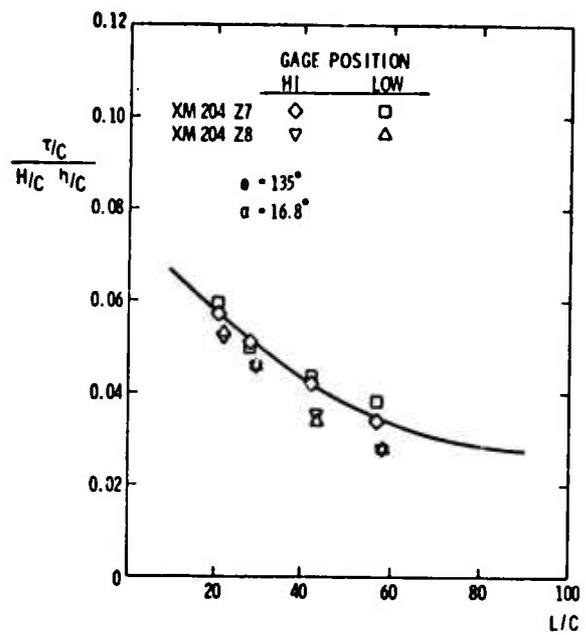
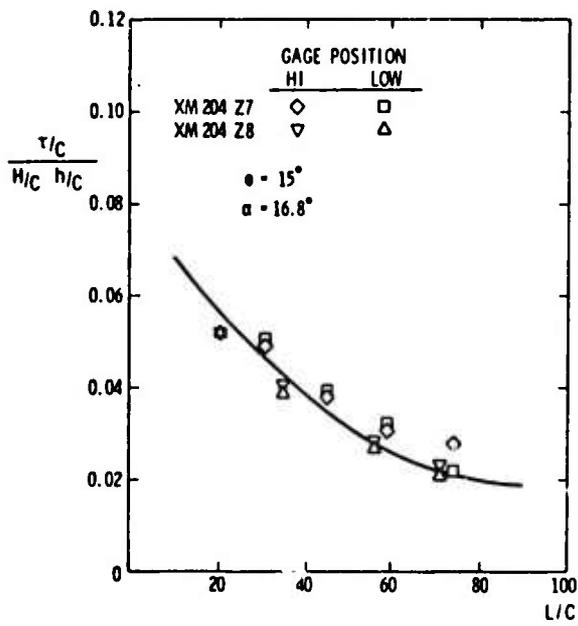


FIGURE 10 (CONT'D)

TABLE F. TIME OF ARRIVAL COEFFICIENTS

$\alpha(\text{radians})$	$\sigma$	$S_1$	$S_2$	$S_3$	$S_4$	$S_5$	$S_6$
0	31.1%/ 22.1%	0.1148	$-5.431 \times 10^{-3}$	$-2.452 \times 10^{-3}$	$2.373 \times 10^{-4}$	$1.117 \times 10^{-5}$	$-1.432 \times 10^{-6}$
0.293	10.3%	0.08151	$-1.985 \times 10^{-3}$	$-1.401 \times 10^{-3}$	$1.439 \times 10^{-4}$	$7.693 \times 10^{-6}$	$-8.461 \times 10^{-7}$
1.197	7.6%	0.02676	$3.101 \times 10^{-3}$	$-1.863 \times 10^{-4}$	$1.857 \times 10^{-5}$	$6.116 \times 10^{-7}$	$-3.276 \times 10^{-7}$

large, even if the error is small in absolute terms. The second standard deviation in Table F for  $\alpha = 0^\circ$  was obtained by ignoring all data with

scaled time  $\frac{\tau}{c}$  less than 0.01 and is significantly smaller.  
 $\left(\frac{h}{c}\right) \left(\frac{H}{c}\right)$

The solid lines passing through the test data in Figures 10 are the appropriate form of the curve fit, Eq. (29). As can be seen visually, results are excellent. Equation (29) must be used for values of  $\frac{L}{c}$  between 0 and the lowest positive root when scaled time equals zero. Negative values for  $\frac{\tau}{c}$  are not valid and mean that  $\tau = 0$  with the blast wave  
 $\left(\frac{h}{c}\right) \left(\frac{H}{c}\right)$

being in the Mach stem. By setting scaled time equal to zero for  $\alpha = 0$ , and curve fitting results to predictions along eleven different radial lines, we obtained the approximate relationship, Eq. (6), presented in Section II for location of the triple point.

The curve fit itself for obtaining coefficients to Eq. (29) is a least squares procedure. Equation (29) was written in matrix notation as:

$$\begin{bmatrix} \bar{\tau}_1 \\ \bar{\tau}_2 \\ \cdot \\ \cdot \\ \cdot \\ \bar{\tau}_N \end{bmatrix} = \begin{bmatrix} 1.0, \theta_1, \left(\frac{L}{c}\right)_1, \left(\theta \frac{L}{c}\right)_1, \left(\frac{L}{c}\right)_1^2, \left(\theta \frac{L^2}{c^2}\right)_1 \\ 1.0, \theta_2, \left(\frac{L}{c}\right)_2, \left(\theta \frac{L}{c}\right)_2, \left(\frac{L}{c}\right)_2^2, \left(\theta \frac{L^2}{c^2}\right)_2 \\ \cdot \\ \cdot \\ \cdot \\ 1.0, \theta_N, \left(\frac{L}{c}\right)_N, \left(\theta \frac{L}{c}\right)_N, \left(\frac{L}{c}\right)_N^2, \left(\theta \frac{L^2}{c^2}\right)_N \end{bmatrix} = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix} \quad (30)$$

or more concisely as:

$$[\bar{\tau}] = [C][S] \quad (31)$$

where

$[\bar{\tau}]$  is the  $1 \times N$  matrix of experimentally observed scaled times of arrival

$[C]$  is the  $6 \times N$  scaled position matrix

and  $[S]$  is the  $1 \times N$  matrix of undetermined coefficients.

Equation (31) was solved for the undetermined coefficients by premultiplying both sides of Eq. (31) by  $[[C^T][C]]^{-1}[C^T]$  to obtain:

$$[S] = [[C^T][C]]^{-1}[C^T][\bar{\tau}] \quad (32)$$

All coefficients found in Table F were obtained from Eq. (32) from three different computer runs, one each for the different values of  $\alpha$ . All data on time of arrival came from Rock Island Arsenal howitzer firings. The average values for time of arrival used in these curve fits can be found in the Appendix to this report.

## V. RECOMMENDATIONS AND SUMMARY

The procedure and resulting nomographs which have been developed work well for closed breech weapons; however, these guns do not yield the most severe conditions in a crew area. Whenever a flash suppressor and particularly muzzle brake are attached, the blast field is enhanced in the crew area. The procedures which have been applied in this study can be extended to predict limiting safe standoff distances around guns with specific muzzle brakes. If muzzle brakes with several different efficiencies had their blast fields measured and the data nondimensionalized appropriately, additional nomographs could be drawn for use by weapon designers and gun crew members. From a limited amount of data on the M102 with a medium efficiency, single baffle brake (WTV-F8769538), we had sufficient funds for obtaining only an equation to predict peak overpressure. If exactly the same six-coefficient equation, Eq. (1), is used to predict overpressure with a brake as was used without a brake, the accuracy is essentially the same, one standard deviation of 28.7% at  $\alpha = 0$  instead of 28.2% when no brake was present. The muzzle brake overpressure coefficients to be used for this specific brake at  $\alpha = 0$  are  $\xi = -4.151$ ,  $\epsilon = 1.105$ ,  $\beta = 0.700$ ,  $\psi = 0.165$ ,  $\gamma = 0.306$ , and  $\delta = -0.265$ . Figures 11 show three plots of scaled pressure versus scaled standoff for  $\alpha = 0$ ,  $\theta = 45, 90$  or  $135$  degrees with a WTV-F8769538 muzzle brake on an M102 howitzer. The solid lines are the curve fits obtained by using Eq. (1) and the preceding coefficients. At  $\theta = 135^\circ$ , the gun with a brake has overpressures three to four times those in a gun without a brake. At  $\theta = 45^\circ$ , the gun with a brake has 60% lower overpressures close to the muzzle than a gun without a brake. As can be seen, the presence of a brake amplifies and rotates the contours. If MIL-STD-1474 is to be applied to guns with brakes, the approach used in this study can be extended to handle these weapons.

Another group of weapons which will need to meet MIL-STD-1474 includes recoilless rifles. The blast pressures and their durations from recoilless rifle back blast can and have been scaled. This observation means, that with very little effort, nomographs for limiting safe standoff could be drawn for this class of weapon. More experimental measurements alongside recoilless rifle gun tubes where gunners have their heads would be valuable if accurate contours for safe standoff are to be established.

All overpressure, duration, and time of arrival curve fits for  $\alpha = 16.8^\circ$  or  $68.6^\circ$  were made over a very limited 20 to 70 caliber range in standoff positions. Although standard deviation for any of these responses is small, the small magnitude may be caused by sampling data over a very narrow range in  $\frac{L}{c}$ . Extrapolations beyond an  $\frac{L}{c}$  of 70 for

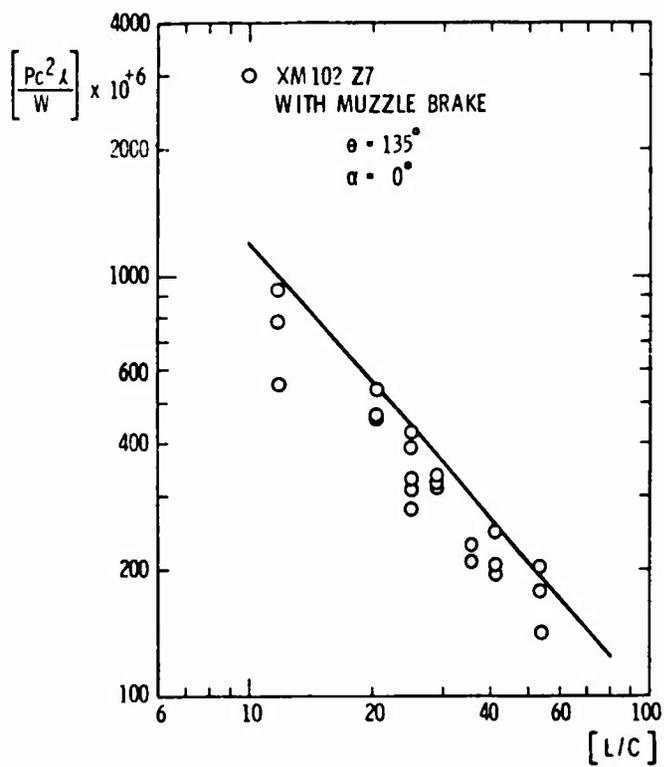
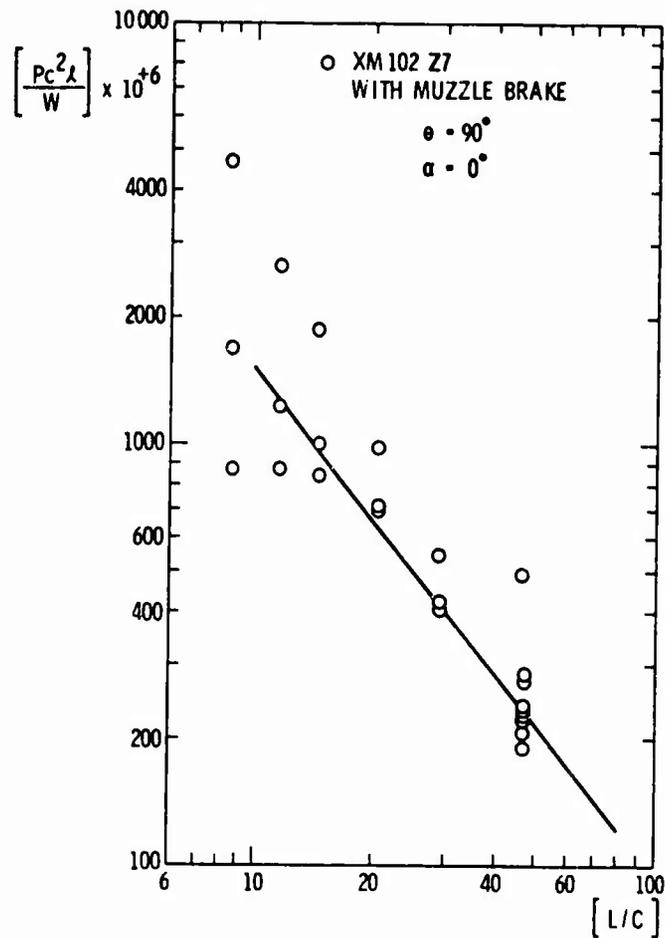
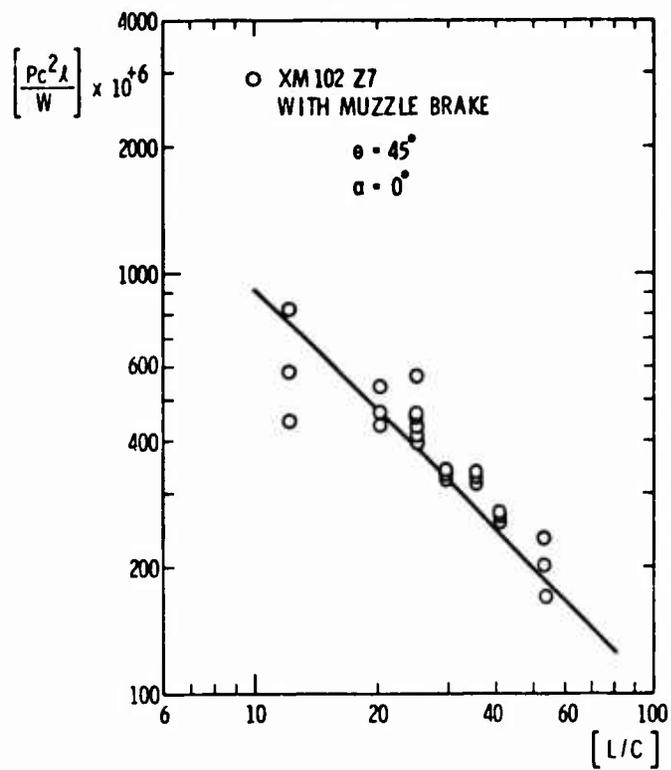


FIGURE 11. SCALED PRESSURE VS STANDOFF FOR GUNS WITH A MUZZLE BRAKE

these higher gun tube elevation angles could yield inaccurate estimates for pressure, duration, or arrival time. Should extra data become available, the curve fitting procedures should be applied once again to obtain new coefficients for  $\alpha = 16.8^\circ$  and  $68.6^\circ$  in Tables A, C, and D.

In Section II of this report, we disagreed with how durations are determined and applied in MIL-STD-1474. We strongly recommend that HEL reevaluate blast record and hearing loss experiments so that the positive duration from initial peak to wherever the trace crosses the baseline can be used with the duration axis from Figure 1. In addition, we believe that the  $\bar{W}$  criterion is presently too conservative for short duration impulsive noises. We would expect that the  $\bar{W}$  criterion for short duration impulsive noises would also parallel the  $\bar{Y}$  and  $\bar{Z}$  criteria lines in Figure 1. Finally, it is disturbing to those of us with a mechanics background that the short duration  $\bar{Y}$  and  $\bar{Z}$  lines do not terminate in a constant impulse criterion, that is, do not terminate with  $PT = \text{constant}$ . This result may be a consequence of using the 20 dB envelope for both compressive waves and their rarefactions to establish a duration that we believe is unrelated to muzzle blast.

The pertinent results from this study can be summarized by referring to several equations, tables, and figures. The effective energy  $W$  entering the blast field is obtained by using Eq. (2) and Table B. If one wishes to predict peak overpressures, Eq. (1) and Table A should be used; blast wave durations, Eq. (5) and Table C should be used; and/or time of arrival, Eq. (29) and Table F should be used. Weapon designers and gun crew members, wishing to directly estimate limiting safe standoff positions for any closed breech gun, can use Figures 5 if no ear protection is to be worn, and Figures 6 if plugs and/or muffs are to be worn. These specific equations, tables, and figures are our results stated concisely.

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## APPENDIX

This Appendix contains a summary of the average test data accumulated by Mark Salsbury of Rock Island Arsenal. For each test condition, the weapon system, weapon orientation, gauge and muzzle height above the reflecting plane and gauge position in polar coordinates are given along with the measured responses: peak pressure (psi), positive duration (ms) and time of arrival (ms). Characteristics of the individual weapons are found in Table G. The peak pressure presented below was generally the initial compressive blast pressure, although the reflected wave was occasionally more severe than the initial wave. The positive duration presented below is the time in milliseconds that the recorded pressure at a particular gauge location was above the 20 dB line, for both initial and ground reflected waves. In some cases the measured pressure traces were exceptionally noisy or inconsistent and were therefore eliminated from the curve fitting procedure. The words "-NREC-" in the duration column indicate that for that particular test condition no duration was recorded. The symbol "+" after an entry in the duration column indicates that the duration recorded for that test condition appeared inconsistent relative to durations for other test conditions. In these cases the average durations usually had a significantly higher standard deviation than was true for the test conditions. The time of arrival is the delay time in milliseconds between the arrival of the initial wave and the ground reflected wave at a particular gauge location. An arrival time of zero indicates that both blast waves have coalesced into a single Mach wave. The words "-NREC-" in the arrival time column indicate that the measured arrival time was not included in the curve fit for that particular test condition.

TABLE G. SUMMARY OF INTERIOR BALLISTICS FOR  
THE HOWITZER WEAPON SYSTEMS

<u>Interior Ballistics</u>	<u>XM10Z</u> <u>Zone 7</u>	<u>XM204</u> <u>Zone 5</u>	<u>XM204</u> <u>Zone 7</u>	<u>XM204</u> <u>Zone 8</u>
Shot travel (ft)	9.16	11.65	11.65	11.65
Projectile caliber (ft)	0.345	0.345	0.345	0.345
Projectile weight (lb)	33.0	33.0	33.0	33.0
Nominal muzzle velocity (fps)	1617.0	1090.0	1655.0	2133.0
Propellant weight (lb)	2.828	1.38	2.828	4.419
Propellant type	M1	M1	M1	M30A1
Propellant heat of explosion (ft-lb/lb)	$0.98 \times 10^6$	$0.98 \times 10^6$	$0.98 \times 10^6$	$1.36 \times 10^6$

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
1	XM102 Z7	7.26	7.26	13.00	38.73	4.825	3.722*	-NREC-
2	XM102 Z7	13.07	7.26	13.00	38.73	4.800	3.941*	-NREC-
3	XM102 Z7	18.87	7.26	13.00	38.73	3.200	4.105*	-NREC-
4	XM102 Z7	7.26	7.26	16.70	30.31	7.375	3.175*	-NREC-
5	XM102 Z7	13.07	7.26	16.70	30.31	4.875	3.887*	-NREC-
6	XM102 Z7	18.87	7.26	16.70	30.31	3.725	3.394*	-NREC-
7	XM102 Z7	7.26	7.26	23.20	22.11	7.850	2.518	1.126
8	XM102 Z7	13.07	7.26	23.20	22.11	6.925	3.175	1.622
9	XM102 Z7	18.87	7.26	23.20	22.11	5.550	2.901	2.547
10	XM102 Z7	7.26	7.26	26.57	32.46	6.800	2.737	.995
11	XM102 Z7	13.07	7.26	26.57	32.46	4.350	2.901	1.216
12	XM102 Z7	18.87	7.26	26.57	32.46	3.775	3.394	1.805
13	XM102 Z7	7.26	7.26	28.31	42.87	4.050	3.230	.527
14	XM102 Z7	13.07	7.26	28.31	42.87	3.330	3.120	.920
15	XM102 Z7	18.87	7.26	28.31	42.87	3.140	3.394	1.264
16	XM102 Z7	7.26	7.26	30.96	16.93	11.350	2.299	1.257
17	XM102 Z7	13.07	7.26	30.96	16.93	10.000	1.587	2.325
18	XM102 Z7	18.87	7.26	30.96	16.93	7.375	1.861	2.910
19	XM102 Z7	7.26	7.26	34.99	35.44	7.375	3.175	.716
20	XM102 Z7	13.07	7.26	34.99	35.44	4.875	3.887	1.109
21	XM102 Z7	18.87	7.26	34.99	35.44	3.725	3.394	1.608
22	XM102 Z7	7.26	7.26	35.54	24.98	6.600	2.737	.957
23	XM102 Z7	13.07	7.26	35.54	24.98	5.250	2.846	1.357
24	XM102 Z7	18.87	7.26	35.54	24.98	5.225	2.792	2.232
25	XM102 Z7	7.26	7.26	45.00	12.32	14.650	1.040	-NREC-
26	XM102 Z7	13.07	7.26	45.00	12.32	10.751	1.150	-NREC-
27	XM102 Z7	18.87	7.26	45.00	12.32	8.075	1.045	-NREC-
28	XM102 Z7	7.26	7.26	45.00	20.53	8.750	2.025	1.147
29	XM102 Z7	13.07	7.26	45.00	20.53	7.150	1.861	-NREC-
30	XM102 Z7	18.87	7.26	45.00	20.53	6.250	1.800	-NREC-
31	XM102 Z7	7.26	7.26	45.00	28.74	4.424	2.463	.854
32	XM102 Z7	13.07	7.26	45.00	28.74	4.100	3.065	-NREC-
33	XM102 Z7	18.87	7.26	45.00	28.74	3.750	2.299	-NREC-
34	XM102 Z7	7.26	7.26	45.00	41.06	3.175	2.573	.482
35	XM102 Z7	13.07	7.26	45.00	41.06	2.400	2.628	-NREC-
36	XM102 Z7	18.87	7.26	45.00	41.06	2.525	2.901	-NREC-
37	XM102 Z7	7.26	7.26	45.00	53.37	2.624	2.354	.307
38	XM102 Z7	13.07	7.26	45.00	53.37	2.425	2.737	.448
39	XM102 Z7	18.87	7.26	45.00	53.37	2.000	2.573	.548
40	XM102 Z7	7.26	7.26	54.46	24.98	4.575	1.976	.975
41	XM102 Z7	13.07	7.26	54.46	24.98	3.800	1.478	1.450
42	XM102 Z7	18.87	7.26	54.46	24.98	3.800	1.478	2.214
43	XM102 Z7	7.26	7.26	58.73	16.93	6.950	1.697	1.444
44	XM102 Z7	13.07	7.26	58.73	16.93	6.950	1.314	2.546
45	XM102 Z7	18.87	7.26	58.73	16.93	5.400	1.314	3.275

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DFG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
46	XM102 Z7	7.26	7.26	61.73	42.87	2.500	2.299	.461
47	XM102 Z7	13.07	7.26	61.73	42.87	1.910	2.628	.623
48	XM102 Z7	18.87	7.26	61.73	42.87	2.235	2.956	1.209
49	XM102 Z7	7.26	7.26	63.43	12.49	10.533	1.095	1.884
50	XM102 Z7	13.07	7.26	63.43	12.49	8.617	1.150	2.662
51	XM102 Z7	18.87	7.26	63.43	12.49	6.217	1.150	3.496
52	XM102 Z7	7.26	7.26	63.44	32.46	2.750	2.409	.820
53	XM102 Z7	13.07	7.26	63.44	32.46	2.650	2.518	1.281
54	XM102 Z7	18.87	7.26	63.44	32.46	2.475	2.190	1.929
55	XM102 Z7	7.26	7.26	66.80	22.11	4.475	1.478	1.047
56	XM102 Z7	13.07	7.26	66.80	22.11	4.175	1.423	1.967
57	XM102 Z7	18.87	7.26	66.80	22.11	3.725	1.478	2.903
58	XM102 Z7	7.26	7.26	67.92	54.79	2.275	2.354	.258
59	XM102 Z7	13.07	7.26	67.92	54.79	1.850	2.628	.482
60	XM102 Z7	18.87	7.26	67.92	54.79	1.650	2.737	.668
61	XM102 Z7	7.26	7.26	70.72	58.40	1.700	2.244	.172
62	XM102 Z7	13.07	7.26	70.72	58.40	1.350	2.409	.410
63	XM102 Z7	18.87	7.26	70.72	58.40	1.375	2.682	.455
64	XM102 Z7	7.26	7.26	72.67	48.67	2.075	2.299	.313
65	XM102 Z7	13.07	7.26	72.67	48.67	1.750	2.354	.568
66	XM102 Z7	18.87	7.26	72.67	48.67	1.425	2.737	.975
67	XM102 Z7	7.26	7.26	77.00	38.73	1.600	2.135+	.720
68	XM102 Z7	13.07	7.26	77.00	38.73	1.525	2.518	.948
69	XM102 Z7	18.87	7.26	77.00	38.73	1.522	2.956	1.911
70	XM102 Z7	7.26	7.26	80.37	47.24	1.525	1.416+	.389
71	XM102 Z7	13.07	7.26	80.37	47.24	1.100	2.463	.610
72	XM102 Z7	18.87	7.26	80.37	47.24	1.250	2.573	1.178
73	XM102 Z7	7.26	7.26	90.00	8.71	4.250	.657	-NREC-
74	XM102 Z7	13.07	7.26	90.00	8.71	5.025	.876	3.230
75	XM102 Z7	18.87	7.26	90.00	8.71	4.125	.876	3.664
76	XM102 Z7	7.26	7.26	90.00	11.61	7.509	1.423	-NREC-
77	XM102 Z7	13.07	7.26	90.00	11.61	5.728	1.368	3.031
78	XM102 Z7	18.87	7.26	90.00	11.61	4.083	1.368	3.547
79	XM102 Z7	7.26	7.26	90.00	14.52	4.550	1.150	-NREC-
80	XM102 Z7	13.07	7.26	90.00	14.52	3.775	1.259	2.710
81	XM102 Z7	18.87	7.26	90.00	14.52	3.725	.931	3.268
82	XM102 Z7	7.26	7.26	90.00	20.33	3.200	1.697	1.350
83	XM102 Z7	13.07	7.26	90.00	20.33	2.850	2.354	2.363
84	XM102 Z7	18.87	7.26	90.00	20.33	2.875	1.821	2.910
85	XM102 Z7	7.26	7.26	90.00	29.04	2.050	2.024	.758
86	XM102 Z7	13.07	7.26	90.00	29.04	1.725	2.573	1.653
87	XM102 Z7	18.87	7.26	90.00	29.04	1.950	2.354	2.438
88	XM102 Z7	7.26	7.26	90.00	46.46	1.250	2.299	-NREC-
89	XM102 Z7	13.07	7.26	90.00	46.46	1.075	2.518	.820
90	XM102 Z7	18.87	7.26	90.00	46.46	1.635	3.065+	1.522

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
91	XM102 Z7	7.26	7.26	100.63	47.24	1.075	1.752+	.382
92	XM102 Z7	13.07	7.26	100.63	47.24	1.050	2.409	.848
93	XM102 Z7	18.87	7.26	100.63	47.24	.925	2.846	1.185
94	XM102 Z7	7.26	7.26	103.00	38.73	1.050	2.080	-NREC-
95	XM102 Z7	13.07	7.26	103.00	38.73	1.072	2.682	1.085
96	XM102 Z7	18.87	7.26	103.00	38.73	1.100	2.737	1.743
97	XM102 Z7	7.26	7.26	107.36	48.66	.950	1.642+	.327
98	XM102 Z7	13.07	7.26	107.36	48.66	.825	2.135	.765
99	XM102 Z7	18.87	7.26	107.36	48.66	.875	2.244	.930
100	XM102 Z7	7.26	7.26	110.22	58.80	.700	1.533+	.189
101	XM102 Z7	13.07	7.26	110.22	58.80	.650	2.080	.413
102	XM102 Z7	18.87	7.26	110.22	58.80	.575	2.354	.475
103	XM102 Z7	7.26	7.26	113.20	22.11	1.725	1.971	1.195
104	XM102 Z7	13.07	7.26	113.20	22.11	.993	1.971	2.035
105	XM102 Z7	18.87	7.26	113.20	22.11	1.600	1.916	2.707
106	XM102 Z7	7.26	7.26	116.57	32.46	.900	2.080	.734
107	XM102 Z7	13.07	7.26	116.57	32.46	1.000	2.463	1.436
108	XM102 Z7	18.87	7.26	116.57	32.46	.475	2.135	2.318
109	XM102 Z7	7.26	7.26	119.31	42.86	2.717	1.916	1.923
110	XM102 Z7	13.07	7.26	119.31	42.86	2.883	1.423	2.859
111	XM102 Z7	18.87	7.26	119.31	42.86	2.367	1.478	-NREC-
112	XM102 Z7	7.26	7.26	121.27	16.93	.775	2.170	.400
113	XM102 Z7	13.07	7.26	121.27	16.93	.825	2.901	.654
114	XM102 Z7	18.87	7.26	121.27	16.93	.700	2.901	1.543
115	XM102 Z7	7.26	7.26	121.27	16.93	1.875	1.752	1.536
116	XM102 Z7	13.07	7.26	121.27	16.93	1.925	1.697	2.400
117	XM102 Z7	18.87	7.26	121.27	16.93	1.775	1.642	3.062
118	XM102 Z7	7.26	7.26	122.00	54.74	.525	1.423+	.248
119	XM102 Z7	13.07	7.26	122.00	54.74	.525	2.518	.685
120	XM102 Z7	18.87	7.26	122.00	54.74	.620	3.065+	1.171
121	XM102 Z7	7.26	7.26	125.54	24.98	1.200	2.135	.999
122	XM102 Z7	13.07	7.26	125.54	24.98	1.150	1.916	1.815
123	XM102 Z7	18.87	7.26	125.54	24.98	1.150	1.752	2.480
124	XM102 Z7	7.26	7.26	135.00	12.32	1.600	1.478	1.748
125	XM102 Z7	13.07	7.26	135.00	12.32	1.900	1.587	2.715
126	XM102 Z7	18.87	7.26	135.00	12.32	1.900	1.478	3.396
127	XM102 Z7	7.26	7.26	135.00	20.53	1.100	1.533	1.226
128	XM102 Z7	13.07	7.26	135.00	20.53	1.100	1.642	2.060
129	XM102 Z7	18.87	7.26	135.00	20.53	1.100	1.368	2.745
130	XM102 Z7	7.26	7.26	135.00	28.74	.825	1.752	.889
131	XM102 Z7	13.07	7.26	135.00	28.74	.800	1.806	1.598
132	XM102 Z7	18.87	7.26	135.00	28.74	.925	1.806	2.183
133	XM102 Z7	7.26	7.26	135.00	41.06	.625	1.642	.554
134	XM102 Z7	13.07	7.26	135.00	41.06	.600	2.135	1.123
135	XM102 Z7	18.87	7.26	135.00	41.06	.625	2.409	1.646

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 0.0 DEGREES G.A.E.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
136	XM102 Z7	7.26	7.26	135.01	53.37	.475	1.642+	.400
137	XM102 Z7	13.07	7.26	135.01	53.37	.425	1.697+	.813
138	XM102 Z7	18.87	7.26	135.01	53.37	.550	2.190	1.247
139	XM102 Z7	7.26	7.26	144.46	24.98	.450	1.061	1.061
140	XM102 Z7	13.07	7.26	144.46	24.98	.775	2.190	1.263
141	XM102 Z7	18.87	7.26	144.46	24.98	1.050	1.916	2.366
142	XM102 Z7	7.26	7.26	145.01	35.44	.600	1.533	.754
143	XM102 Z7	13.07	7.26	145.01	35.44	.650	1.806	1.288
144	XM102 Z7	18.87	7.26	145.01	35.44	.650	1.697	1.770
145	XM102 Z7	7.26	7.26	149.04	16.93	1.075	1.642	1.405
146	XM102 Z7	13.07	7.26	149.04	16.93	1.100	1.547	2.225
147	XM102 Z7	18.87	7.26	149.04	16.93	1.386	1.533	2.918
148	XM102 Z7	7.26	7.26	151.73	42.86	.300	1.150	.641
149	XM102 Z7	13.07	7.26	151.73	42.86	.380	1.264	1.660
150	XM102 Z7	18.87	7.26	151.73	42.86	.550	2.956	1.847
151	XM102 Z7	7.26	7.26	153.43	32.46	.700	1.861	.847
152	XM102 Z7	13.07	7.26	153.43	32.46	.750	1.697	1.443
153	XM102 Z7	18.87	7.26	153.43	32.46	.750	1.642	1.918
154	XM102 Z7	7.26	7.26	154.69	22.11	.900	1.647	1.116
155	XM102 Z7	13.07	7.26	154.69	22.11	.750	1.697	1.874
156	XM102 Z7	18.87	7.26	154.69	22.11	.800	1.587	2.628
157	XM102 Z7	7.26	7.26	156.80	22.11	.375	1.533	.448
158	XM102 Z7	13.07	7.26	161.99	39.69	.500	1.587	.875
159	XM102 Z7	18.87	7.26	161.99	39.69	.475	1.045+	1.574
160	XM102 Z7	7.26	7.26	163.30	30.31	.575	1.806	1.240
161	XM102 Z7	13.07	7.26	163.30	30.31	.575	1.423	1.498
162	XM102 Z7	18.87	7.26	163.30	30.31	.600	1.368	2.035

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 1.5 DEGREES O.E.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
1	XM204 Z5	14.52	9.69	13.65	31.81	1.920	3.736+	2.431
2	XM204 Z5	10.65	9.69	13.65	31.81	1.900	2.980+	1.856
3	XM204 Z5	14.52	9.69	14.07	46.41	1.061	2.822+	1.436
4	XM204 Z5	10.65	9.69	14.07	46.41	1.530	2.742+	.768
5	XM204 Z5	14.52	9.69	26.58	24.36	2.959	3.060+	2.445
6	XM204 Z5	10.65	9.69	26.58	24.36	2.939	3.656+	2.221
7	XM204 Z5	14.52	9.69	27.84	30.84	1.500	2.822	2.004
8	XM204 Z5	10.65	9.69	27.84	30.84	1.599	2.742	1.450
9	XM204 Z5	14.52	9.69	28.61	60.63	.719	2.782	-NREC-
10	XM204 Z5	10.65	9.69	28.61	60.63	.881	2.861	-NREC-
11	XM204 Z5	14.52	9.69	28.63	75.13	.580	3.100+	0.000
12	XM204 Z5	10.65	9.69	28.63	75.13	.541	1.828+	0.000
13	XM204 Z5	14.52	9.69	28.89	75.13	2.100	2.225	2.976
14	XM204 Z5	10.65	9.69	28.89	75.13	2.240	2.543+	2.318
15	XM204 Z5	14.52	9.69	40.08	23.94	2.240	2.265	2.480
16	XM204 Z5	10.65	9.69	41.21	31.12	1.719	2.583+	1.812
17	XM204 Z5	14.52	9.69	41.21	31.12	1.240	3.338	1.942
18	XM204 Z5	10.65	9.69	41.93	38.41	1.139	3.179	1.405
19	XM204 Z5	14.52	9.69	42.42	45.70	.844	2.941	1.660
20	XM204 Z5	10.65	9.69	42.42	45.70	.470	2.861	1.109
21	XM204 Z5	14.52	9.69	43.04	60.19	.499	2.424	1.016
22	XM204 Z5	10.65	9.69	43.04	60.19	.51	2.583	.449
23	XM204 Z5	14.52	9.69	43.42	74.68	.550	2.663	0.000
24	XM204 Z5	10.65	9.69	43.42	74.68	.379	3.139	0.000
25	XM204 Z5	14.52	9.69	51.04	16.15	3.801	1.152	4.279
26	XM204 Z5	10.65	9.69	51.04	16.15	4.240	1.033	3.248
27	XM204 Z5	14.52	9.69	55.28	30.56	1.890	1.828	2.655
28	XM204 Z5	10.65	9.69	55.28	30.56	1.470	2.345+	1.960
29	XM204 Z5	14.52	9.69	56.80	45.12	.879	2.623+	1.822
30	XM204 Z5	10.65	9.69	56.80	45.12	.740	2.027	1.257
31	XM204 Z5	14.52	9.69	58.05	74.10	.671	2.702+	-NREC-
32	XM204 Z5	10.65	9.69	58.05	74.10	.240	-NREC-	0.000
33	XM204 Z5	14.52	9.69	67.91	22.73	1.879	1.629	3.249
34	XM204 Z5	10.65	9.69	67.91	22.73	1.950	1.510	2.518
35	XM204 Z5	14.52	9.69	70.67	37.16	.890	1.788	2.259
36	XM204 Z5	10.65	9.69	70.67	37.16	1.080	2.027	1.577
37	XM204 Z5	14.52	9.69	72.27	58.42	.571	1.351+	1.319
38	XM204 Z5	10.65	9.69	72.27	58.42	.580	1.909	.472
39	XM204 Z5	14.52	9.69	72.81	73.41	.450	1.311+	.937
40	XM204 Z5	10.65	9.69	72.81	73.41	.260	1.232+	0.000
41	XM204 Z5	14.52	9.69	78.67	14.79	2.669	1.629	4.136
42	XM204 Z5	10.65	9.69	78.67	14.79	2.751	2.543+	3.251
43	XM204 Z5	14.52	9.69	84.28	24.15	1.130	1.311	2.445
44	XM204 Z5	10.65	9.69	84.28	24.15	1.221	2.106+	2.025
45	XM204 Z5	14.52	9.69	85.42	36.42	.822	1.908	2.294

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 1.5 DEGREES Q.E.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	MUZZLE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
46	XM204 Z5	10.65	9.69	85.47	36.42	.770	2.543+	1.450	
47	XM204 Z5	14.52	9.69	86.19	43.70	.660	1.590	2.080	
48	XM204 Z5	10.65	9.69	84.19	43.70	.639	1.073+	1.450	
49	XM204 Z5	14.52	9.69	87.14	58.17	.519	1.709	1.371	
50	XM204 Z5	10.65	9.69	87.14	58.17	.520	1.709	.920	
51	XM204 Z5	14.52	9.69	87.71	72.66	.354	1.908	.942	
52	XM204 Z5	10.65	9.69	87.71	72.66	.502	2.186	.575	
53	XM204 Z5	14.52	9.69	97.40	21.23	.820	1.987	3.327	
54	XM204 Z5	10.65	9.69	97.40	21.23	1.179	1.028	2.545	
55	XM204 Z5	14.52	9.69	99.33	28.39	.751	1.709	2.783	
56	XM204 Z5	10.65	9.69	94.33	28.39	.664	1.550	2.008	
57	XM204 Z5	14.52	9.69	101.25	42.94	.591	1.510	1.847	
58	XM204 Z5	10.65	9.69	101.25	42.94	.411	2.186	1.422	
59	XM204 Z5	14.52	9.69	102.20	57.42	.310	2.146	1.515	
60	XM204 Z5	10.65	9.69	102.20	57.42	.130	1.113+	.968	
61	XM204 Z5	14.52	9.69	114.76	27.66	.600	1.192	2.484	
62	XM204 Z5	10.65	9.69	114.76	27.66	.621	1.431	1.619	
63	XM204 Z5	14.52	9.69	117.44	56.70	.304	1.749	1.550	
64	XM204 Z5	10.65	9.69	117.44	56.70	.141	-NREC-	.310	
65	XM204 Z5	14.52	9.69	125.62	12.61	1.441	1.073	4.288	
66	XM204 Z5	10.65	9.69	125.62	12.61	1.255	.835	3.348	
67	XM204 Z5	14.52	9.69	129.06	19.85	.730	.954	3.482	
68	XM204 Z5	10.65	9.69	129.06	19.85	.848	.074	2.569	
69	XM204 Z5	14.52	9.69	130.64	27.02	.621	.914	2.669	
70	XM204 Z5	10.65	9.69	130.64	27.02	.570	1.272	2.060	
71	XM204 Z5	14.52	9.69	132.17	41.60	.400	1.510	1.446	
72	XM204 Z5	10.65	9.69	132.17	41.60	.260	1.391	-NREC-	
73	XM204 Z5	14.52	9.69	145.69	19.34	.719	1.272	3.399	
74	XM204 Z5	10.65	9.69	145.69	19.34	.740	1.272	2.549	
75	XM204 Z5	14.52	9.69	146.86	26.52	.439	1.192	2.821	
76	XM204 Z5	10.65	9.69	146.86	26.52	.561	.994	2.097	
77	XM204 Z5	14.52	9.69	147.97	41.11	.401	1.152	2.356	
78	XM204 Z5	10.65	9.69	147.97	41.11	.349	1.351	1.595	
79	XM204 Z5	14.52	9.69	158.00	55.61	.290	1.192+	1.636	
80	XM204 Z5	10.65	9.69	143.36	26.20	.541	1.272	3.141	
81	XM204 Z5	14.52	9.69	163.36	26.20	.309	1.590	2.204	
82	XM204 Z5	10.65	9.69	163.71	33.50	.441	1.311	2.418	
83	XM204 Z5	14.52	9.69	163.71	33.50	.329	1.391	1.874	
84	XM204 Z5	10.65	9.69	165.00	43.06	.310	1.709	2.139	
85	XM204 Z5	14.52	9.69	165.00	43.06	.279	1.351	1.429	
86	XM204 Z5	10.65	9.69	165.40	38.44	.281	1.669	2.235	
87	XM204 Z5	14.52	9.69	165.40	38.44	.299	1.351	1.622	
88	XM204 Z7	10.65	9.76	14.90	24.20	3.454	5.658+	3.062	
89	XM204 Z7	14.52	9.76	14.90	24.20	4.479	4.244+	2.249	
90	XM204 Z7	14.52	9.76	14.90	43.80	2.322	4.047+	1.791	

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 1.5 DEGREES O.E.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
91	XM204 Z7	10.65	9.76	14.90	43.80	2.973	3.610*	1.219
92	XM204 Z7	14.52	9.76	14.96	87.34	1.564	2.243*	-NREC-
93	XM204 Z7	10.65	9.76	14.96	87.34	2.110	2.390*	-NREC-
94	XM204 Z7	14.52	9.76	14.96	101.84	1.349	1.854*	-NREC-
95	XM204 Z7	10.65	9.76	14.46	101.84	2.010	2.585*	-NREC-
96	XM204 Z7	14.52	9.76	14.97	116.34	.979	2.244*	-NREC-
97	XM204 Z7	10.65	9.76	14.97	116.34	.839	2.243*	-NREC-
98	XM204 Z7	14.52	9.76	14.97	130.44	.860	1.902*	-NREC-
99	XM204 Z7	10.65	9.76	14.97	130.44	.589	2.829*	-NREC-
100	XM204 Z7	14.52	9.76	29.70	22.00	5.298	2.976	-NREC-
101	XM204 Z7	10.65	9.76	29.70	22.00	5.699	2.976	-NREC-
102	XM204 Z7	14.52	9.76	29.80	36.50	2.418	3.854*	1.812
103	XM204 Z7	10.65	9.76	29.80	36.50	2.901	3.415	1.639
104	XM204 Z7	14.52	9.76	29.90	58.30	1.318	2.585	.789
105	XM204 Z7	10.65	9.76	29.90	58.30	1.649	3.214	.396
106	XM204 Z7	14.52	9.76	29.90	72.80	1.082	3.171	0.000
107	XM204 Z7	10.65	9.76	29.90	72.80	1.082	2.976	0.000
108	XM204 Z7	14.52	9.76	44.50	22.00	4.521	2.195	3.406
109	XM204 Z7	10.65	9.76	44.50	22.00	4.719	1.659	2.146
110	XM204 Z7	14.52	9.76	44.70	29.20	3.082	2.098	2.731
111	XM204 Z7	10.65	9.76	44.70	29.20	3.397	2.683	1.905
112	XM204 Z7	14.52	9.76	44.70	36.50	2.620	3.122*	1.940
113	XM204 Z7	10.65	9.76	44.70	36.50	2.699	2.780	1.236
114	XM204 Z7	14.52	9.76	44.80	43.80	2.017	3.171*	1.526
115	XM204 Z7	10.65	9.76	44.80	43.80	2.277	2.585	.868
116	XM204 Z7	14.52	9.76	44.80	58.30	1.380	2.878	.651
117	XM204 Z7	10.65	9.76	44.80	58.30	1.260	3.024*	.310
118	XM204 Z7	14.52	9.76	44.90	72.80	1.240	3.073	0.000
119	XM204 Z7	10.65	9.76	44.90	72.80	1.260	2.829	0.000
120	XM204 Z7	14.52	9.76	59.20	14.60	6.301	1.024	4.381
121	XM204 Z7	10.65	9.76	59.20	14.60	7.058	1.171	3.437
122	XM204 Z7	14.52	9.76	59.60	29.10	2.401	2.439	2.786
123	XM204 Z7	10.65	9.76	59.60	29.10	2.497	2.098	1.894
124	XM204 Z7	14.52	9.76	59.70	43.70	1.935	2.390	1.471
125	XM204 Z7	10.65	9.76	59.70	43.70	1.873	2.537	-NREC-
126	XM204 Z7	14.52	9.76	59.80	72.70	.959	2.243	0.000
127	XM204 Z7	10.65	9.76	59.80	72.70	.897	2.195	0.000
128	XM204 Z7	14.52	9.76	74.40	21.40	3.099	1.512	3.654
129	XM204 Z7	10.65	9.76	74.40	21.40	3.449	1.512	2.500
130	XM204 Z7	14.52	9.76	74.60	36.40	1.428	2.341	2.122
131	XM204 Z7	10.65	9.76	74.60	36.40	1.661	2.341	1.405
132	XM204 Z7	14.52	9.76	74.80	58.20	.959	2.293	.930
133	XM204 Z7	10.65	9.76	74.80	58.20	.974	2.340	.549
134	XM204 Z7	14.52	9.76	74.80	72.70	.832	2.244	.499
135	XM204 Z7	10.65	9.76	74.80	72.70	.781	2.732	.344

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 1.5 DEGREES U.E.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
136	XM204 Z7	14.52	9.76	89.00	14.50	3.397	1.073	4.019
137	XM204 Z7	10.65	9.76	89.00	14.50	3.363	1.219	3.210
138	XM204 Z7	14.52	9.76	89.50	29.00	1.521	-NREC-	2.580
139	XM204 Z7	14.52	9.76	89.50	36.30	1.123	1.317+	2.011
140	XM204 Z7	10.65	9.76	89.50	36.30	1.123	1.951	1.429
141	XM204 Z7	14.52	9.76	89.70	43.60	.877	1.756	1.801
142	XM204 Z7	10.65	9.76	89.70	43.60	.959	1.192	1.537
143	XM204 Z7	14.52	9.76	89.80	58.10	.801	2.340	1.092
144	XM204 Z7	10.65	9.76	89.80	58.10	.801	2.340	.678
145	XM204 Z7	14.52	9.76	89.80	72.60	.949	2.340	.692
146	XM204 Z7	10.65	9.76	89.80	72.60	.812	2.341	.365
147	XM204 Z7	14.52	9.76	104.40	21.70	1.582	1.902	3.127
148	XM204 Z7	10.65	9.76	104.40	21.70	1.719	1.756	2.421
149	XM204 Z7	14.52	9.76	104.50	28.40	1.084	2.293	2.654
150	XM204 Z7	10.65	9.76	104.50	28.40	1.312	2.146	1.898
151	XM204 Z7	14.52	9.76	104.70	43.50	.791	2.430	1.754
152	XM204 Z7	10.65	9.76	104.70	43.50	.832	2.195	1.250
153	XM204 Z7	14.52	9.76	104.80	58.00	.640	2.293	1.205
154	XM204 Z7	10.65	9.76	104.80	58.00	.901	2.439	.968
155	XM204 Z7	14.52	9.76	119.60	28.40	.928	1.707	2.528
156	XM204 Z7	10.65	9.76	119.60	28.40	.849	1.512	1.853
157	XM204 Z7	14.52	9.76	119.80	58.00	.459	1.951	1.304
158	XM204 Z7	10.65	9.76	119.80	58.00	.229	1.512+	1.006
159	XM204 Z7	14.52	9.76	134.30	14.30	1.281	1.317	3.840
160	XM204 Z7	10.65	9.76	134.30	14.30	1.214	1.171	2.993
161	XM204 Z7	14.52	9.76	134.50	21.60	.781	1.219	3.124
162	XM204 Z7	10.65	9.76	134.50	21.60	.978	1.559	2.287
163	XM204 Z7	14.52	9.76	134.70	28.80	.682	1.366	2.425
164	XM204 Z7	10.65	9.76	134.70	28.80	.668	1.756	1.849
165	XM204 Z7	14.52	9.76	134.80	43.40	.469	1.756	1.767
166	XM204 Z7	10.65	9.76	134.80	43.40	.260	1.902	1.150
167	XM204 Z7	14.52	9.76	149.70	21.60	.781	1.171	3.141
168	XM204 Z7	10.65	9.76	149.70	21.60	.750	1.654	2.335
169	XM204 Z7	14.52	9.76	149.80	28.80	.479	1.707	2.597
170	XM204 Z7	10.65	9.76	149.80	28.80	.562	1.854	1.942
171	XM204 Z7	14.52	9.76	149.80	43.40	.418	2.049	1.880
172	XM204 Z7	10.65	9.76	149.80	43.40	.387	2.878+	1.477
173	XM204 Z7	14.52	9.76	159.50	58.80	.312	2.195	-NREC-
174	XM204 Z7	14.52	9.76	164.40	28.80	.514	1.902	2.542
175	XM204 Z7	10.65	9.76	164.40	28.80	.301	1.561	2.194
176	XM204 Z7	14.52	9.76	164.90	36.10	.510	2.732+	2.152
177	XM204 Z7	10.65	9.76	164.90	36.10	.438	1.854	1.608
178	XM204 Z7	14.52	9.76	165.00	45.70	.360	1.756	1.839
179	XM204 Z7	10.65	9.76	165.00	45.70	.322	2.732+	1.243
180	XM204 Z7	14.52	9.76	165.90	41.10	.342	1.415	1.918



SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
181	XM204 Z7	10.65	4.74	165.90	41.10	332	2.390	1.491
182	XM204 Z8	14.52	9.86	14.84	21.24	7.539	4.188+	2.762
183	XM204 Z8	10.65	9.86	14.84	29.24	6.785	4.127+	2.022
184	XM204 Z8	14.52	9.86	14.92	43.84	4.533	4.673+	1.636
185	XM204 Z8	10.65	9.86	14.92	43.84	3.926	3.641+	1.002
186	XM204 Z8	14.52	9.86	14.91	58.34	2.969	3.127+	-NREC-
187	XM204 Z8	10.65	9.86	14.91	58.34	3.073	3.763+	-NREC-
188	XM204 Z8	14.52	9.86	14.95	72.84	2.346	3.095+	-NREC-
189	XM204 Z8	10.65	9.86	14.95	72.84	2.895	3.884+	-NREC-
190	XM204 Z8	14.52	9.86	14.94	87.34	2.770	2.610+	-NREC-
191	XM204 Z8	10.65	9.86	14.94	87.34	3.248	2.488+	-NREC-
192	XM204 Z8	14.52	9.86	14.94	101.84	2.089	2.913+	-NREC-
193	XM204 Z8	10.65	9.86	14.94	101.84	2.500	2.731+	-NREC-
194	XM204 Z8	14.52	9.86	14.97	116.34	1.570	2.913+	-NREC-
195	XM204 Z8	10.65	9.86	14.97	116.34	1.546	2.913+	-NREC-
196	XM204 Z8	14.52	9.86	14.97	130.44	1.446	2.731+	-NREC-
197	XM204 Z8	10.65	9.86	14.97	130.44	1.230	3.277+	-NREC-
198	XM204 Z8	14.52	9.86	29.76	29.21	6.220	3.445	2.307
199	XM204 Z8	10.65	9.86	29.76	21.21	7.171	3.641	2.364
200	XM204 Z8	14.52	9.86	29.88	58.31	3.294	3.581+	.403
201	XM204 Z8	10.65	9.86	29.88	58.31	3.613	3.034	-NREC-
202	XM204 Z8	14.52	9.86	29.92	87.31	2.153	3.459	-NREC-
203	XM204 Z8	10.65	9.86	29.92	87.31	2.153	3.459	-NREC-
204	XM204 Z8	14.52	9.86	29.94	116.31	1.362	3.702	-NREC-
205	XM204 Z8	10.65	9.86	29.94	116.31	1.503	3.702	-NREC-
206	XM204 Z8	14.52	9.86	44.55	21.97	8.924	2.306	3.599
207	XM204 Z8	10.65	9.86	44.55	21.97	9.601	2.610	2.373
208	XM204 Z8	14.52	9.86	44.55	21.17	5.944	3.217	3.344
209	XM204 Z8	10.65	9.86	44.66	21.17	6.993	2.670	2.008
210	XM204 Z8	14.52	9.86	44.73	35.47	4.006	3.277	2.452
211	XM204 Z8	10.65	9.86	44.73	35.47	4.208	3.338	1.622
212	XM204 Z8	14.52	9.86	44.77	43.77	3.116	3.702	1.808
213	XM204 Z8	10.65	9.86	44.77	43.77	3.797	3.641	1.471
214	XM204 Z8	14.52	9.86	44.83	58.27	3.147	3.034	1.322
215	XM204 Z8	10.65	9.86	44.83	58.27	3.840	3.034	.716
216	XM204 Z8	14.52	9.86	44.86	72.77	2.380	3.095	.482
217	XM204 Z8	10.65	9.86	44.86	72.77	2.742	2.913	.310
218	XM204 Z8	14.52	9.86	44.89	87.27	2.215	2.852	-NREC-
219	XM204 Z8	10.65	9.86	44.89	87.27	2.392	3.459	-NREC-
220	XM204 Z8	14.52	9.86	44.90	101.77	1.448	2.731	-NREC-
221	XM204 Z8	10.65	9.86	44.90	101.77	1.349	3.520	-NREC-
222	XM204 Z8	14.52	9.86	74.34	21.86	4.650	2.124	3.344
223	XM204 Z8	10.65	9.86	74.34	21.86	4.908	2.306	2.480
224	XM204 Z8	14.52	9.86	74.63	36.36	3.030	3.338	1.960
225	XM204 Z8	10.65	9.86	74.63	36.36	2.478	2.792	1.212

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SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 1.5 DEGREES O.E.

REC'D	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
226	XM204 ZR	14.52	9.86	74.77	58.16	1.785	3.034	.537
227	XM204 ZB	10.65	9.86	71.77	58.16	2.092	2.913	.124
228	XM204 ZB	14.52	9.86	74.84	87.16	1.288	3.034	0.000
229	XM204 ZB	10.65	9.86	74.84	87.16	1.374	3.338	0.000
230	XM204 ZB	14.52	9.86	84.03	14.50	6.920	1.639	3.971
231	XM204 ZB	10.65	9.86	89.03	14.50	7.411	1.517	3.124
232	XM204 ZB	14.52	9.86	89.36	21.80	4.613	2.367	3.027
233	XM204 ZB	10.65	9.86	89.16	21.80	5.282	2.306	2.349
234	XM204 ZR	14.52	9.86	89.52	29.00	3.030	2.913	2.414
235	XM204 ZB	10.65	9.86	89.52	29.00	2.451	2.731	1.563
236	XM204 ZB	14.52	9.86	89.61	36.30	2.239	3.156	1.939
237	XM204 ZB	10.65	9.86	89.61	36.30	2.129	2.549	1.226
238	XM204 ZB	14.52	9.86	89.48	43.60	1.914	3.459+	1.512
239	XM204 ZB	10.65	9.86	89.68	43.60	1.938	3.399+	.889
240	XM204 ZB	14.52	9.86	89.76	58.10	1.911	2.913	.734
241	XM204 ZB	10.65	9.86	89.76	58.10	1.640	2.852	.503
242	XM204 ZB	14.52	9.86	89.81	72.60	1.172	2.852	.386
243	XM204 ZB	10.65	9.86	89.81	72.60	1.570	2.185	.162
244	XM204 ZB	14.52	9.86	89.84	87.10	1.297	2.488	0.000
245	XM204 ZB	10.65	9.86	89.84	87.10	1.196	2.452	0.000
246	XM204 ZB	14.52	9.86	119.58	28.48	2.558	2.610	2.476
247	XM204 ZB	10.65	9.86	119.58	28.48	1.724	2.610	1.801
248	XM204 ZB	14.52	9.86	119.72	43.48	1.000	3.217	1.681
249	XM204 ZB	10.65	9.86	119.72	43.48	1.196	3.217	1.054
250	XM204 ZB	14.52	9.86	119.79	57.48	.828	3.277	1.019
251	XM204 ZB	10.65	9.86	119.79	57.48	.914	3.034	.599
252	XM204 ZB	14.52	9.86	119.83	72.48	.673	3.095	.634
253	XM204 ZB	10.65	9.86	119.83	72.48	.644	3.864+	.393
254	XM204 ZB	14.52	9.86	134.54	21.63	1.650	2.792	2.945
255	XM204 ZB	10.65	9.86	134.54	21.63	1.577	2.246	2.147
256	XM204 ZB	14.52	9.86	134.73	36.13	.877	2.731.	2.015
257	XM204 ZB	10.65	9.86	134.73	36.13	1.098	2.913	1.336
258	XM204 ZB	14.52	9.86	134.80	50.63	.724	3.217+	1.274
259	XM204 ZB	10.65	9.86	134.80	50.63	.724	3.156+	.402
260	XM204 ZB	14.52	9.86	134.86	72.13	.644	3.034+	.744
261	XM204 ZB	10.65	9.86	134.86	72.13	.521	3.217+	.492
262	XM204 ZB	14.52	9.86	149.68	21.59	1.209	2.246	2.976
263	XM204 ZB	10.65	9.86	149.68	21.59	1.190	2.185	2.194
264	XM204 ZB	14.52	9.86	149.76	28.79	.865	2.610	2.490
265	XM204 ZB	10.65	9.86	149.76	28.79	1.043	2.670	1.750
266	XM204 ZB	14.52	9.86	149.84	43.39	.799	3.156	1.626
267	XM204 ZB	10.65	9.86	149.84	43.39	.693	3.277	1.126
268	XM204 ZB	14.52	9.86	149.84	57.89	.521	2.913	1.195
269	XM204 ZB	10.65	9.86	149.84	57.89	.491	2.670	.799
270	XM204 ZB	14.52	9.86	160.80	61.73	.442	3.702+	1.374

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
271	XM204 Z8	10.65	9.86	160.00	61.73	.497	3.156	.833
272	XM204 Z8	14.52	9.86	162.20	94.78	.386	2.792	-MREC-
273	XM204 Z8	10.65	9.86	162.20	94.78	.423	2.913	-MREC-
274	XM204 Z8	14.52	9.86	164.27	28.76	.834	3.156	2.483
275	XM204 Z8	10.65	9.86	164.87	28.76	.810	2.792	1.719
276	XM204 Z8	14.52	9.86	164.90	36.06	.687	3.034	2.039
278	XM204 Z8	14.52	9.86	164.94	36.06	.926	2.549	1.426
279	XM204 Z8	10.65	9.86	164.94	57.86	.460	2.792	1.440
280	XM204 Z8	14.52	9.86	164.94	57.86	.503	2.731	.964
281	XM204 Z8	10.65	9.86	167.00	49.40	.423	3.641+	1.360
282	XM204 Z8	14.52	9.86	167.00	49.40	.577	3.641+	1.133
283	XM204 Z8	10.65	9.86	167.50	44.85	.620	2.670	1.598
284	XM204 Z8	14.52	9.86	173.70	44.85	.626	2.731	1.209
285	XM204 Z8	10.65	9.86	173.70	52.81	.429	3.884+	1.526
					52.81	.521	3.520+	.985

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 16.8 DEGREES G.F.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZLE HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
1	XM204 Z7	14.52	20.95	14.24	30.51	2.600	3.512	5.128
2	XM204 Z7	10.65	20.95	14.24	30.51	2.640	3.805	3.806
3	XM204 Z7	14.52	20.95	14.49	45.11	1.480	4.293	3.940
4	XM204 Z7	10.65	20.95	14.49	45.11	1.620	3.756	2.976
5	XM204 Z7	14.52	20.95	14.61	59.61	1.140	5.073	3.268
6	XM204 Z7	10.65	20.95	14.61	59.61	1.184	5.415	2.993
7	XM204 Z7	14.52	20.95	14.69	74.11	.980	4.780	2.931
8	XM204 Z7	10.65	20.95	14.69	74.11	1.000	4.585	1.684
9	XM204 Z7	14.52	20.95	42.25	22.93	1.561	1.561	5.993
10	XM204 Z7	10.65	20.95	42.25	22.93	3.485	2.049	4.463
11	XM204 Z7	14.52	20.95	43.31	37.42	2.440	2.098	4.828
12	XM204 Z7	10.65	20.95	43.31	37.42	2.380	2.049	3.434
13	XM204 Z7	14.52	20.95	43.93	59.21	1.280	2.683	3.007
14	XM204 Z7	10.65	20.95	43.93	59.21	1.260	2.927	2.159
15	XM204 Z7	14.52	20.95	44.14	73.71	1.020	2.537	2.311
16	XM204 Z7	10.65	20.95	44.14	73.71	1.360	3.171	1.519
17	XM204 Z7	14.52	20.95	83.87	14.58	4.140	1.024	6.668
18	XM204 Z7	10.65	20.95	83.87	14.58	3.520	1.248	5.094
19	XM204 Z7	14.52	20.95	86.93	24.04	1.860	1.415	5.228
20	XM204 Z7	10.65	20.95	86.93	24.04	1.840	1.317	3.885
21	XM204 Z7	14.52	20.95	87.95	43.63	.980	2.195	3.813
22	XM204 Z7	10.65	20.95	87.95	43.63	1.000	2.829	2.828
23	XM204 Z7	14.52	20.95	88.46	58.12	.700	2.049	3.158
24	XM204 Z7	10.65	20.95	88.46	58.12	2.585	2.585	2.349
25	XM204 Z7	14.52	20.95	131.74	20.73	1.340	1.219	5.989
26	XM204 Z7	10.65	20.95	131.74	20.73	1.160	1.659	4.515
27	XM204 Z7	14.52	20.95	132.74	27.42	.400	1.659	5.304
28	XM204 Z7	10.65	20.95	132.74	27.42	.900	1.756	3.874
29	XM204 Z7	14.52	20.95	133.52	42.51	.560	2.000	4.422
30	XM204 Z7	10.65	20.95	133.52	42.51	.540	2.049	3.344
31	XM204 Z7	14.52	20.95	133.89	57.01	.440	2.439	3.540
32	XM204 Z7	10.65	20.95	133.89	57.01	.400	2.144	2.890
33	XM204 Z7	14.52	20.95	159.10	56.87	.300	3.316	4.384
34	XM204 Z7	10.65	20.95	159.10	56.87	.330	2.146	2.821
35	XM204 Z7	14.52	20.95	165.50	44.39	.380	2.878	4.813
36	XM204 Z7	10.65	20.95	165.50	44.39	.430	2.146	4.119
37	XM204 Z7	14.52	20.95	165.90	39.79	.340	1.902	4.492
38	XM204 Z7	10.65	20.95	165.90	39.79	.300	1.902	4.439
39	XM204 Z7	14.52	20.95	173.00	47.68	.310	1.702	4.811
40	XM204 Z7	10.65	20.95	173.00	47.68	.410	1.805	3.565
41	XM204 Z8	14.52	21.93	15.35	70.97	1.556	4.916	2.400
42	XM204 Z8	10.65	21.93	15.35	70.97	1.476	5.037	1.661
43	XM204 Z8	14.52	21.93	15.44	56.47	2.194	5.280	3.041
44	XM204 Z8	10.65	21.93	15.44	56.47	2.035	4.734	2.170
45	XM204 Z8	14.52	21.93	15.72	34.67	3.312	4.127	4.478

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SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	GAGE ANGLF (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
46	XM204 Z8	10.65	21.93	15.72	34.67	3.340	3.763	3.131
47	XM204 Z8	14.52	21.93	16.24	20.17	7.301	3.034	5.664
48	XM204 Z8	10.65	21.93	16.24	20.17	6.344	3.156	4.202
49	XM204 Z8	14.52	21.93	45.96	71.42	1.596	1.942+	2.311
50	XM204 Z8	10.65	21.93	45.96	71.42	1.596	1.274+	1.519
51	XM204 Z8	14.52	21.93	46.20	56.92	2.075	2.544	3.062
52	XM204 Z8	10.65	21.93	46.20	56.92	1.955	1.821+	2.140
53	XM204 Z8	14.52	21.93	46.95	35.13	5.306	4.066+	4.880
54	XM204 Z8	10.65	21.93	46.95	35.13	3.910	2.913	3.509
55	XM204 Z8	14.52	21.93	48.32	20.64	8.738	5.044+	6.127
56	XM204 Z8	10.65	21.93	48.32	20.64	8.738	3.884+	4.670
57	XM204 Z8	14.52	21.93	71.67	58.12	1.237	4.127	3.174
58	XM204 Z8	10.65	21.93	71.67	58.12	1.237	3.045	2.232
59	XM204 Z8	14.52	21.93	92.22	43.63	7.754	3.034	3.841
60	XM204 Z8	10.65	21.93	92.22	43.63	1.754	2.670	2.810
61	XM204 Z8	14.52	21.93	93.34	29.05	3.032	2.003	5.321
62	XM204 Z8	10.65	21.93	93.34	29.05	2.873	2.367	3.950
63	XM204 Z8	14.52	21.93	96.65	14.60	6.104	1.517	6.750
64	XM204 Z8	10.65	21.93	96.65	14.60	4.509	2.063	5.090
65	XM204 Z8	14.52	21.93	135.44	58.55	.678	3.217	3.120
66	XM204 Z8	10.65	21.93	135.44	58.55	.594	3.034	2.254
67	XM204 Z8	14.52	21.93	135.58	44.05	.878	2.731	3.788
68	XM204 Z8	10.65	21.93	135.58	44.05	.834	3.217	2.754
69	XM204 Z8	14.52	21.93	135.87	29.45	1.436	2.185	5.011
70	XM204 Z8	10.65	21.93	135.87	29.45	1.197	2.488	3.682
71	XM204 Z8	14.52	21.93	136.15	22.25	1.696	1.821	5.658
72	XM204 Z8	10.65	21.93	136.15	22.25	1.556	1.821	4.260
73	XM204 Z8	14.52	21.93	159.80	58.90	.452	3.156	3.506
74	XM204 Z8	10.65	21.93	159.80	58.90	.446	2.610	2.945
75	XM204 Z8	14.52	21.93	161.60	41.92	.485	2.124+	3.048
76	XM204 Z8	10.65	21.93	161.60	41.92	.446	4.370	2.647
77	XM204 Z8	14.52	21.93	166.40	46.44	.532	2.852	4.040
78	XM204 Z8	10.65	21.93	166.40	46.44	.618	3.034	3.492
79	XM204 Z8	14.52	21.93	173.30	49.83	.406	2.742	3.426
80	XM204 Z8	10.65	21.93	173.30	49.83	.412	2.610	3.396

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
1	XM204 Z7	14.52	49.46	13.04	16.63	.647	1.463	-NREC-
2	XM204 Z7	10.65	49.46	13.04	16.63	.521	1.268	-NREC-
3	XM204 Z7	14.52	49.46	13.64	23.93	.531	1.415	-NREC-
4	XM204 Z7	10.65	49.46	13.64	23.93	.541	1.512	-NREC-
5	XM204 Z7	14.52	49.46	13.95	31.13	.510	1.317	-NREC-
6	XM204 Z7	10.65	49.46	13.95	31.13	.479	1.415	-NREC-
7	XM204 Z7	14.52	49.46	14.15	38.43	.510	1.610	-NREC-
8	XM204 Z7	10.65	49.46	14.15	38.43	.428	1.756	-NREC-
9	XM204 Z7	14.52	49.46	14.29	45.72	.469	1.854	5.070
10	XM204 Z7	10.65	49.46	14.29	45.72	.479	1.805	3.795
11	XM204 Z7	14.52	49.46	14.46	60.22	.390	1.561	4.408
12	XM204 Z7	10.65	49.46	14.46	60.22	.408	1.707	3.565
13	XM204 Z7	14.52	49.46	14.56	74.72	.408	1.561	3.912
14	XM204 Z7	10.65	49.46	14.56	74.72	.411	1.707	3.358
15	XM204 Z7	14.52	49.46	14.64	89.22	.380	1.902	3.871
16	XM204 Z7	10.65	49.46	14.64	89.22	.342	1.268	3.086
17	XM204 Z7	14.52	49.46	42.09	30.59	.582	2.049	5.789
18	XM204 Z7	10.65	49.46	42.09	30.59	.562	1.756	4.333
19	XM204 Z7	14.52	49.46	43.03	45.18	.438	2.146	5.362
20	XM204 Z7	10.65	49.46	43.03	45.18	.449	2.341	3.988
21	XM204 Z7	14.52	49.46	43.51	59.67	.459	2.634	4.873
22	XM204 Z7	10.65	49.46	43.51	59.67	.438	2.268	3.561
23	XM204 Z7	14.52	49.46	43.80	74.17	.408	2.878	4.339
24	XM204 Z7	10.65	49.46	43.80	74.17	.377	3.317	3.103
25	XM204 Z7	14.52	49.46	81.39	14.67	.620	1.268	7.301
26	XM204 Z7	10.65	49.46	81.39	14.67	.610	1.317	5.407
27	XM204 Z7	14.52	49.46	84.25	21.91	.500	1.512	7.184
28	XM204 Z7	10.65	49.46	84.25	21.91	.541	1.756	5.176
29	XM204 Z7	14.52	49.46	85.67	29.08	.551	1.268	6.860
30	XM204 Z7	10.65	49.46	85.67	29.08	.479	1.219	5.032
31	XM204 Z7	14.52	49.46	86.54	36.37	.579	1.268	6.550
32	XM204 Z7	10.65	49.46	86.54	36.37	.418	1.659	4.691
33	XM204 Z7	14.52	49.46	87.12	43.66	.548	1.171	5.951
34	XM204 Z7	10.65	49.46	87.12	43.66	.469	1.951	4.491
35	XM204 Z7	14.52	49.46	87.52	50.85	.418	1.366	5.848
36	XM204 Z7	10.65	49.46	87.52	50.85	.500	1.317	4.398
37	XM204 Z7	14.52	49.46	87.84	58.14	.459	1.463	5.438
38	XM204 Z7	10.65	49.46	87.84	58.14	.408	1.463	4.019
39	XM204 Z7	14.52	49.46	88.27	72.63	.390	1.073	4.963
40	XM204 Z7	10.65	49.46	88.27	72.63	.380	1.463	3.578
41	XM204 Z7	14.52	49.46	111.92	13.53	.580	1.268	8.152
42	XM204 Z7	10.65	49.46	111.92	13.53	.570	1.512	5.900
43	XM204 Z7	14.52	49.46	114.75	20.79	.490	.927	7.649
44	XM204 Z7	10.65	49.46	114.75	20.79	.460	1.463	5.731
45	XM204 Z7	14.52	49.46	116.10	27.97	.481	1.073	7.504

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 68.6 DEGREES O.E.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
46	XM204 Z7	10.65	49.46	116.10	27.47	.410	1.073	5.552
47	XM204 Z7	14.52	49.46	116.90	35.25	.480	1.122	7.456
48	XM204 Z7	10.65	49.46	116.90	35.25	.420	1.659	5.466
49	XM204 Z7	14.52	49.46	117.44	42.54	.560	1.415	7.422
50	XM204 Z7	10.65	49.46	117.44	42.54	.490	1.463	5.349
51	XM204 Z7	14.52	49.46	117.81	49.74	.410	1.317	7.026
52	XM204 Z7	10.65	49.46	117.81	49.74	.440	1.317	5.066
53	XM204 Z7	14.52	49.46	118.09	57.03	.480	1.512	6.185
54	XM204 Z7	10.65	49.46	118.09	57.03	.430	1.610	4.674
55	XM204 Z7	14.52	49.46	118.48	71.53	.370	1.463	5.851
56	XM204 Z7	10.65	49.46	118.48	71.53	.361	1.707	4.405
57	XM204 Z7	14.52	49.46	128.16	13.04	.590	1.171	8.021
58	XM204 Z7	10.65	49.46	128.16	13.04	.510	.878	6.389
59	XM204 Z7	14.52	49.46	130.61	20.31	.411	.927	6.736
60	XM204 Z7	10.65	49.46	130.61	20.31	.370	1.415	6.172
61	XM204 Z7	14.52	49.46	131.76	27.49	.530	1.366	-NREC-
62	XM204 Z7	10.65	49.46	131.76	27.49	.334	.829	5.152
63	XM204 Z7	14.52	49.46	132.44	34.78	.340	1.122	-NREC-
64	XM204 Z7	10.65	49.46	132.44	34.78	.330	1.366	7.842
65	XM204 Z7	14.52	49.46	132.89	42.08	.500	1.707	5.986
66	XM204 Z7	10.65	49.46	132.89	42.08	.440	1.024	7.597
67	XM204 Z7	14.52	49.46	133.19	49.27	.360	.927	5.576
68	XM204 Z7	10.65	49.46	133.19	49.27	.430	1.317	7.064
69	XM204 Z7	14.52	49.46	133.43	56.57	.450	1.171	5.173
70	XM204 Z7	10.65	49.46	133.43	56.57	.420	1.171	6.285
71	XM204 Z7	14.52	49.46	133.75	71.06	.360	.976	4.667
72	XM204 Z7	10.65	49.46	133.75	71.06	.350	.878	4.856
73	XM204 Z7	14.52	49.46	158.80	56.27	.380	1.073	4.408
74	XM204 Z7	10.65	49.46	158.80	56.27	.350	1.512	4.326
75	XM204 Z7	14.52	49.46	161.00	89.26	.290	1.415	3.546
76	XM204 Z7	10.65	49.46	161.00	89.26	.280	1.756	8.186
77	XM204 Z7	14.52	49.46	163.35	19.69	.570	1.512	6.723
78	XM204 Z7	10.65	49.46	163.35	19.69	.480	1.463	5.650
79	XM204 Z7	14.52	49.46	164.05	34.1R	.370	1.512	5.641
80	XM204 Z7	10.65	49.46	164.05	34.1R	.370	1.610	4.457
81	XM204 Z7	14.52	49.46	164.54	70.48	.380	1.512	4.057
82	XM204 Z7	10.65	49.46	164.54	70.48	.280	1.024	5.586
83	XM204 Z7	14.52	49.46	165.30	43.73	.440	1.756	5.266
84	XM204 Z7	10.65	49.46	165.30	43.73	.380	1.659	6.378
85	XM204 Z7	14.52	49.46	165.70	39.16	.430	1.463	5.324
86	XM204 Z7	10.65	49.46	165.70	39.16	.360	1.659	5.445
87	XM204 Z7	14.52	49.46	172.90	47.02	.350	.976	5.018
88	XM204 Z7	10.65	49.46	172.90	47.02	.380	1.219	4.439
89	XM204 Z8	14.52	56.66	15.11	86.49	.548	2.367	3.763
90	XM204 Z8	10.65	56.66	15.11	86.49	.515	3.763	

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL.)	MUZZEL HEIGHT (CAL.)	GUN ORIENTATION, ALPHA = 68.6 DEGREES G.F.		GAGE DISTANCE (CAL.)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
				GAGE ANGLE (DEG)	GAGE DISTANCE (CAL.)				
91	XM204 Z8	14.52	56.66	15.13	71.99	.632	2.246	4.691	
92	XM204 Z8	10.65	56.66	15.13	71.99	.570	3.034	3.682	
93	XM204 Z8	14.52	56.66	15.14	57.49	.583	2.367	5.717	
94	XM204 Z8	10.65	56.66	15.16	57.49	.675	3.095	3.775	
95	XM204 Z8	14.52	56.66	15.22	42.99	.712	2.731	5.896	
96	XM204 Z8	10.65	56.66	15.22	42.99	.699	3.277+	4.360	
97	XM204 Z8	14.52	56.66	15.26	35.69	.761	2.428	6.378	
98	XM204 Z8	10.65	56.66	15.26	35.69	.619	2.367	4.677	
99	XM204 Z8	14.52	56.66	15.33	28.39	.797	2.428	6.674	
100	XM204 Z8	10.65	56.66	15.33	28.39	.730	2.549	4.946	
101	XM204 Z8	14.52	56.66	15.44	21.19	.687	2.988	7.081	
102	XM204 Z8	10.65	56.66	15.44	21.19	.724	2.428	5.121	
103	XM204 Z8	14.52	56.66	15.67	13.89	.828	2.367+	7.243	
104	XM204 Z8	10.65	56.66	15.67	13.89	.742	2.488+	5.476	
105	XM204 Z8	14.52	56.66	30.25	72.05	.589	3.581	5.014	
106	XM204 Z8	10.65	56.66	30.25	72.05	.546	3.702	3.575	
107	XM204 Z8	14.52	56.66	30.36	50.25	.663	3.338	5.648	
108	XM204 Z8	10.65	56.66	30.36	50.25	.601	3.338	4.333	
109	XM204 Z8	14.52	56.66	30.51	35.75	.632	3.217	6.554	
110	XM204 Z8	10.65	56.66	30.51	35.75	.718	2.792	4.656	
111	XM204 Z8	14.52	56.66	30.85	21.26	.908	2.792	6.898	
112	XM204 Z8	10.65	56.66	30.85	21.26	.767	3.338	5.045	
113	XM204 Z8	14.52	56.66	45.35	72.15	.632	2.610+	5.008	
114	XM204 Z8	10.65	56.66	45.35	72.15	.521	2.610+	3.592	
115	XM204 Z8	14.52	56.66	45.44	57.65	.711	3.034	5.507	
116	XM204 Z8	10.65	56.66	45.44	57.65	.570	3.520	4.040	
117	XM204 Z8	14.52	56.66	45.59	43.16	.558	2.246+	4.506	
118	XM204 Z8	10.65	56.66	45.59	43.16	.724	3.217	4.550	
119	XM204 Z8	14.52	56.66	45.90	28.56	.774	2.913	6.716	
120	XM204 Z8	10.65	56.66	45.90	28.56	.736	3.156	4.884	
121	XM204 Z8	14.52	56.66	75.60	57.94	.677	3.034	5.993	
122	XM204 Z8	10.65	56.66	75.60	57.94	.584	2.185	4.663	
123	XM204 Z8	14.52	56.66	75.81	43.44	.738	2.713	6.254	
124	XM204 Z8	10.65	56.66	75.81	43.44	.635	3.520	4.915	
125	XM204 Z8	14.52	56.66	75.21	28.84	.637	2.428	6.733	
126	XM204 Z8	10.65	56.66	75.21	28.84	.674	2.974	5.369	
127	XM204 Z8	14.52	56.66	76.62	21.65	.751	2.549	7.515	
128	XM204 Z8	10.65	56.66	76.62	21.65	.714	3.034	5.504	
129	XM204 Z8	14.52	56.66	90.50	72.60	.605	3.156	5.404	
130	XM204 Z8	10.65	56.66	90.50	72.60	.525	2.852	4.167	
131	XM204 Z8	14.52	56.66	90.60	58.10	.608	2.852	6.061	
132	XM204 Z8	10.65	56.66	90.60	58.10	.579	2.670	4.408	
133	XM204 Z8	14.52	56.66	90.71	50.80	.618	2.792	6.526	
134	XM204 Z8	10.65	56.66	90.71	50.80	.678	2.474	4.787	
135	XM204 Z8	14.52	56.66	90.83	43.60	.738	2.792	6.585	

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

GUN ORIENTATION, ALPHA = 68.6 DEGREES O.E.

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	FLIGHT ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
136	XM204 Z8	10.65	56.66	90.83	43.60	.692	3.641+	4.832
137	XM204 Z8	14.52	56.66	91.00	36.31	.705	2.424	7.126
138	XM204 Z8	10.65	56.66	91.00	36.31	.613	2.670	5.076
139	XM204 Z8	14.52	56.66	91.25	29.01	.791	2.610	7.432
140	XM204 Z8	10.65	56.66	91.25	29.01	.654	1.821	5.149
141	XM204 Z8	14.52	56.66	91.64	21.81	.675	2.428	7.622
142	XM204 Z8	10.65	56.66	91.64	21.81	.767	2.488	5.504
143	XM204 Z8	14.52	56.66	92.50	14.51	.779	1.578	7.746
144	XM204 Z8	10.65	56.66	92.50	14.51	.699	2.610+	5.686
145	XM204 Z8	14.52	56.66	105.48	72.77	.572	2.367	6.141
146	XM204 Z8	10.65	56.66	105.48	72.77	.446	2.063	4.508
147	XM204 Z8	14.52	56.66	105.80	43.77	.678	1.881	7.263
148	XM204 Z8	10.65	56.66	105.80	43.77	.585	2.185	5.352
149	XM204 Z8	14.52	56.66	106.20	29.17	.618	1.457	7.432
150	XM204 Z8	10.65	56.66	106.20	29.17	.678	1.942	5.741
151	XM204 Z8	14.52	56.66	106.59	21.97	.692	1.746	7.883
152	XM204 Z8	10.65	56.66	106.59	21.97	.698	1.335	5.851
153	XM204 Z8	14.52	56.66	120.43	72.92	.545	2.488	6.488
154	XM204 Z8	10.65	56.66	120.43	72.92	.430	3.217+	4.634
155	XM204 Z8	14.52	56.66	120.54	58.42	.585	1.821	6.991
156	XM204 Z8	10.65	56.66	120.54	58.42	.578	1.881	5.121
157	XM204 Z8	14.52	56.66	120.61	51.12	.578	2.367	7.508
158	XM204 Z8	10.65	56.66	120.61	51.12	.605	1.760	5.510
159	XM204 Z8	14.52	56.66	120.71	43.92	.559	1.942	7.794
160	XM204 Z8	10.65	56.66	120.71	43.92	.645	2.003	5.810
161	XM204 Z8	14.52	56.66	120.86	36.62	.608	2.003	7.873
162	XM204 Z8	10.65	56.66	120.86	36.62	.489	1.396	5.676
163	XM204 Z8	14.52	56.66	121.07	29.32	.665	1.578	7.918
164	XM204 Z8	10.65	56.66	121.07	29.32	.565	2.124	5.865
165	XM204 Z8	14.52	56.66	121.42	22.12	.618	1.796	8.114
166	XM204 Z8	10.65	56.66	121.42	22.12	.672	1.760	6.037
167	XM204 Z8	14.52	56.66	122.12	14.83	.711	1.457	8.310
168	XM204 Z8	10.65	56.66	122.12	14.83	.672	1.578	6.310
169	XM204 Z8	14.52	56.66	135.35	73.05	.459	1.457	6.709
170	XM204 Z8	10.65	56.66	135.35	73.05	.432	1.760	4.760
171	XM204 Z8	14.52	56.66	135.44	58.55	.559	2.063	7.369
172	XM204 Z8	10.65	56.66	135.44	58.55	.532	1.517	5.452
173	XM204 Z8	14.52	56.66	135.50	51.25	.465	1.694	7.797
174	XM204 Z8	10.65	56.66	135.50	51.25	.552	1.760	5.669
175	XM204 Z8	14.52	56.66	135.58	44.05	.618	2.246	8.066
176	XM204 Z8	10.65	56.66	135.58	44.05	.625	2.063	5.931
177	XM204 Z8	14.52	56.66	135.70	36.75	.572	1.760	8.249
178	XM204 Z8	10.65	56.66	135.70	36.75	.459	1.639	5.948
179	XM204 Z8	14.52	56.66	135.87	29.45	.705	1.681	8.472
180	XM204 Z8	10.65	56.66	135.87	29.45	.532	2.367+	6.234

SUMMARY OF GUN BLAST DATA FOR ROCK ISLAND ARSENAL

RECORD	GUN TYPE	GAGE HEIGHT (CAL)	MUZZEL HEIGHT (CAL)	GAGE ANGLE (DEG)	GAGE DISTANCE (CAL)	PEAK PRESSURE (PSI)	POSITIVE DURATION (M.S.)	ARRIVAL TIME (M.S.)
181	XM204 Z8	14.52	56.66	136.15	22.25	.585	1.881	8.741
182	XM204 Z8	10.65	56.66	136.15	22.25	.638	1.881	6.237
183	XM204 Z8	14.52	56.66	136.71	14.95	.718	1.457	8.527
184	XM204 Z8	10.65	56.66	136.71	14.95	.692	1.699	6.506
185	XM204 Z8	14.52	56.66	150.25	73.15	.446	1.639	6.905
186	XM204 Z8	10.65	56.66	150.25	73.15	.399	1.639	5.104
187	XM204 Z8	14.52	56.66	150.31	58.65	.483	1.881	8.142
188	XM204 Z8	10.65	56.66	150.31	58.65	.344	1.517	5.473
189	XM204 Z8	14.52	56.66	150.41	44.15	.481	1.517	8.359
190	XM204 Z8	10.65	56.66	150.41	44.15	.485	1.881	6.030
191	XM204 Z8	14.52	56.66	150.61	29.55	.593	1.517	8.672
192	XM204 Z8	10.65	56.66	150.61	29.55	.578	1.457	6.389
193	XM204 Z8	14.52	56.66	159.80	58.90	.472	1.517	7.298
194	XM204 Z8	10.65	56.66	159.80	58.90	.479	3.277	5.541
195	XM204 Z8	14.52	56.66	161.60	91.92	.412	1.760	6.206
196	XM204 Z8	10.65	56.66	161.60	91.92	.432	2.003	4.811
197	XM204 Z8	14.52	56.66	165.13	73.21	.412	1.578	6.826
198	XM204 Z8	10.65	56.66	165.13	73.21	.319	2.003	5.243
199	XM204 Z8	14.52	56.66	165.25	36.91	.439	1.699	8.474
200	XM204 Z8	10.65	56.66	165.25	36.91	.479	1.821	6.712
201	XM204 Z8	14.52	56.66	165.42	22.41	.625	1.517	9.003
202	XM204 Z8	10.65	56.66	165.42	22.41	.539	1.760	7.133
203	XM204 Z8	14.52	56.66	166.20	46.49	.598	1.442	7.752
204	XM204 Z8	10.65	56.66	166.20	46.49	.552	1.442	6.564
205	XM204 Z8	14.52	56.66	166.70	41.42	.505	1.092	6.400
206	XM204 Z8	10.65	56.66	166.70	41.42	.439	1.639	6.571
207	XM204 Z8	14.52	56.66	173.30	49.83	.439	1.639	7.556
208	XM204 Z8	10.65	56.66	173.30	49.83	.479	1.735	6.042

ARTILLERY & ARMORED WEAPON SYSTEMS DIRECTORATE  
GENERAL THOMAS J. RODMAN LABORATORY  
ROCK ISLAND ARSENAL

ERRATA SHEET

9 July 1975

Technical Report: R-CR-75-003

Title: PREDICTION OF STANDOFF DISTANCES TO PREVENT LOSS OF HEARING  
FROM MUZZLE BLAST

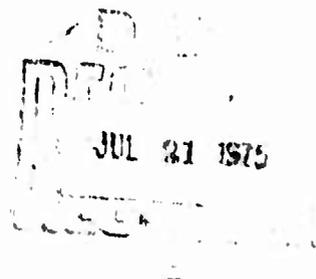
Authors: Peter Westine and James Hokanson of  
Southwest Research Institute

Table C on Page 18 should read as follows:

Table C. Coefficients for Duration Equation

<u><math>\alpha</math> (radians)</u>	<u><math>\sigma</math></u>	<u>a</u>	<u>b</u>	<u>d</u>	<u>e</u>	<u>f</u>
0	23.0%	0.1192	-0.02346	28.0	0.03224	-0.001215
0.293	26.0%	0.1971	-0.04871	42.0	0.04200	0.0
1.197	22.7%	0.05603	-0.000228	42.0	0.05617	+0.004501

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