U.S. ARMY ORDNANCE

Technical Memorandum 12-60

# MUZZLE BLAST MEASUREMENTS ON HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8

OCO, Research Branch Project No. TB1-1000

*human* ENGINEERING



LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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# MUZZLE BLAST MEASUREMENTS ON HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8

By

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August 1960

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## ACKNOWLEDGEMENTS

This blast measurement program involved the active participation of several sections of the Development and Proof Services. The Human Engineering Laboratories wish to express thanks and appreciation to the groups listed below:

The Field and Antiaircraft Artillery Section
for the direction of the firing program.

The Field Instrumentation Section
for the recording of the blast phenomena.

The Weapons Facilities Section
for the installation and firing of the weapon.

The Air Blast Section of the Ballistic Research Laboratories is also due an expression of gratitude for technical consultation on blast phenomena.

## ABSTRACT

Measurements of muzzle blast in the crew area of the 105mm Howitzer, M2A2E2, with Muzzle Brake No. 8, were made primarily to determine the peak overpressures produced. Measures of positive impulse and duration of positive phase were also made. The howitzer was fired at elevations of 1 degree - 14 minutes, 35 degrees - 0 minutes, and 70 degrees - 0 minutes with 2 propelling charges: Charge Zone No. 10 (7.22 ounces of T34 and 3.75 pounds of M17) and 115 per cent of maximum rated pressure (7.22 ounces of T34 and 4.00 pounds of M17). Some of the overpressures measured were high enough to rupture unprotected human eardrums. It is recommended that attempts be made to lower the peak overpressure below 4 psi. If this criterion is not met, ear protection should be mandatory.

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# MUZZLE BLAST MEASUREMENTS ON HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8

## INTRODUCTION

These blast measurements were made as a result of an agreement at a United States-Canadian Technical Steering Committee held at Valcartier, Quebec on 1 and 2 May 1957. At this meeting it was decided that the United States would conduct a blast measurement program on the 105mm Howitzer, M2A2E2

The Human Engineering Laboratories are concerned about all weapons which subject U. S Army personnel to harmful blast effects One of the effects known to be harmful is excessive overpressure. hence the current program

## OBJECTIVES

1. Immediate. The immediate purpose of this program was the determination of peak overpressures within the area occupied by the howitzer crew.

2. Ultimate: The ultimate purposes of the program are:

   a. Protection of the howitzer crew from blast.

   b. Further development of howitzers and muzzle brakes.

### Scope

1. Measurements: Peak overpressure, positive impulse, and duration of positive phase.

2. Area: The crew area on one side of the 105mm Howitzer.

3. Howitzer Elevations: 1 degree - 14 minutes, ($1^{o}$ 14'), 35 degrees - 0 minutes ($35^{o}$ 0'), and 70 degrees - 0 minutes ($70^{o}$ 0').

4. Propelling Charges: Zone No. 10 and 115 per cent of maximum rated pressure.

5. Gage Elevation: Approximately 5 feet 9 inches above the ground.

### Definitions

The following definitions, obtained from the glossary of "The Effects of Nuclear Weapons" (1957), published by the United States Atomic Energy Commission, will obtain in this report.

1. Overpressure: The transient pressure, usually expressed in pounds per square inch, exceeding the ambient pressure, manifested in the shock (or blast) wave from an explosion. The variation of the overpressure with time depends on the energy yield of the explosion, the distance from the point of burst, and the medium in which the weapon is detonated. The peak overpressure is the maximum value of the overpressure at a given location and is generally experienced at the instant the shock (or blast) wave reaches that location. (See Fig. 1).

2. Positive Phase: The transitory state during which the pressure rises very sharply to a value that is higher than ambient and then decreases rapidly to the ambient pressure. The duration of the positive phase increases and the maximum (peak) pressure decreases with increasing distance from an explosion of given energy yield. (See Fig. 1).

3. Impulse: The product of the overpressure from the blast wave of an explosion and the time during which it acts at a given point. More specifically, it is the integral, with respect to time, of the overpressure, the integration being between the time of arrival of the blast wave and that at which the overpressure returns to zero at the given point. (See Fig. 1).

## METHOD

### Apparatus

The following information on gages and recording equipment was obtained from the Field Instrumentation Section of the Development and Proof Services, Aberdeen Proving Ground, Maryland.

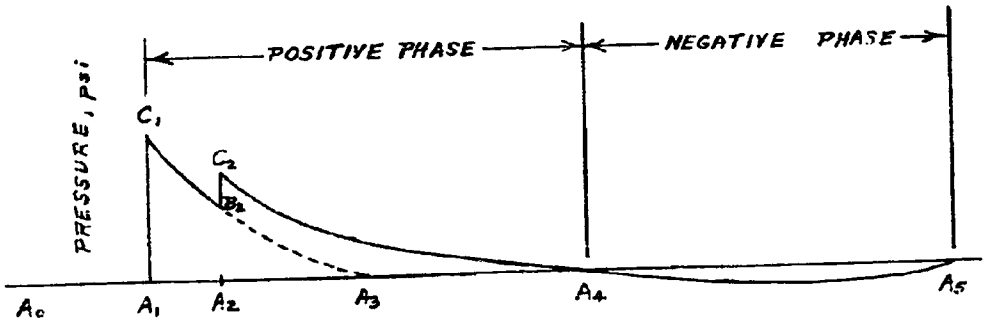
1. Item tested: 105mm Howitzer, M2A2E2 (Mowitzer) with Muzzle Brake No. 8.

2. Blast gages: Eight pencil type LC-33C (Atlantic Research Corp.) gages. This type of gage is pencil-shaped, 10 inches long and 5/8 inch in diameter, with a cylindrical sensitive element of piezoelectric zirconate. The cylinder is mounted coaxially on a spindle under a neoprene cover which is flush with the outer surface. The gage body has an ogive forward section to reduce turbulence and improve the air flow past the sensing element. The sensitivity or calibration factor (KA) of this type of gage is approximately 1200 micro-micro coulombs/psi.

3. Recording system: This system was constructed by the Instrumentation Laboratory of the Development and Proof Services.

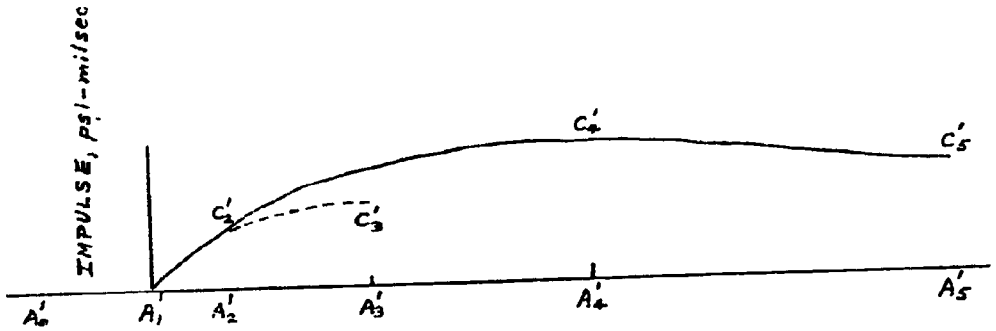
a. Amplifiers having a high input impedance, maximum gain of 70,000 and wide band (0 to 100,000 cps) frequency response.

b. Cathode ray tubes, 5 inch P11 phosphor for display of the amplified gage signal.




TIME, milsec

A PRESSURE-TIME CURVE OF MUZZLE BLAST




TIME, milsec

AN IMPULSE-TIME CURVE OF MUZZLE BLAST
(This curve is the integral of the pressure-time curve)

**TERMS**

| | |
|---|---|
| $A_0A_1$ | Is at atmospheric pressure |
| $A_1C_1$ | Incident or peak overpressure |
| $A_2C_2$ | Total overpressure after reflection |
| $A_1$ | Arrival time of incident shock front |
| $A_2$ | Arrival time of reflected shock front |
| $A_3^1C_3^1$ or Area $A_1C_1B_2A_3$ ) | Incident Positive Impulse |
| $A_0^1A_1^1$ | Is at zero impulse |

Fig. 1. Terms Used to Describe Muzzle Blast

c. Charge calibrator, to apply known charge steps to the gage line.

d. Time standard, crystal controlled, decade divider, frequency standard to provide accurate time markers of 0.1 millisecond and 1.0 millisecond intervals.

e. 35mm strip film cameras, Model 651 (General Radio), to photograph a bank of 4 cathode ray tube beams and associated timing lamps. The cameras operate at a film speed of approximately 80 frames per second.

f. Event sequence timer to control the various operations within the instrument trailer, i.e., starting cameras and applying calibration steps.

Firing dates: 4, 8 and 9 December 1959.

Firing Location: Plate Range, Aberdeen Proving Ground, Maryland.

## PROCEDURE

### General

Pencil-type piezoelectric air blast gages were placed in 16 locations as shown on Chart 1 and Figure 2. Gage locations were determined by the crew positions when the howitzer is fired, as per FM 6-75 and the U. S. Army Ordnance School. The gages were located approximately 5 feet 9 inches above the ground, and on one side of the howitzer. A symmetrical muzzle blast phenomena about the line of fire was assumed.

The howitzer was fired at 3 elevations, $1^{o}$ 14', $35^{o}$ 0', and $70^{o}$ 0'. The gages were located relative to the muzzle when the howitzer was at the $1^{o}$ 14' elevation. This elevation was used rather than $0^{o}$ 0' in order to fire above a down range railroad track. The gages were at these same locations when the howitzer was fired at $35^{o}$ 0' and $70^{o}$ 0' and were pointed toward the muzzle for all firings.

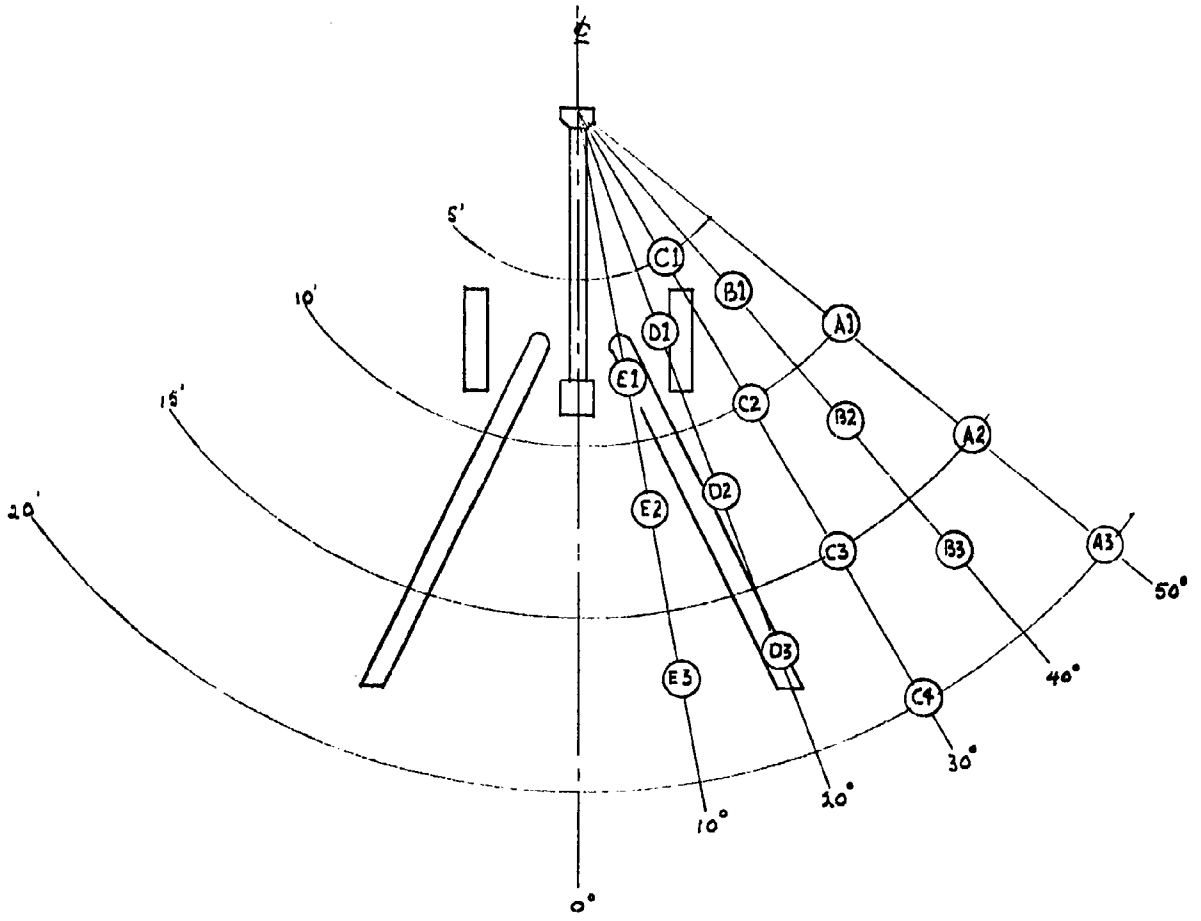
Two types of propelling charge were fired at each elevation for this program:

a. Charge Zone No. 10 (service charge)
   Charge weight: 4.2 lb.
   Propellants: 7.22 oz. T34 and 3.75 lb. M17.

b. 115 percent charge
   Charge weight: 4.5 lb.
   Propellants: 7.22 oz. T34 and 4.00 lb. M17.

CHART 1.
GAGE LOCATIONS FOR
HOWITZER, 105mm, M2A2E2
WITH MUZZLE BRAKE NO. 8

ELEVATION 1° 14'



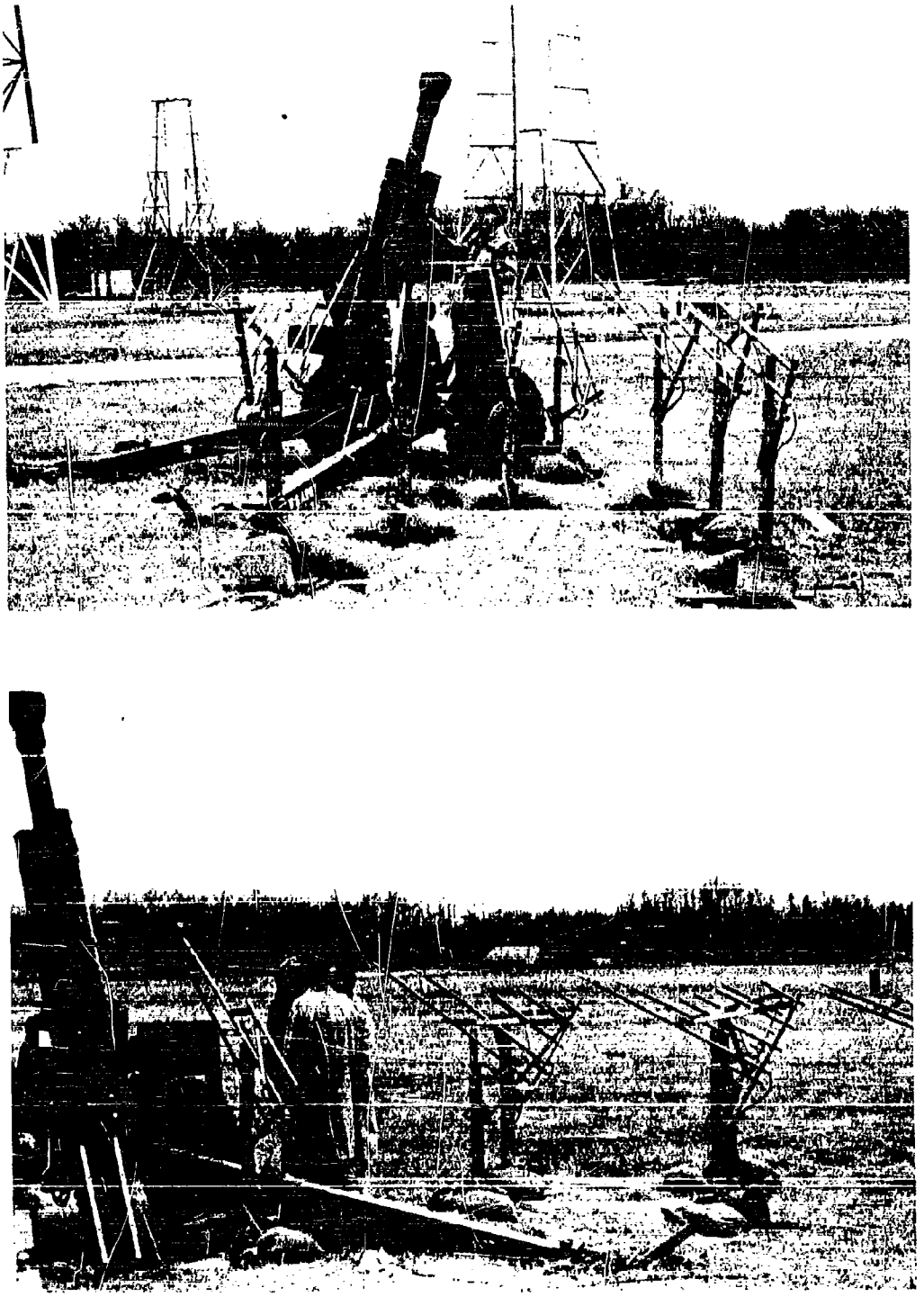


Fig. 2. Views of Gages Pointed Toward Muzzle. Howitzer Elevation: $70^{o}$

## Gage Calibration

The following information on gage calibration was obtained from Report 60-AL-29 (1) and from the Field Instrumentation Section, Development and Proof Services.

Preliminary. Prior to actual firing of the howitzer, each blast gage was calibrated at the pressure level expected to be encountered at that position during the test. This was accomplished by subjecting the gages to detonation of bare charges of spherical pentolite. A pair of velocity gages was used with each blast pressure gage to obtain the shock front velocity. The velocity of the shock front obtained in these firings at each gage position was used in the following Rankine-Hugoniot equation to obtain peak overpressures at that position.

$$\frac{Ps}{Po} = \frac{2\ \gamma}{\gamma + 1}\left[\frac{V^2}{C^2} - 1\right]$$

where,

Ps = peak overpressure
Po = ambient pressure
$\gamma$ = ratio of specific heats = 7/5 for air
V = shock velocity
C = ambient sound velocity

These computed pressures were applied to the recorded peak overpressures to obtain gage constants which were then used in the reduction of the muzzle blast records. Each gage calibration constant used in the reduction of the muzzle blast records represents an average value for 5 individual detonations.

During Firing. Immediately before the firing of each round, charge or calibration steps were applied to the gage lines by the charge calibrator. The values of the steps were adjusted by calibrated capacitance decades corresponding to the expected values developed by the gages. The capacitance of the cables connecting the decades was measured and included in the charge step calculations.

## RESULTS

### Presentation

The average peak overpressure values are presented in tabular form in Table 1, and graphically in Charts 2 - 7. These overpressures, as well as their values of positive impulse and duration of positive phase, are located in the complete summary table in the Appendix.

TABLE 1

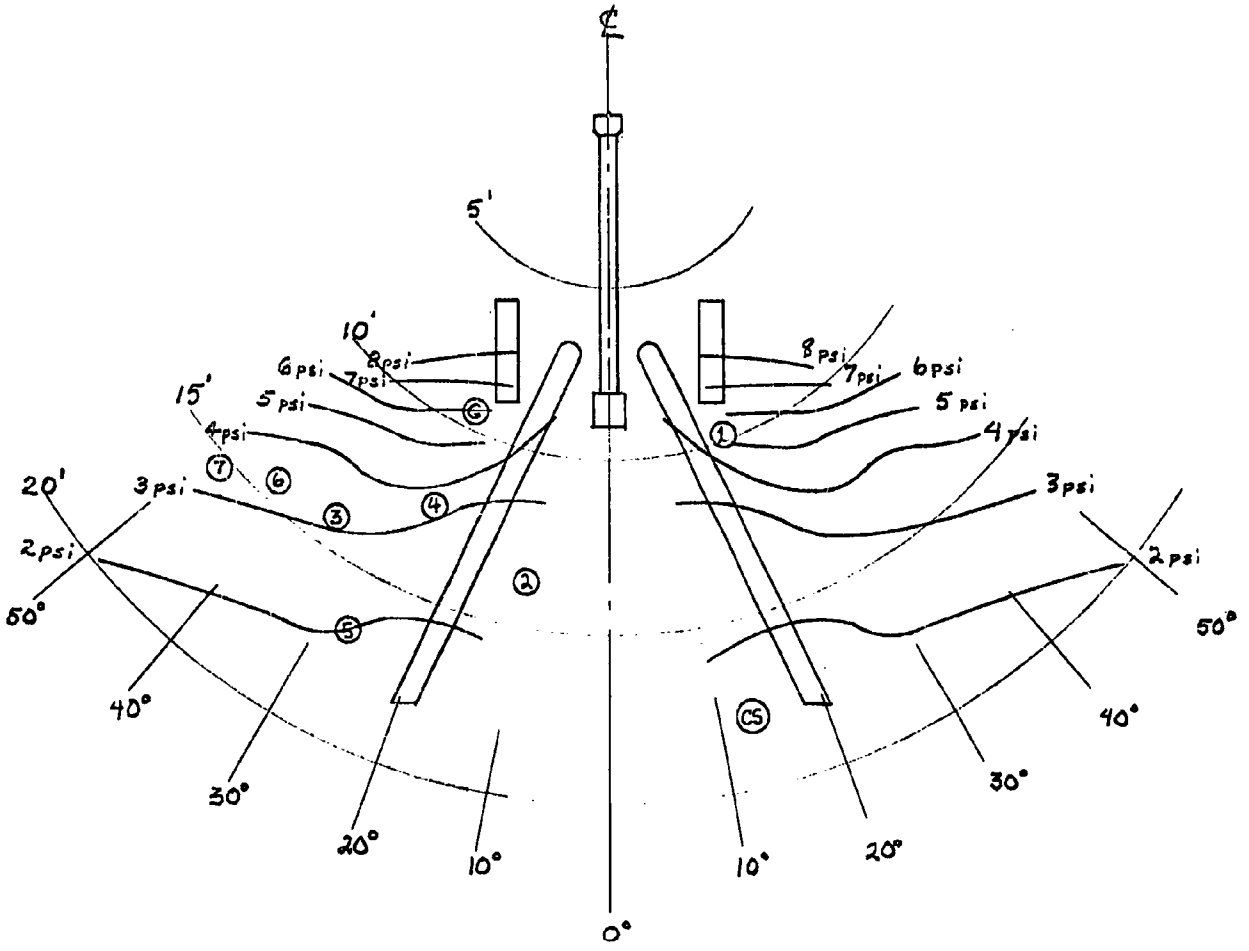
AVERAGE PEAK OVERPRESSURES

| GAGE POSITION* | CHARGE ZONE #10 | | | 115% OVERPRESSURE | | |
|---|---|---|---|---|---|---|
| | Elevation | | | Elevation | | |
| | $1^{o}$ 14' | $35^{o}$ 0' | $70^{o}$ 0' | $1^{o}$ 14' | $35^{o}$ 0' | $70^{o}$ 0' |
| C1 | 12.0 | 15.8 | 9.7 | 12.0 | 16.6 | 10.2 |
| B1 | 11.4 | 11.3 | 9.2 | 11.7 | 11.8 | 10.4 |
| D1 | 8.6 | 10.0 | 8.4 | 8.5 | 10.4 | 9.2 |
| A1 | 6.8 | 6.6 | 6.6 | 7.1 | 7.4 | 6.6 |
| E1 | 4.4 | 5.0 | 5.6 | 5.2 | 5.2 | 5.8 |
| C2 | 5.8 | 6.7 | 8.2 | 6.3 | 7.0 | 7.4 |
| B2 | 4.5 | 5.2 | 5.8 | 4.3 | 5.8 | 6.0 |
| D2 | 2.7 | 4.1 | 5.1 | 3.0 | 4.4 | 6.4 |
| A2 | 3.5 | 3.6 | 4.2 | 3.6 | 3.8 | 3.8 |
| E2 | 2.8 | 3.5 | 3.7 | 2.9 | 4.0 | 4.0 |
| C3 | 2.4 | 3.1 | 3.8 | 2.4 | 3.0 | 4.2 |
| B3 | 2.2 | 2.6 | 3.0 | 2.3 | 3.0 | 3.2 |
| D3 | 1.5 | 2.0 | 2.6 | 1.6 | 2.2 | 2.6 |
| A3 | 2.0 | 2.4 | 2.6 | 2.0 | 2.5 | 2.5 |
| E3 | 1.9 | 2.3 | 2.3 | 1.8 | 2.4 | 2.4 |
| C4 | 1.5 | 1.9 | 2.6 | 1.6 | 2.0 | 2.5 |

* Positions shown on Chart 1

CHART 2.
MUZZLE BLAST MEASUREMENTS
FOR HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8
AT CHARGE ZONE NO. 10

ELEVATION 1° 14'



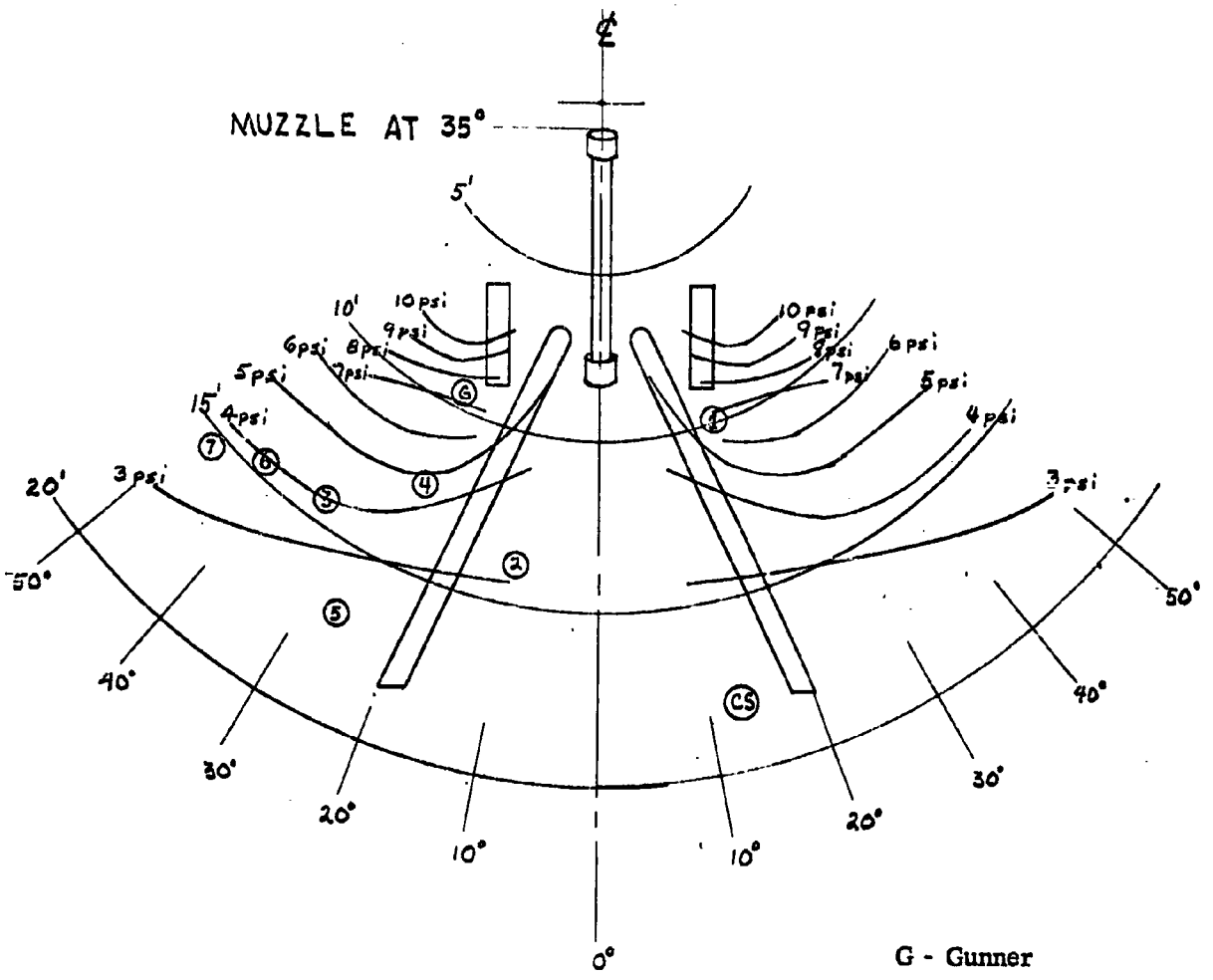

G - Gunner

CS - Chief of Section

CREW POSITIONS SHOWN IN CIRCLES

CHART 3.
MUZZLE BLAST MEASUREMENTS
FOR HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8
AT CHARGE ZONE NO. 10

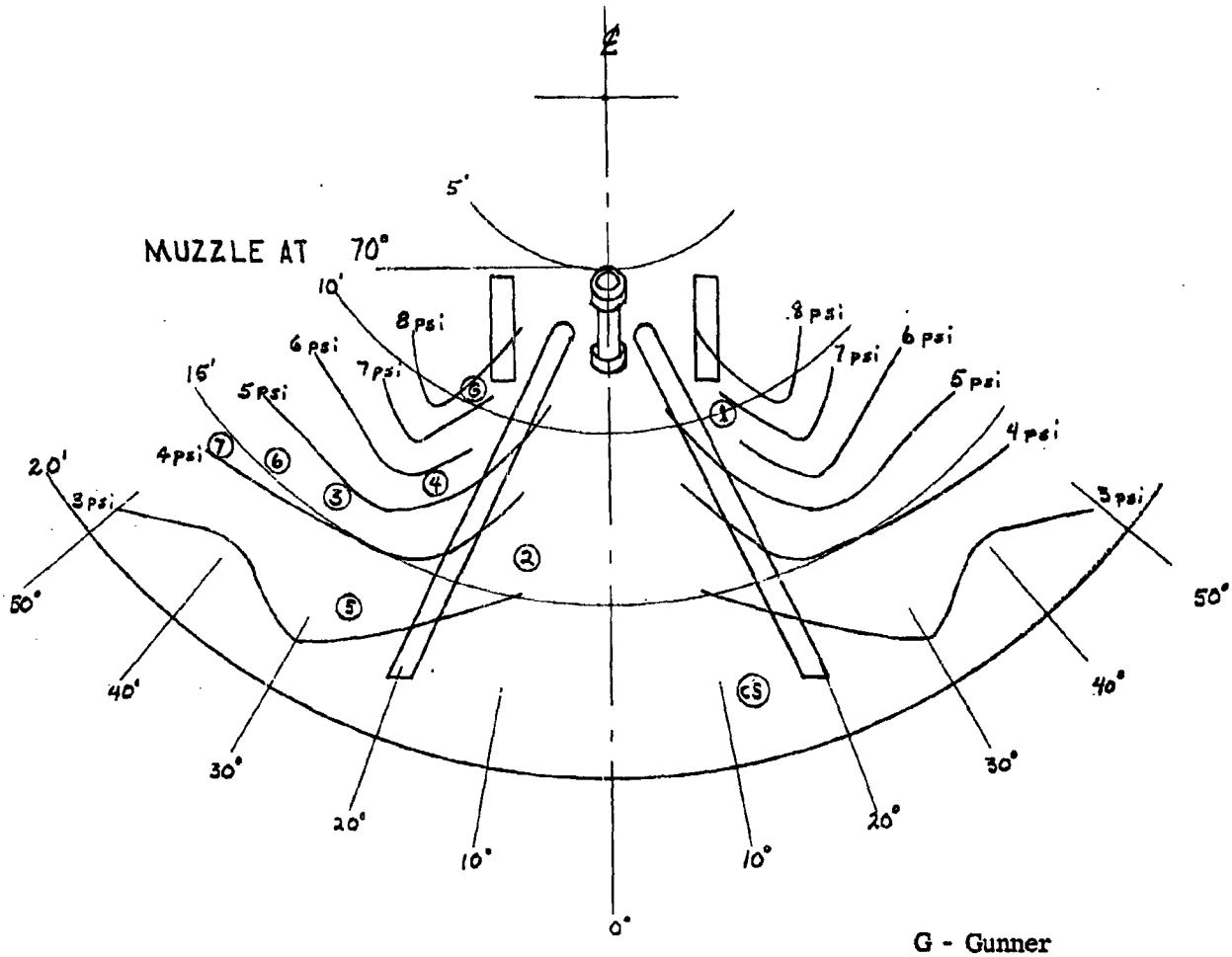
ELEVATION 35°




CREW POSITIONS SHOWN IN CIRCLES

CHART 4.
MUZZLE BLAST MEASUREMENTS
FOR HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8
AT CHARGE ZONE NO. 10

ELEVATION 70°



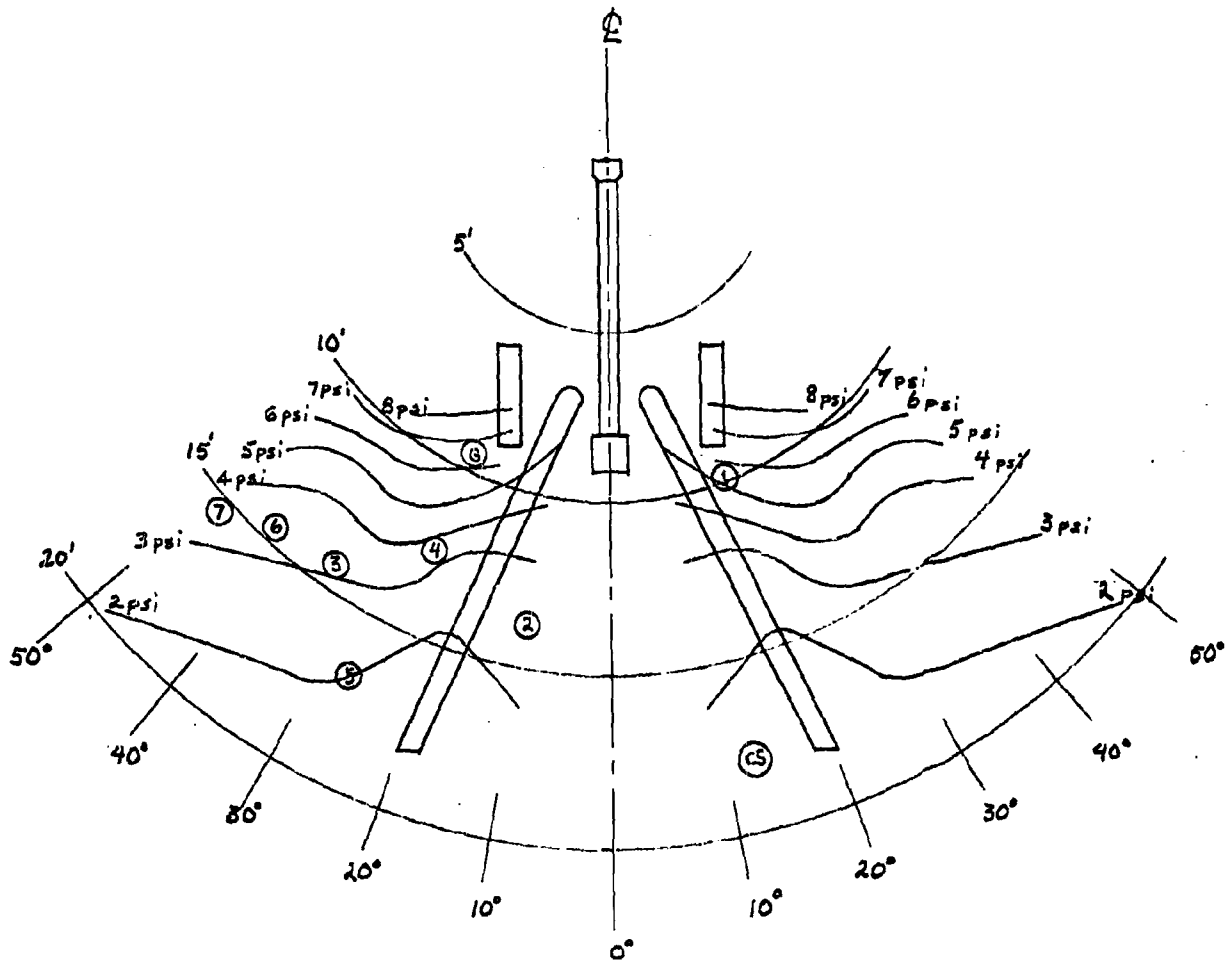

G - Gunner

CS - Chief of Section

CREW POSITIONS SHOWN IN CIRCLES

CHART 5.
MUZZLE BLAST MEASUREMENTS
FOR HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8
AT CHARGE ZONE NO. 115%

ELEVATION 1° 14'

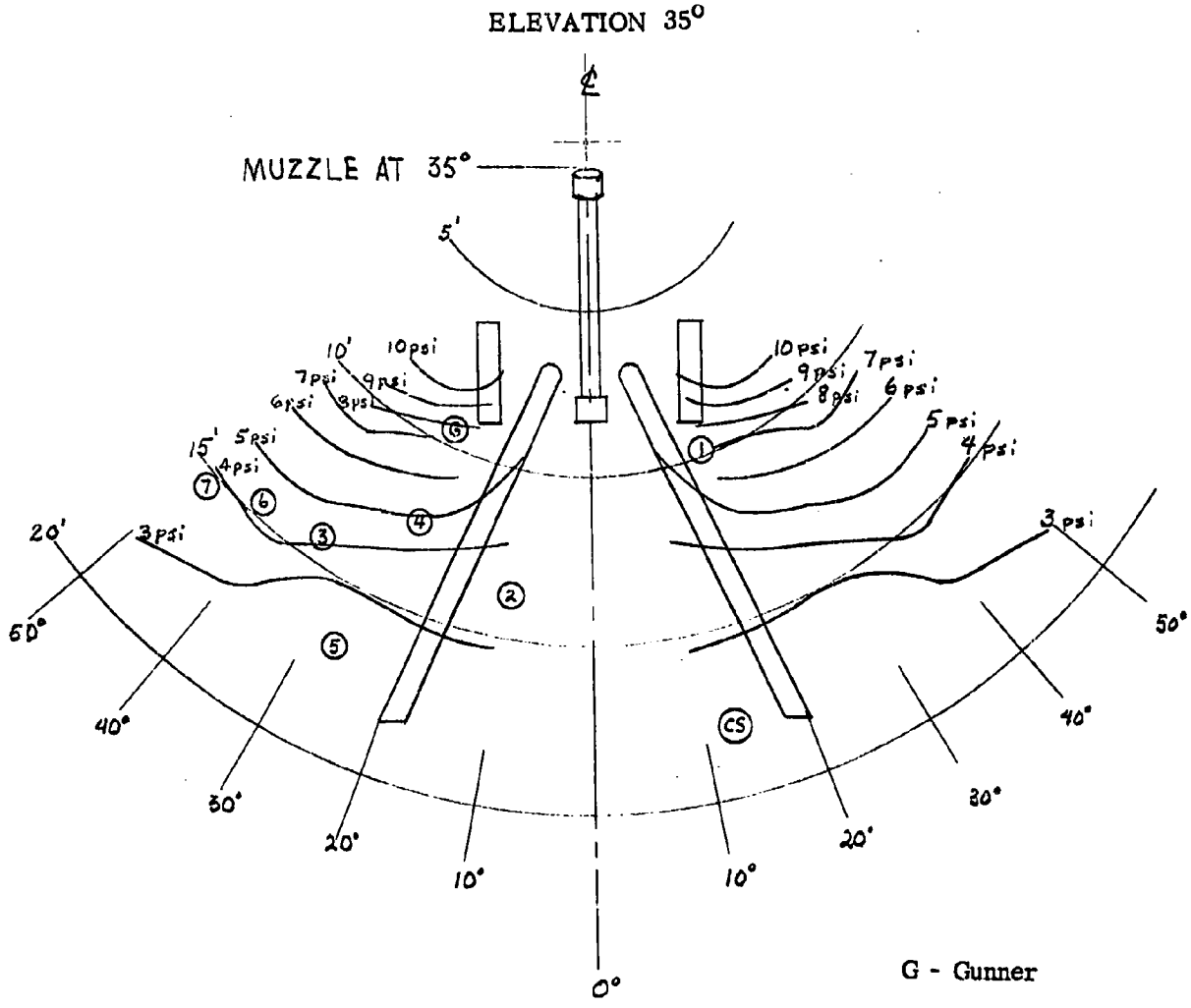



G - Gunner

CS - Chief of Section

CREW POSITIONS SHOWN IN CIRCLES

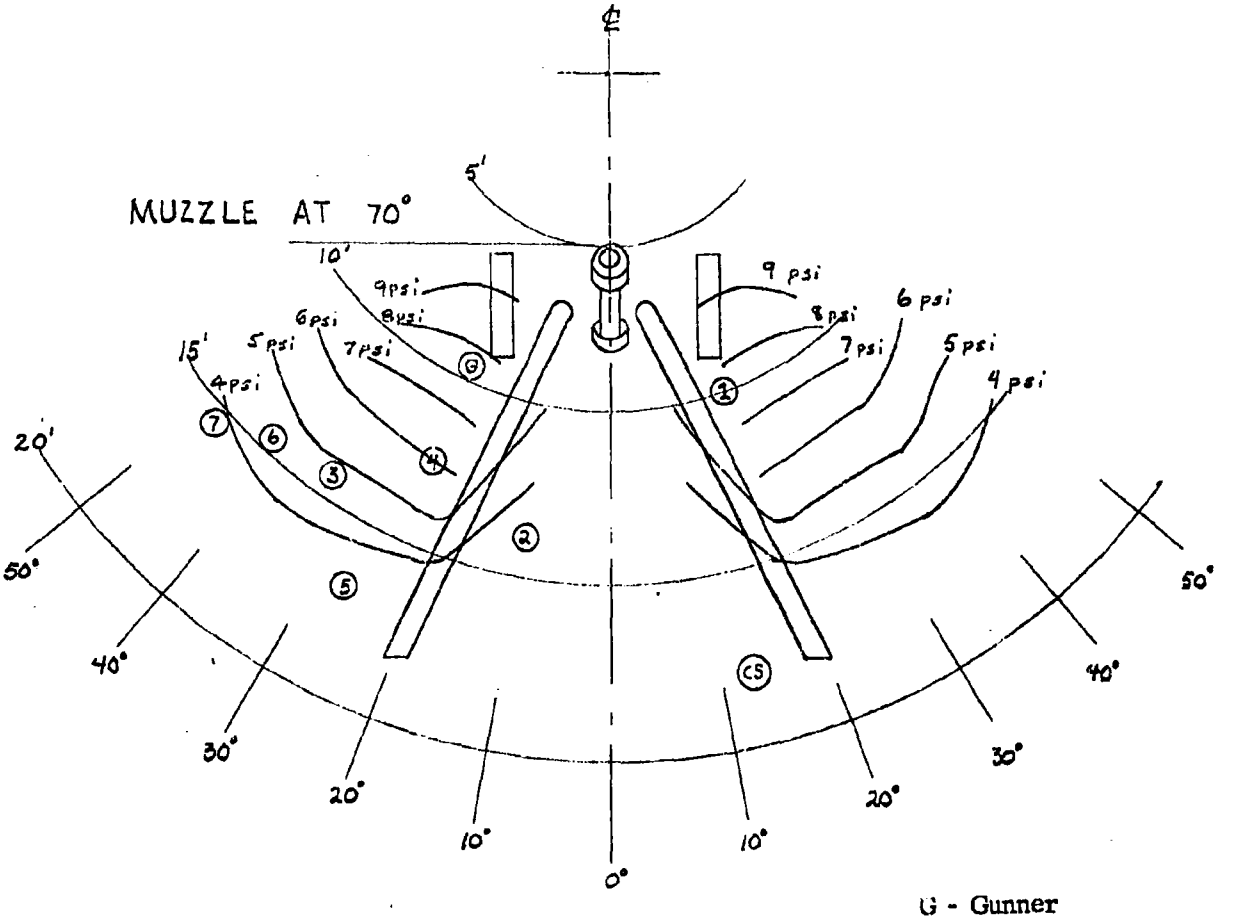
CHART 6.
MUZZLE BLAST MEASUREMENTS
FOR HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8
AT CHARGE ZONE NO. 115%




CREW POSITIONS SHOWN IN CIRCLES

CHART 7.
MUZZLE BLAST MEASUREMENTS
FOR HOWITZER, 105mm, M2A2E2 WITH MUZZLE BRAKE NO. 8
AT CHARGE ZONE NO. 115%

ELEVATION 70°




G - Gunner

CS - Chief of Section

CREW POSITIONS SHOWN IN CIRCLES

Interpretation

A description of muzzle blast pressure, impulse and duration is shown on Fig. 1 (page 3). Three parameters (pressure, impulse and duration) are normally used to express blast gage results. While measurements were obtained on only one side of the howitzer, the peak overpressures were plotted (Charts 2 - 7) on both sides in order to show the overpressure locations relative to the crew positions. Impulse was not presented graphically because less is known about its effect upon personnel, as compared with peak overpressure. These impulses, generally, parallel the peak overpressures in comparative magnitude.

## CONCLUSIONS

Considering only the Charge Zone No. 10 rounds, the results show that six crew members, i.e., all except the numbers 2 and 5 men and the chief of section will be exposed to overpressures exceeding 4 psi and that three crew members, the numbers 1 and 4 men and the gunner will be exposed to 6 to 8 psi.

It is believed that a few normal human eardrums may fail at 4 to 6 psi with high explosive type pressure pulses (5), and known that they have been ruptured by 6 psi, (3) & (5).

Table 1 and Chart 1 show that, except for those gages forward of the crew area, the peak overpressures increased with howitzer elevation. This is attributable to the muzzle coming closer to the crew area with increasing muzzle elevation.

## RECOMMENDATIONS

It is recommended that further design studies and tests be considered on this weapon system to reduce the peak overpressure in the crew area to a value less than 4 psi. If, however, this weapon, as presently developed with Muzzle Brake No. 8, is adopted, ear protection should be mandatory.

## REFERENCES


1. Kokinakis, William. "Muzzle Blast Distribution for Howitzer, 105mm, M2A2E2, with Muzzle Brake No. 8", Analytical Laboratory, Report 60-AL-29, Development and Proof Services, Aberdeen Proving Ground, Maryland, 1960.

2. Meade, R. D., and Eckenrode, R. T. "Psychological and Physiological Effects of Gun Blast With Special Reference to Recoilless Rifles. A Preliminary Literature Survey", Frankford Arsenal Report No. R-1283, 1955.

3. National Research Council. "Report on Blast Injuries", 1943.

4. U.S Atomic Energy Commission. "The Effects of Nuclear Weapons", Washington, D.C., U. S. Government Printing Office, 1957.

5. White, Clayton S. "The Biological Effects of Blast: A Critical Review", (Confidential Report) (Unclassified Title), TID-5251, Lovelace Foundation, Albuquerque, N.M., 1954.

# APPENDIX

SUMMARY OF:

1. Peak Overpressures
2. Positive Impulses
3. Positive Phase Durations

Symbols:

Ps = peak overpressure in pounds per square inch

I = positive impulse in pounds per square inch-milliseconds

T = positive phase duration in milliseconds

| Gage Positions | A1 | | | A2 | | | A3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Charge Zone No. | Ps psi | I psi-ms | T ms | Ps psi | I psi-ms | T ms | Ps psi | I psi-ms | T ms |
| | | | | Elevation 1° 14' | | | | | |
| 10 | 6.8 | 5.9 | 1.7 | 3.8 | 6.1 | 4.1 | 2.2 | 5.1 | 4.3 |
| 10 | 6.7 | 6.0 | 2.3 | 3.2 | 5.8 | 4.2 | 1.9 | 4.4 | 4.0 |
| Average | 6.8 | 6.0 | 2.0 | 3.5 | 6.0 | 4.2 | 2.0 | 4.8 | 4.2 |
| 115% | 7.2 | 7.2 | 2.0 | 3.7 | 4.4 | 2.4 | 2.0 | 4.9 | 4.3 |
| 115% | 7.0 | 6.8 | 2.0 | 3.6 | 3.9 | 2.2 | 2.0 | 4.5 | 4.4 |
| Average | 7.1 | 7.0 | 2.0 | 3.6 | 4.2 | 2.3 | 2.0 | 4.7 | 4.4 |
| | | | | Elevation 35° 0' | | | | | |
| 10 | 6.7 | 7.2 | 2.5 | 3.6 | 4.5 | 2.7 | 2.3 | 2.6 | 3.0 |
| 10 | 6.4 | 6.2 | 2.1 | 3.6 | 4.3 | 2.5 | 2.4 | 2.9 | 2.6 |
| Average | 6.6 | 6.7 | 2.3 | 3.6 | 4.4 | 2.6 | 2.4 | 2.8 | 2.8 |
| 115% | 7.5 | 7.0 | 2.4 | 3.5 | 4.3 | 2.7 | 2.4 | 2.9 | 2.9 |
| 115% | 7.2 | 6.7 | 2.2 | 3.7 | 5.0 | 3.2 | 2.5 | 3.0 | 3.5 |
| 115% | 7.4 | 7.5 | 2.2 | 4.2 | 5.2 | 3.0 | 2.5 | 3.3 | 3.0 |
| Average | 7.4 | 7.1 | 2.3 | 3.8 | 4.8 | 3.0 | 2.5 | 3.1 | 3.1 |
| | | | | Elevation 70° 0' | | | | | |
| 10 | 6.5 | 6.6 | 2.6 | 4.2 | 5.0 | 3.0 | 2.6 | 3.4 | 3.0 |
| 10 | 6.6 | 6.7 | 2.6 | 4.2 | 4.7 | 2.8 | | Lost | |
| Average | 6.6 | 6.6 | 2.6 | 4.2 | 4.8 | 2.9 | 2.6 | 3.4 | 3.0 |
| 115% | 6.8 | 7.1 | 2.5 | 3.5 | 4.2 | 2.7 | 2.4 | 3.3 | 2.8 |
| 115% | 6.4 | 6.7 | 2.5 | 4.2 | 5.0 | 2.9 | 2.6 | 3.5 | 3.1 |
| Average | 6.6 | 6.9 | 2.5 | 3.8 | 4.6 | 2.8 | 2.5 | 3.4 | 3.0 |

| Gage Positions | B1 | | | B2 | | | B3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Charge Zone No. | Ps psi | I psi-ms | T ms | Ps psi | I psi-ms | T ms | Ps psi | I psi-ms | T ms |
| | | | | Elevation 1° 14' | | | | | |
| 10 | 11.2 | 7.5 | 1.6 | 4.1 | 4.1 | 2.1 | 2.2 | 4.6 | 4.3 |
| 10 | 10.0 | 6.9 | 1.6 | 4.7 | 4.2 | 2.3 | 2.2 | 4.3 | 4.0 |
| 10 | 12.2 | 7.7 | 1.6 | 4.6 | 4.2 | 2.2 | 2.3 | 4.9 | 4.5 |
| 10 | 12.0 | 7.7 | 1.8 | 4.5 | 4.5 | 2.6 | 2.1 | 4.6 | 4.1 |
| Average | 11.4 | 7.4 | 1.6 | 4.5 | 4.2 | 2.3 | 2.2 | 4.6 | 4.2 |
| 115% | 11.7 | 8.6 | 1.7 | 4.3 | 4.8 | 2.2 | 2.3 | 4.7 | 4.1 |
| | | | | Elevation 35° 0' | | | | | |
| 10 | 10.5 | 8.4 | 1.6 | 5.1 | 4.9 | 2.2 | 2.7 | 3.0 | 2.6 |
| 10 | 12.0 | 7.6 | 1.6 | 5.3 | 5.2 | 2.6 | 2.7 | 3.1 | 2.7 |
| 10 | 11.4 | 8.1 | 2.1 | 5.1 | 4.8 | 2.2 | 2.5 | 3.0 | 2.5 |
| Average | 11.3 | 8.0 | 1.8 | 5.2 | 5.0 | 2.3 | 2.6 | 3.0 | 2.6 |
| 115% | 12.0 | 8.5 | 1.5 | 6.0 | 5.1 | 2.3 | 2.9 | 3.3 | 2.8 |
| 115% | 11.7 | 8.5 | 1.7 | 5.6 | 5.0 | 2.4 | 3.0 | 3.2 | 2.8 |
| Average- | 11.8 | 8.5 | 1.6 | 5.8 | 5.0 | 2.4 | 3.0 | 3.2 | 2.8 |
| | | | | Elevation 70° 0' | | | | | |
| 10 | 9.5 | 7.4 | 1.9 | 5.7 | 5.7 | 2.4 | 3.1 | 3.3 | 2.7 |
| 10 | 8.7 | 7.6 | 1.9 | 6.0 | 5.6 | 2.4 | 3.0 | 3.5 | 2.9 |
| 10 | 9.3 | 7.3 | 1.9 | 5.8 | 5.5 | 2.4 | 2.8 | 3.4 | 2.7 |
| Average | 9.2 | 7.4 | 1.9 | 5.8 | 5.6 | 2.4 | 3.0 | 3.4 | 2.8 |
| 115% | 10.9 | 7.4 | 1.8 | 5.9 | 5.4 | 2.4 | 3.0 | 3.4 | 2.8 |
| 115% | 9.8 | 7.0 | 1.7 | 6.1 | 5.7 | 2.4 | 3.3 | 3.7 | 2.8 |
| Average | 10.4 | 7.2 | 1.8 | 6.0 | 5.6 | 2.4 | 3.2 | 3.6 | 2.8 |

| Gage Positions | C1 | | | C2 | | | C3 | | | C4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Charge Zone | Ps | I | T | Ps | I | T | Ps | I | T | Ps | I | T |
| No. | psi | psi-ms | ms | psi | psi-ms | ms | psi | psi-ms | ms | psi | psi-ms | ms |
| | | | | | | | Elevation 1° 14' | | | | | |
| 10 | 11.8 | 5.7 | 1.0 | 5.6 | 5.8 | 2.2 | 2.6 | 5.0 | 4.5 | Lost | | |
| 10 | 12.1 | 5.7 | 1.2 | 5.9 | 5.1 | 2.2 | 2.3 | 4.2 | 3.9 | 1.5 | 3.1 | 3.9 |
| Average | 12.0 | 5.7 | 1.1 | 5.8 | 5.5 | 2.2 | 2.4 | 4.6 | 4.2 | 1.5 | 3.1 | 3.9 |
| 115% | 12.0 | 6.3 | 1.6 | 6.4 | 5.7 | 2.0 | 2.4 | 5.1 | 4.6 | 1.7 | 4.3 | 4.5 |
| 115% | 12.0 | 6.2 | 1.3 | 6.2 | 6.5 | 2.1 | 2.3 | 4.6 | 4.0 | 1.6 | 4.1 | 4.5 |
| Average | 12.0 | 6.2 | 1.4 | 6.3 | 6.1 | 2.0 | 2.4 | 4.8 | 4.3 | 1.6 | 4.2 | 4.5 |
| | | | | | | | Elevation 35° 0' | | | | | |
| 10 | 15.6 | 6.3 | 1.1 | 6.9 | 6.7 | 1.9 | 3.0 | 2.9 | 2.3 | 1.9 | 2.6 | 3.6 |
| 10 | 16.0 | 6.4 | 0.8 | 6.5 | 6.8 | 2.1 | 3.2 | 3.1 | 2.3 | 1.9 | 2.0 | 3.7 |
| Average | 15.8 | 6.4 | 1.0 | 6.7 | 6.8 | 2.0 | 3.1 | 3.0 | 2.3 | 1.9 | 2.3 | 3.6 |
| 115% | 15.6 | 6.3 | 0.8 | 6.6 | 5.9 | 2.2 | 2.9 | 3.3 | 2.8 | 1.9 | 2.4 | 3.0 |
| 115% | 15.7 | 5.9 | 0.8 | 7.1 | 6.3 | 2.3 | 3.1 | 3.0 | 2.6 | 2.0 | 2.4 | 2.9 |
| 115% | 18.4 | 6.4 | 1.0 | 7.3 | 6.2 | 2.5 | 3.1 | 2.7 | 3.1 | 2.0 | 2.4 | 3.2 |
| Average | 16.6 | 6.2 | 0.9 | 7.0 | 6.1 | 2.3 | 3.0 | 3.0 | 2.8 | 2.0 | 2.4 | 3.0 |
| | | | | | | | Elevation 70° 0' | | | | | |
| 10 | 9.9 | 7.0 | 1.9 | 8.0 | 6.3 | 1.8 | 3.9 | 3.6 | 2.0 | 2.6 | 2.6 | 2.4 |
| 10 | 9.5 | 6.8 | 2.0 | 8.3 | 6.2 | 2.0 | 3.7 | 3.9 | 2.5 | 2.6 | 2.8 | 2.6 |
| Average | 9.7 | 6.9 | 2.0 | 8.2 | 6.2 | 1.9 | 3.8 | 3.8 | 2.2 | 2.6 | 2.7 | 2.5 |
| 115% | 10.6 | 7.4 | 1.6 | 7.2 | 6.6 | 2.3 | 4.3 | 4.3 | 2.9 | 2.6 | 2.9 | 2.7 |
| 115% | 9.7 | 7.2 | 1.5 | 7.6 | 6.3 | 2.0 | 4.0 | 3.8 | 2.4 | 2.4 | 2.7 | 2.6 |
| Average | 10.2 | 7.3 | 1.6 | 7.4 | 6.4 | 2.2 | 4.2 | 4.0 | 2.6 | 2.5 | 2.8 | 2.6 |

| Gage Positions | D1 | | | D2 | | | D3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Charge Zone No. | Ps psi | I psi-ms | T ms | Ps psi | I psi-ms | T ms | Ps psi | I psi-ms | T ms |
| | | | | Elevation 1° 14' | | | | | |
| 10 | 8.1 | 6.0 | 1.9 | 2.6 | 3.0 | 2.3 | 1.4 | 3.9 | 4.4 |
| 10 | 7.8 | 7.0 | 2.3 | 2.8 | 4.5 | 3.2 | 1.5 | 4.1 | 4.4 |
| 10 | 8.4 | 6.1 | 2.0 | 2.8 | 3.4 | 2.5 | 1.7 | 3.9 | 4.5 |
| 10 | 10.1 | 7.0 | 2.1 | 2.6 | 3.2 | 2.4 | 1.5 | 4.0 | 4.6 |
| Average | 8.6 | 6.5 | 2.1 | 2.7 | 3.5 | 2.6 | 1.5 | 4.0 | 4.5 |
| 115% | 8.5 | 6.1 | 1.9 | 3.0 | 3.7 | 2.5 | 1.6 | 4.2 | 4.1 |
| | | | | Elevation 35° 0' | | | | | |
| 10 | 10.1 | 7.9 | 2.0 | 4.1 | 3.9 | 2.5 | 2.0 | 2.9 | 3.5 |
| 10 | 10.0 | 6.1 | 1.6 | 4.3 | 3.9 | 2.4 | 2.1 | 2.7 | 3.2 |
| 10 | 10.0 | 6.1 | 2.1 | 3.9 | 3.8 | 2.5 | 2.0 | 2.5 | 3.2 |
| Average | 10.0 | 6.7 | 1.9 | 4.1 | 3.9 | 2.5 | 2.0 | 2.7 | 3.3 |
| 115% | 10.3 | 7.4 | 1.9 | 4.5 | 4.3 | 2.3 | 2.1 | 2.8 | 3.1 |
| 115% | 10.4 | 6.7 | 1.7 | 4.4 | 4.1 | 2.5 | 2.2 | 3.1 | 3.0 |
| Average | 10.4 | 7.0 | 1.8 | 4.4 | 4.2 | 2.4 | 2.2 | 3.0 | 3.0 |
| | | | | Elevation 70° 0' | | | | | |
| 10 | 8.2 | 6.1 | 1.9 | 6.0 | 4.3 | 1.9 | 2.5 | 3.1 | 3.5 |
| 10 | 8.6 | 6.5 | 2.0 | 5.0 | 4.7 | 2.6 | 2.6 | 3.5 | 3.2 |
| 10 | 8.5 | 6.2 | 1.6 | 5.2 | 4.3 | 2.2 | 2.6 | 3.1 | 2.9 |
| Average | 8.4 | 6.3 | 1.8 | 5.1 | 4.4 | 2.2 | 2.6 | 3.2 | 3.2 |
| 115% | 9.5 | 6.4 | 1.6 | 6.1 | 5.2 | 2.3 | 2.5 | 3.2 | 2.9 |
| 115% | 9.0 | 6.1 | 1.9 | 6.8 | 5.2 | 2.5 | 2.6 | 3.1 | 3.1 |
| Average | 9.2 | 6.2 | 1.8 | 6.4 | 5.2 | 2.4 | 2.6 | 3.2 | 3.0 |

| Gage Positions | E1 | | | E2 | | | E3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Charge Zone | Ps | I | T | Ps | I | T | Ps | I | T |
| No. | psi | psi-ms | ms | psi | psi-ms | ms | psi | psi-ms | ms |
| | | | | Elevation 1° 14' | | | | | |
| 10 | | | | 2.8 | 4.6 | 4.0 | 1.9 | 4.4 | 4.7 |
| 10 | 4.5 | 5.3 | 2.5 | 2.7 | 4.1 | 3.6 | 1.8 | 4.3 | 4.8 |
| 10 | 4.2 | Lost | | 2.8 | 5.1 | 4.4 | 2.1 | 4.5 | 4.1 |
| | | | | 2.8 | 4.1 | 4.3 | 1.9 | 4.6 | 4.7 |
| Average | 4.4 | | | 2.8 | 4.4 | 4.1 | 1.9 | 4.4 | 4.6 |
| 115% | 5.5 | 4.8 | 2.2 | 2.9 | 4.0 | 4.2 | 1.8 | 5.2 | 5.0 |
| 115% | 4.9 | 4.3 | 2.1 | | | | | | |
| Average | 5.2 | 4.6 | 2.2 | 2.9 | 4.0 | 4.2 | 1.8 | 5.2 | 5.0 |
| | | | | Elevation 35° 0' | | | | | |
| 10 | 4.7 | 4.2 | 1.9 | 3.7 | 3.8 | 2.6 | 2.3 | 2.9 | 3.2 |
| 10 | 5.3 | 4.4 | 2.2 | 3.5 | 3.3 | 2.3 | 2.3 | 2.9 | 2.6 |
| 10 | | | | 3.3 | 3.1 | 2.5 | 2.4 | 2.5 | 2.8 |
| Average | 5.0 | 4.3 | 2.1 | 3.5 | 3.4 | 2.5 | 2.3 | 2.8 | 2.9 |
| 115% | 5.0 | 4.5 | 2.1 | 4.1 | 4.0 | 2.6 | 2.3 | 3.1 | 3.0 |
| 115% | 5.5 | 4.6 | 2.1 | 3.8 | 3.9 | 2.9 | 2.3 | 3.0 | 3.0 |
| 115% | 5.2 | 4.8 | 1.9 | | | | | | |
| Average | 5.2 | 4.7 | 2.1 | 4.0 | 4.0 | 2.8 | 2.4 | 3.0 | 3.0 |
| | | | | Elevation 70° 0' | | | | | |
| 10 | 5.5 | 4.7 | 1.7 | 3.8 | 4.4 | 2.5 | 2.3 | 3.2 | 3.0 |
| 10 | 5.6 | 4.7 | 2.0 | 3.6 | 4.2 | 2.5 | 2.3 | 3.2 | 2.7 |
| 10 | | | | 3.7 | 3.5 | 1.9 | 2.4 | 3.2 | 2.6 |
| Average | 5.6 | 4.7 | 1.8 | 3.7 | 4.0 | 2.3 | 2.3 | 3.2 | 2.8 |
| 115% | 5.8 | 5.3 | 1.6 | 4.0 | 4.3 | 2.0 | 2.3 | 3.2 | 2.5 |
| 115% | 5.9 | 5.4 | 1.8 | 3.9 | 4.3 | 2.5 | 2.5 | 3.3 | 2.8 |
| Average | 5.8 | 5.4 | 1.7 | 4.0 | 4.3 | 2.2 | 2.4 | 3.2 | 2.6 |