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REPORT
NO. 1280

MEASUREMENTS OF NORMALLY REFLECTED SHOCK PARAMETERS FROM EXPLOSIVE CHARGES UNDER SIMULATED HIGH ALTITUDE CONDITIONS

By W. H. Jack, Jr.
B. F. Armendt, Jr.

APRIL 1965

U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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RDT & E Project No. 1M023201A099

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

LIST OF SYMBOLS

R	Radial distance from center of explosive charge (ft)
r	Nondimensionalized radial distance from center of explosive charge, in units of charge radii
W	Explosive weight (lb)
P_o	Ambient pressure (atm)
p_o	Ambient pressure (psi)
P_R	Normally reflected peak excess pressure (psi)
P_S	Side-on peak excess pressure (psi)
Z	Scaled distance = $\frac{R}{W^{1/3}} P_o^{1/3}$, $\frac{ft}{lb^{1/3}} atm^{1/3}$
I_R	Normally reflected first positive impulse (psi-msec)
T	Ambient temperature in degrees Rankine
T_o	Standard temperature = 518 degrees Rankine (equivalent to 59°F)
t	Shock arrival time from the instant of explosion (msec)
Δt	Positive duration (msec)
U	Shock velocity (ft/sec)

INTRODUCTION

In recent years with the advent of high flying aircraft, missiles, and satellites, much interest has been generated in the vulnerability or defeat of these structures by air blast at high altitudes.

At present there is a large amount of published experimental data on blast wave parameters obtained under sea level conditions; however, relatively little data have been obtained under high altitude conditions. If the sea level data could be readily scaled for altitude conditions, it would facilitate many high altitude investigations. Scaling methods developed by Sachs[1*] have been used for predicting blast parameters at high altitude using blast data acquired at sea level. However, the maximum altitude and minimum distance from the explosive charge for which Sachs' scaling is valid have never been determined. In view of these facts, an experimental investigation was conducted to:

1. Measure normally reflected blast parameters in areas relatively close to the charge (1 to 7 feet per pound$^{1/3}$) and under several altitude conditions

2. Determine the extent to which Sachs' scaling applies to altitude conditions

3. Investigate the region of the normally reflected peak excess pressure curve where work by Hoffman[2] predicted an increase of peak pressure as ambient pressure was reduced.

This report describes the tests and results obtained by statically detonating 1/8-pound spheres of Pentolite (50/50, TNT/PETN) in ambient pressures of 0.3, 0.1, 0.01, and 0.0007 atmospheres.

The normally reflected shock wave parameters measured were peak excess pressure, first positive impulse, positive duration, and shock arrival time (Figure 1). Parameters inferred from the above measurements were side-on peak pressure and shock velocity.

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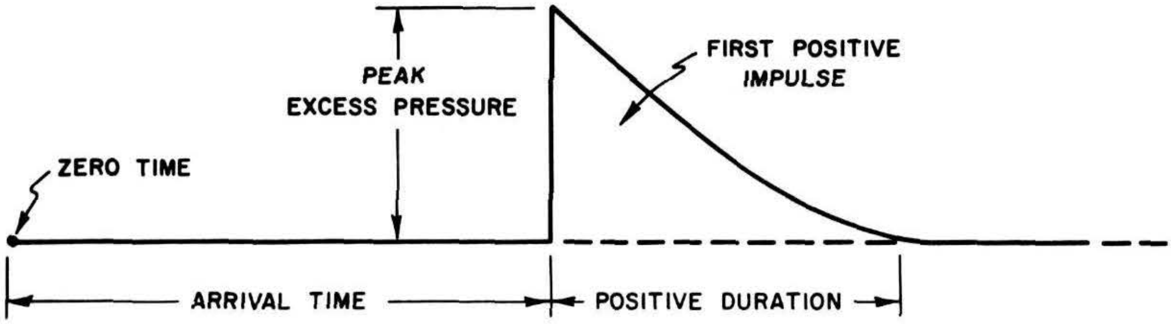
* *Superscript numbers denote references found on page 37.*



PRESSURE TIME HISTORY

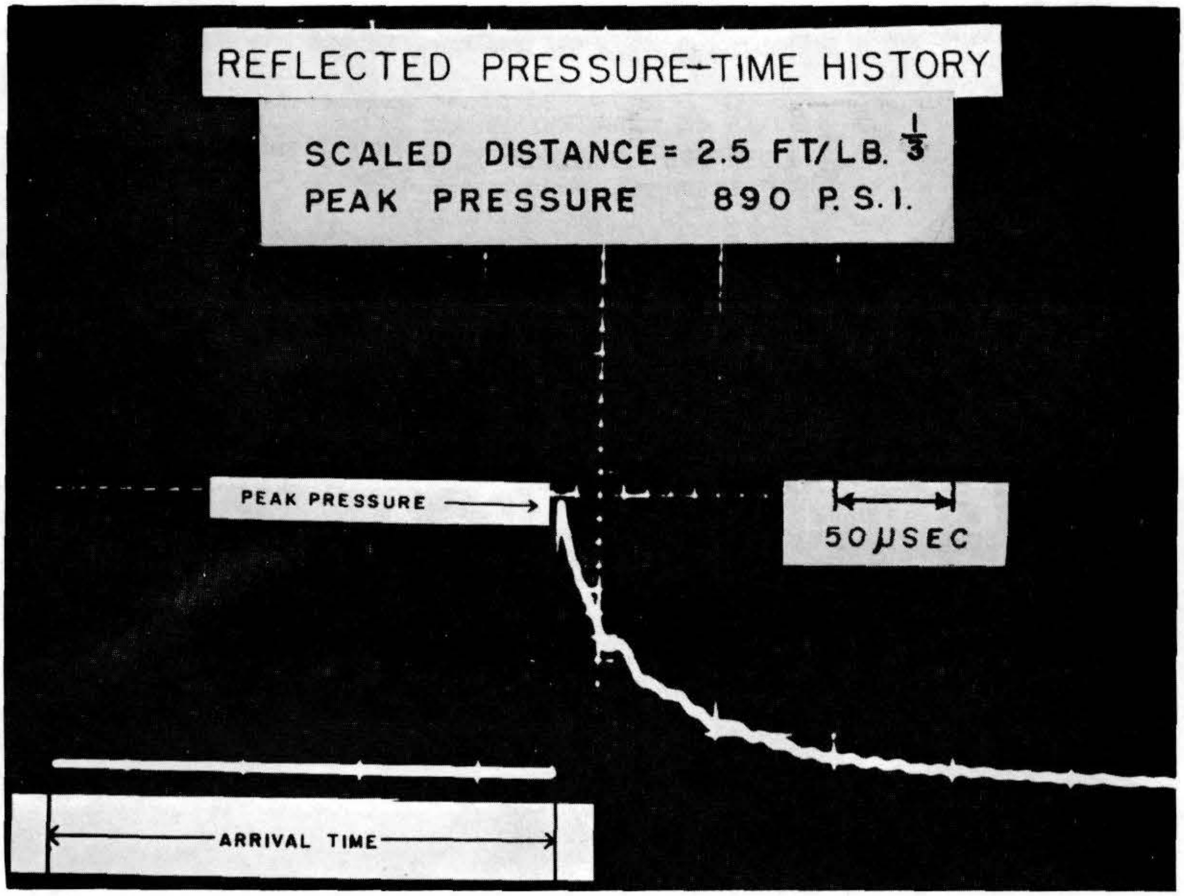


FIGURE I

EXPERIMENTAL FACILITIES

The High Altitude Simulating Blast Sphere Facility (Figure 2) was used for these experiments. This installation consists of two experimental firing chambers. The larger chamber is of spherical shape, 30 feet in diameter, with a nominal wall thickness of 3 inches. At present, this chamber can be evacuated to 0.5 millimeter of mercury (mm Hg), which is equivalent to an altitude of about 175,000 feet[4].

The smaller chamber is of cylindrical shape, 40 feet long and 10 feet in diameter, with a wall thickness of 1/2 inch. At present, this chamber can be evacuated to 10^{-4} mm Hg, which corresponds to an altitude of approximately 350,000 feet*.

Internal temperature in these chambers cannot be controlled. Thus, the ambient temperatures normally found at altitudes equivalent to the ambient pressures used for these experiments were not simulated. Actual ambient temperatures at the times of the detonation ranged from 23 to 81 degrees Fahrenheit.

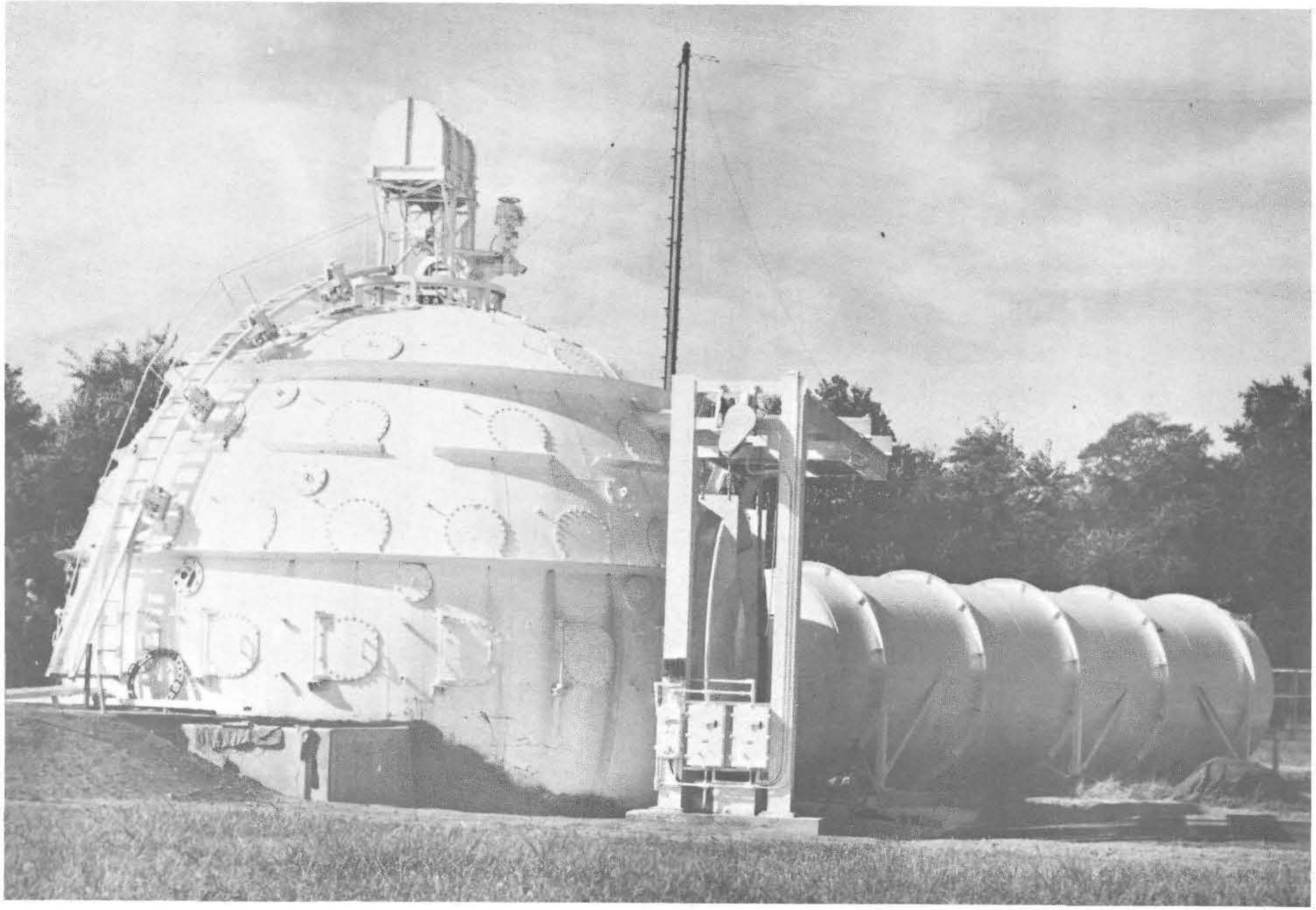
INSTRUMENTATION AND PROCEDURE

Several sizes of piezoelectric transducers were used to obtain the experimental data, two of which are shown in Figure 3. In most cases, at least two transducers were used for blast measurements at each scaled distance and ambient pressure.

To assure a shock-reflecting surface large enough to measure the positive pressure phase before diffraction, a steel plate 6 feet long, 4 feet wide and 3 inches thick was attached to the floor of the

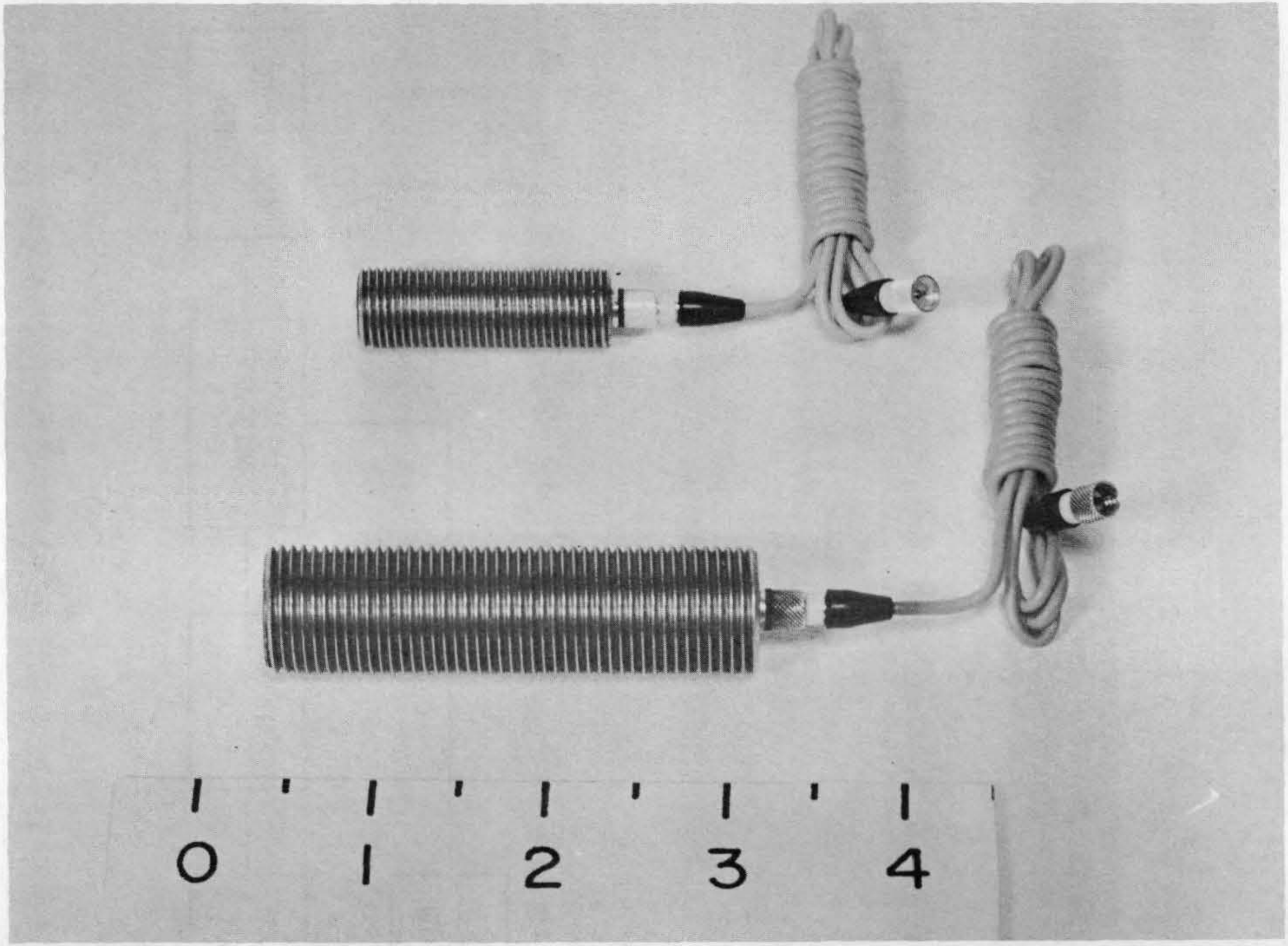
---

* *To be entirely accurate, it should be noted that the conditions produced within the altitude chambers correspond to the altitude mentioned only with regard to ambient pressure. The composition of the atmosphere at high altitude, including the presence of O_3, ions, dissociated particles, lighter gases, etc., is not reproduced. The composition of the atmosphere can affect shock parameters, but any such affects will be ignored in the remainder of this report.*

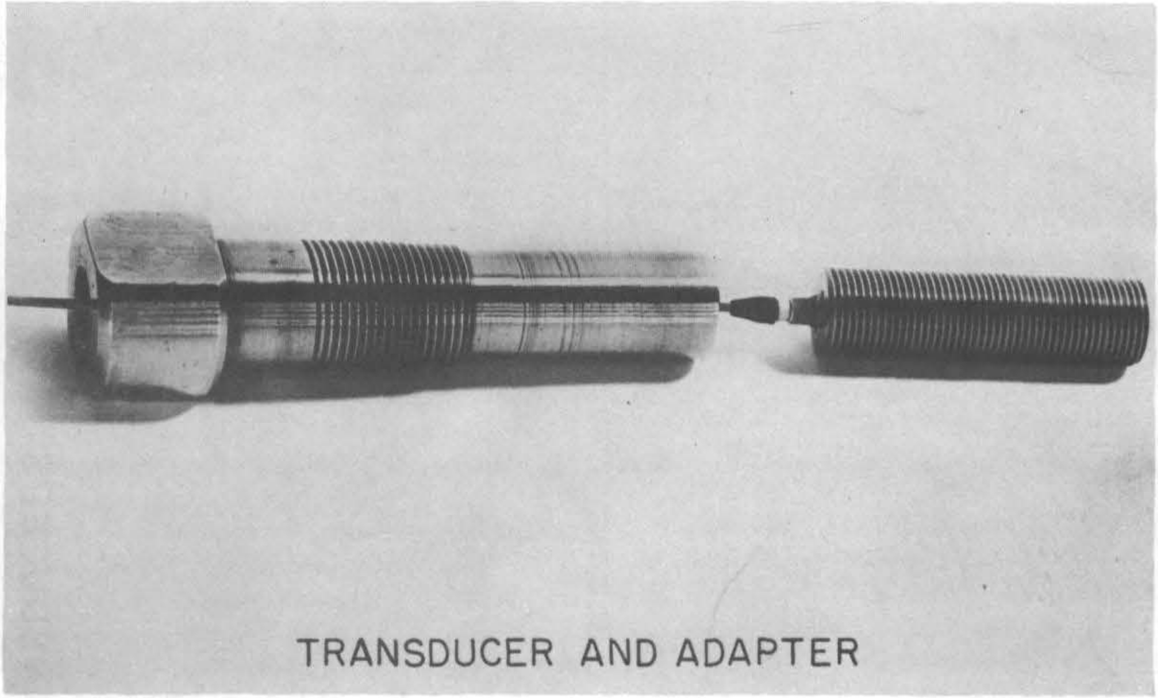


THE HIGH ALTITUDE SIMULATING BLAST SPHERE FACILITY

FIGURE 2

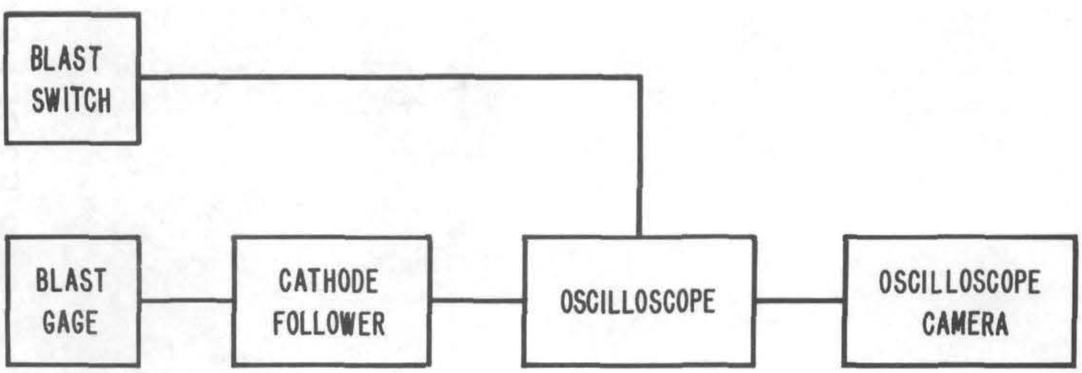


PIEZOELECTRIC TRANSDUCERS
FIGURE 3



TRANSDUCER AND ADAPTER

FIGURE 4



BLOCK DIAGRAM OF THE RECORDING SYSTEM

FIGURE 5

cylindrical blast chamber. The piezoelectric transducers were threaded into a brass adapter (Figure 4) which was then installed in the center of this plate with the element of the transducer flush with the reflecting surface[5].

The recording system (Figure 5) is similar to the one previously used for measurements of normally reflected blast parameters under sea level conditions[5], and consisted of a miniature cathode follower and an oscilloscope equipped with a camera.

Oscilloscope sweep rates between 20 and 200 microseconds per centimeter were used for recording the pressure-time histories, depending upon the scaled distance and ambient pressure for each particular firing. A blast switch mounted on the surface of the charge provided a zero time indication for the measurement of arrival time and was also used to initiate the sweep on the recording oscilloscope.

To measure blast parameters, the recorded pressure-time histories must be calibrated along both the time axis and the pressure axis. To obtain the calibration along the pressure axis for these experiments, pulses of known pressure were applied to the transducer, and the resulting deflection on the oscilloscope was recorded photographically[6]. The values of the blast pressures were obtained by comparing the deflection in the recorded pressure-time histories to that of the calibrations. For time axis calibration the time base unit of the recording equipment (oscilloscope) was used. A typical recorded pressure-time history can be seen in Figure 1 (sea level).

A Wallace and Tiernan absolute pressure gage (mechanical) was used to measure the ambient firing chamber pressures between 0.01 and 1 atmosphere. Ambient pressure less than 0.01 atmosphere was measured by a Magnavac thermocouple gage. Prior to the experimental firings these thermocouple gages were calibrated by comparison with a McLeod gage; the principle of the McLeod gage is the direct application of Boyle's law.

Thermocouples were placed in the chamber at two different locations to record the ambient temperature in the chamber at the time of firing.

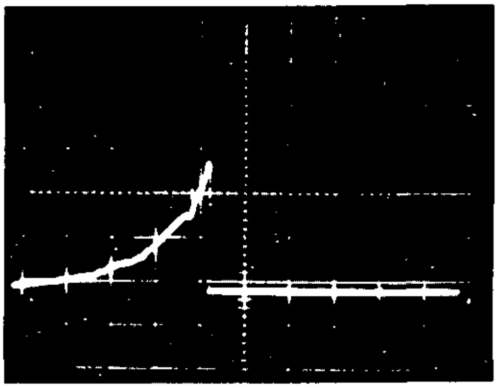
Explosive charges of equal weight were fired at each scaled distance and ambient pressure. The charges were suspended and guyed with cotton string. A miniature tripod alignment jig was used to insure that the center of the charge was along a line perpendicular to the center of the sensing element of the transducer. Electrical detonators, M36A1, were used to initiate the charges. Particular care was taken in positioning the detonators and electrical leads to minimize the possibility of fragments striking the transducers.

RESULTS AND DISCUSSION

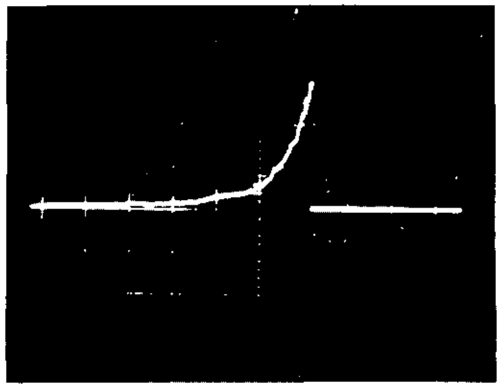
A tabulation of the data by rounds is presented in the Appendix. The data points appearing on the figures in this discussion are the average values of the measured parameters.

Typical recordings of normally reflected pressure-time histories showing the effect of altitude are presented in Figure 6. These recordings were made in ambient pressures ranging from sea level to 0.5 mm Hg at a distance of two feet from the center of the explosive charge. Figure 7 shows further the effect of altitude on shock waves. This particular pressure-time history was recorded in an ambient pressure of approximately 0.1 mm Hg (about 210,000 feet) at a scaled distance of 0.1 feet per pound$^{1/3}$.

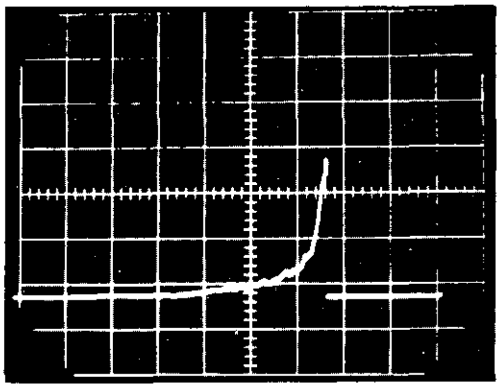
Because of the difficulties encountered in calibrating vacuum gages to measure the very low ambient pressures accurately, no blast data are presented for ambient pressures lower than 0.5 mm Hg or 0.0007 atmospheres. However, the shape of the pressure-time history is of interest because it shows the almost complete disappearance of the sharp shock front normally associated with air blast pressure-time histories. It can be seen in Figures 6 and 7 that pressure-time histories recorded in ambient pressures equivalent to altitudes of 105,000 feet and above and scaled distance between 1 and 7 feet per pound$^{1/3}$ no longer have the characteristics or shape of the sea level pressure-time histories. At sea level there is an instantaneous rise at the shock front to the peak pressure, followed by a relatively slow exponential decay back to



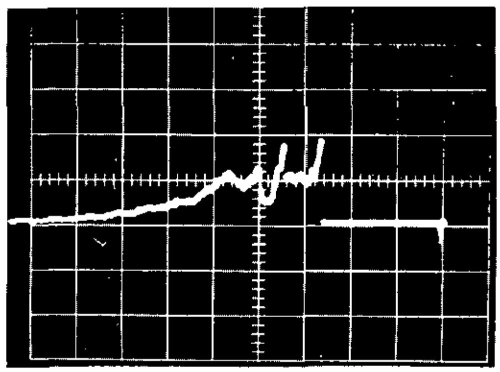
Sea Level



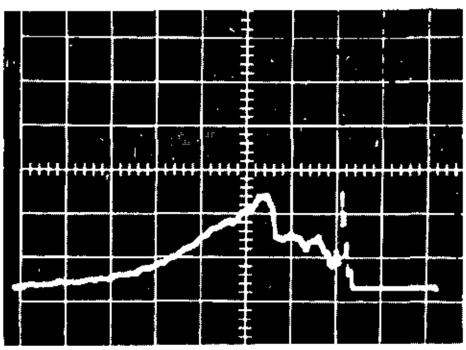
228 mm Hg (approx. 30,000 feet)



76 mm Hg (approx. 52,000 feet)



7.6 mm Hg (approx. 105,000 feet)



0.5 mm Hg (approx. 175,000 feet)

NORMALLY REFLECTED PRESSURE- TIME HISTORIES AT VARIOUS AMBIENT PRESSURES, AT A DISTANCE OF TWO FEET FROM A 1/8 POUND PENTOLITE CHARGE

FIGURE 6

NORMALLY REFLECTED
PRESSURE-TIME HISTORY
SCALED DISTANCE = .10 FT/LB $^{\frac{1}{3}}$
0.1 mm Hq (approx. 210,000 FT.)

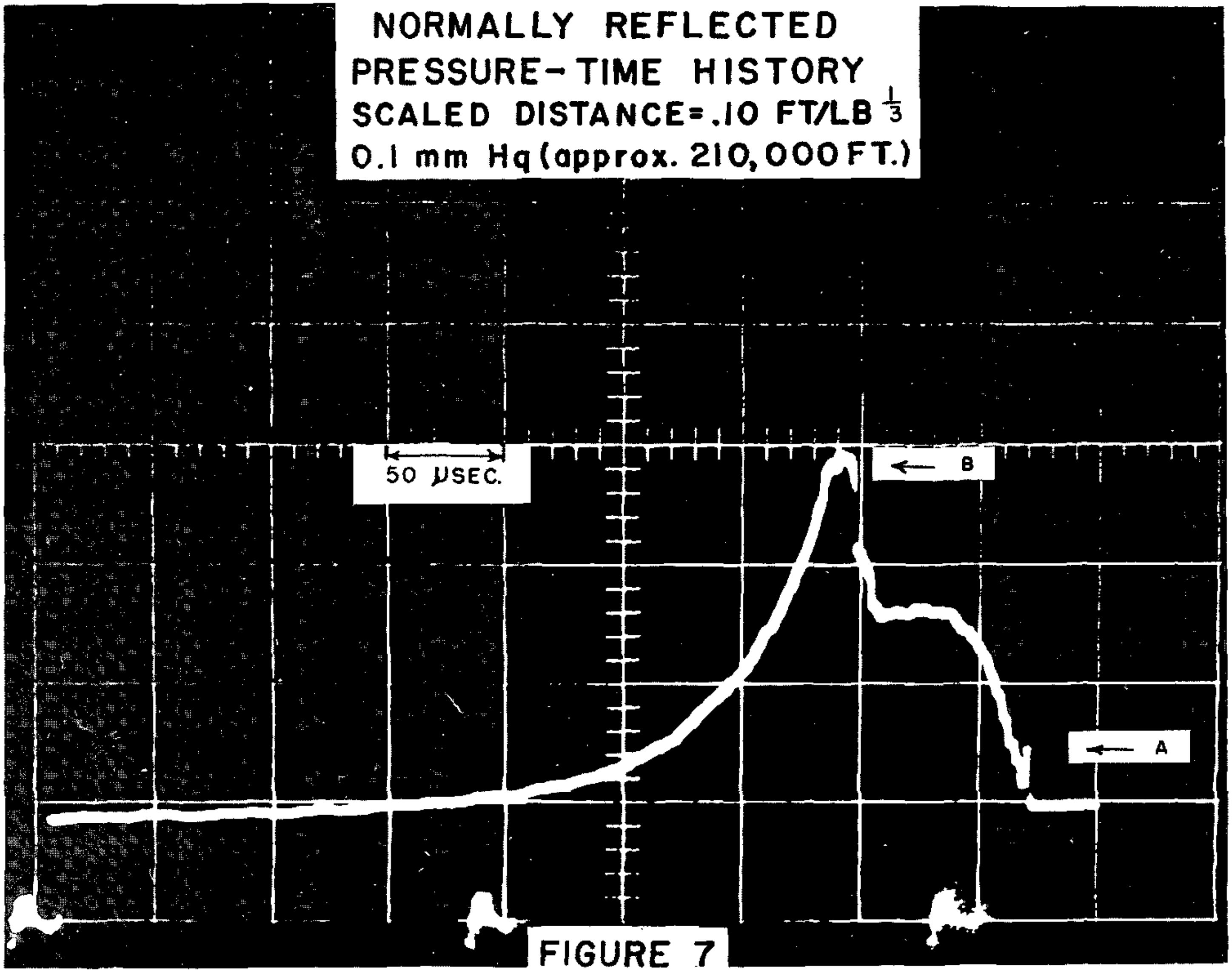


FIGURE 7

(and frequently below) ambient pressure. As the ambient pressure is reduced, the shape of the shock wave gradually begins to change; at pressures equivalent to altitudes *above* 100,000 feet, a more complicated shock wave is observed in which more than one pressure pulse is evident. Even at an ambient pressure equivalent to an altitude of 210,000 feet, the sharp shock front is still observed (see Point A in Figure 7), although as predicted by Sachs' scaling, it is greatly reduced in magnitude. However, at such altitudes the maximum pressure occurs well behind the initial shock front; this second pulse was also observed to have a relatively sharp pressure rise (see Point B in Figure 7). It is believed that as the ambient pressure is reduced further (the lower bound being a perfect vacuum) the initial, sharp-rising shock front will disappear entirely and the pressure pulse observed will be due only to the explosion gases and particles from the charge. Note that theoretical studies of detonation in a perfect vacuum indicate that under such conditions the observed pressure-time history should have a relatively slow rise time and be rounded in shape. It is felt that the rather unusual shapes of the pressure-time histories recorded in these experiments (as in Figure 7) indicate a transition from the classical, sea-level shape to a new "vacuum" shape which is still to be observed.

In the following discussion, each of the blast parameters measured will be treated separately; with regard to peak pressure, separate discussions will be made of the observed pressures in the initial shock front and of the cases where a higher maximum pressure was observed after the initial shock front.

Normally Reflected Peak Excess Pressure

Peak Pressure of Initial Shock Front. The sea level curves that appear in Figures 8, 9, 10, and 11, showing normally reflected peak excess pressure as a function of scaled distance, are based on computations from side-on free-air blast data[3] using the equation:

$$\frac{P_R}{P_S} = 2 + \frac{6Y}{Y + 7} \qquad (1)$$

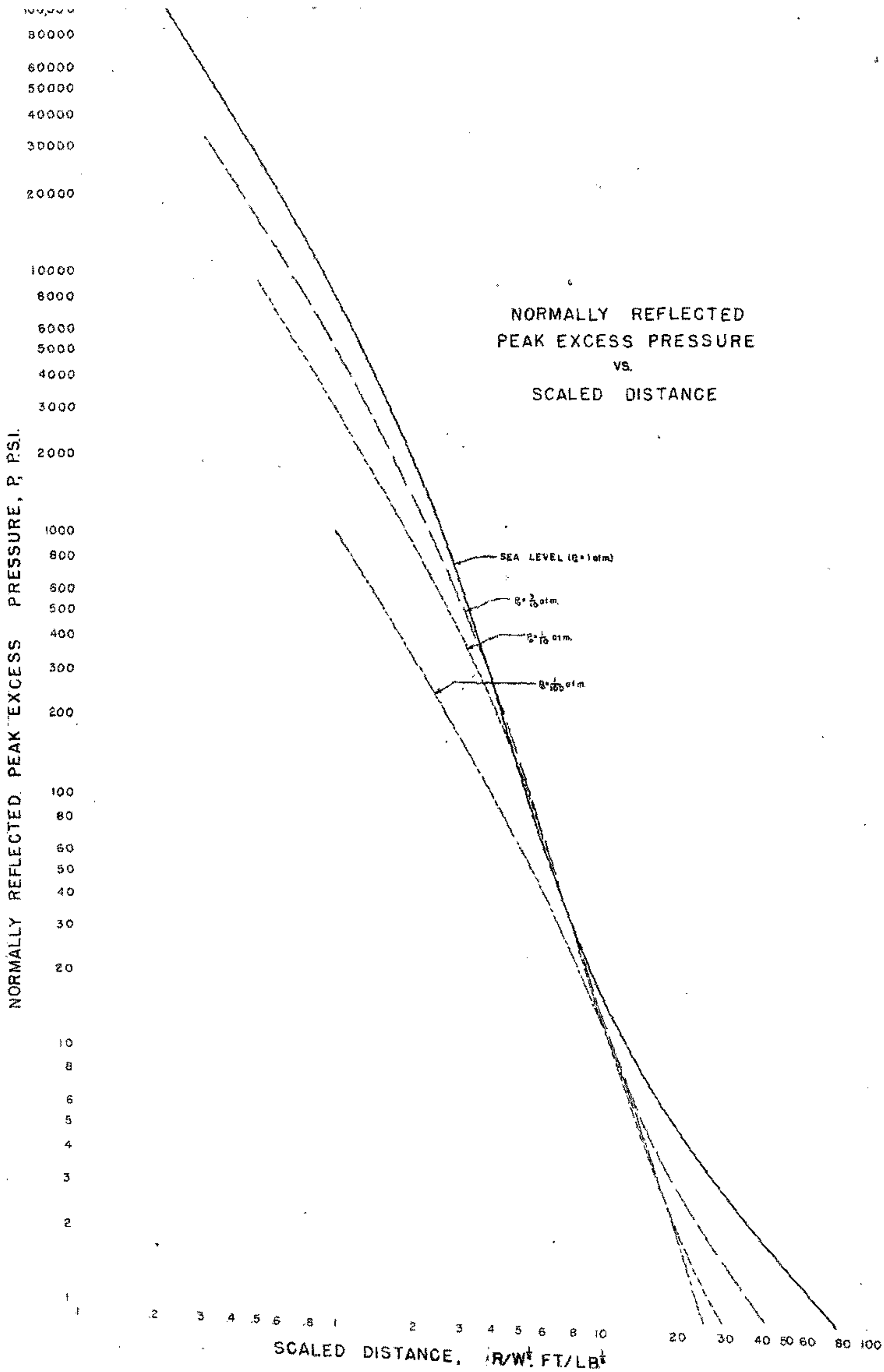

NORMALLY REFLECTED
PEAK EXCESS PRESSURE
VS.
SCALED DISTANCE
SEA LEVEL (P₀ = 1 atm)
$P_0 = \frac{3}{10}$ atm.
$P_0 = \frac{1}{10}$ atm.
$P_0 = \frac{1}{100}$ atm.
NORMALLY REFLECTED PEAK EXCESS PRESSURE, P, P.S.I.
80000
60000
50000
40000
30000
20000
10000
8000
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
.1
.2
.3
.4
.5
.6
.8
1
2
3
4
5
6
8
10
20
30
40
50
60
80
100
SCALED DISTANCE, R/W$^{\frac{1}{3}}$ FT/LB$^{\frac{1}{3}}$

FIGURE 8

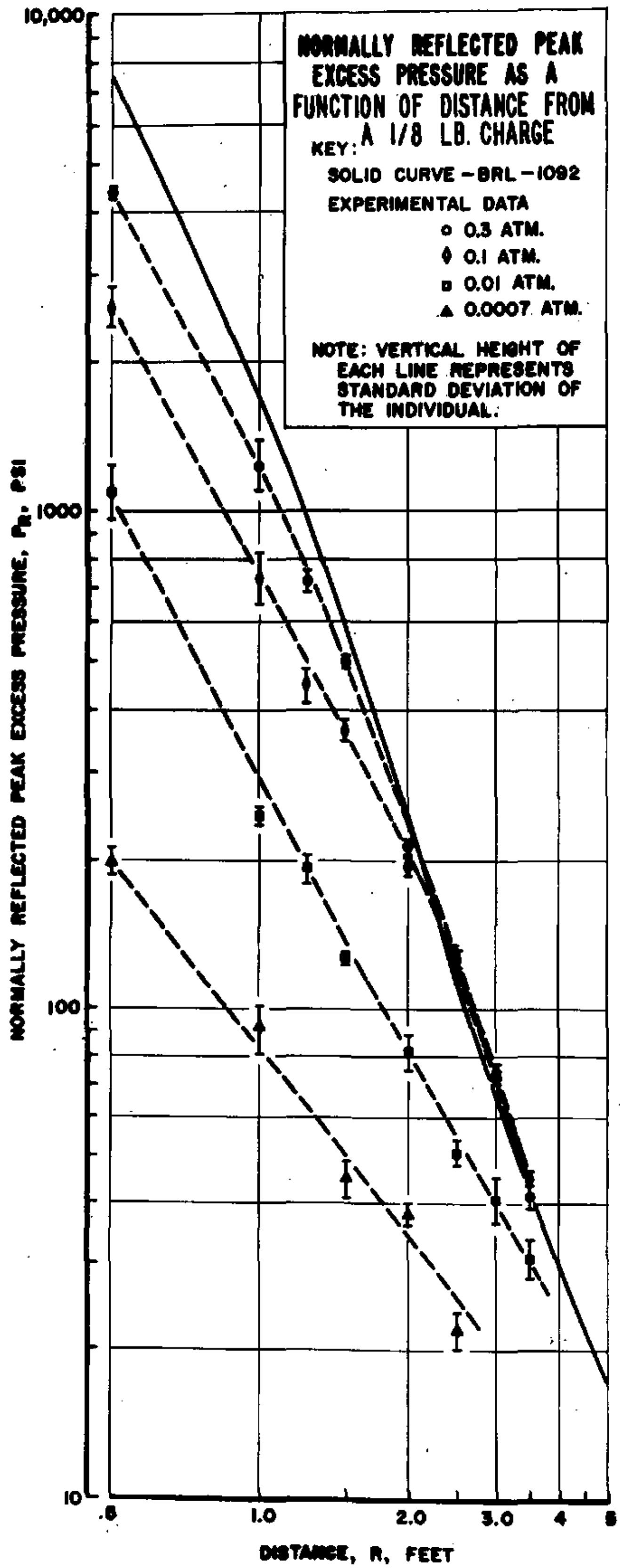

NORMALLY REFLECTED PEAK EXCESS PRESSURE AS A FUNCTION OF DISTANCE FROM A 1/8 LB. CHARGE
KEY:
SOLID CURVE – BRL – 1092
EXPERIMENTAL DATA
0.3 ATM.
0.1 ATM.
0.01 ATM.
0.0007 ATM.
NOTE: VERTICAL HEIGHT OF EACH LINE REPRESENTS STANDARD DEVIATION OF THE INDIVIDUAL.
NORMALLY REFLECTED PEAK EXCESS PRESSURE, P_R, PSI
10,000
1000
100
10
.8
1.0
2.0
3.0
4
5
DISTANCE, R, FEET

FIGURE 9

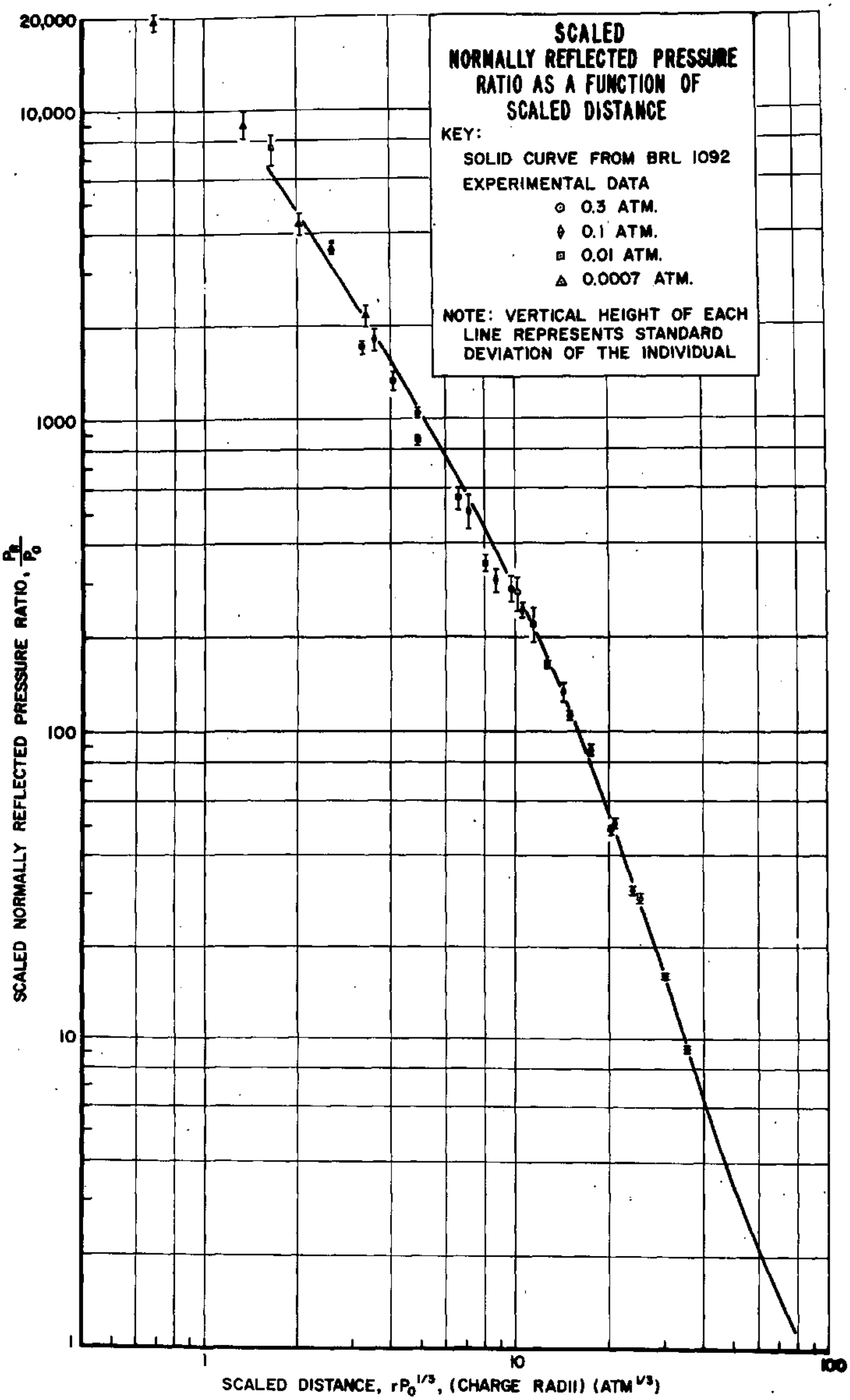

SCALED
NORMALLY REFLECTED PRESSURE
RATIO AS A FUNCTION OF
SCALED DISTANCE
KEY:
SOLID CURVE FROM BRL 1092
EXPERIMENTAL DATA
0.3 ATM.
0.1 ATM.
0.01 ATM.
0.0007 ATM.
NOTE: VERTICAL HEIGHT OF EACH
LINE REPRESENTS STANDARD
DEVIATION OF THE INDIVIDUAL
20,000
10,000
1000
100
10
1
1
10
100
SCALED NORMALLY REFLECTED PRESSURE RATIO, $\frac{P_R}{P_0}$
SCALED DISTANCE, $rP_0^{1/3}$, (CHARGE RADII) (ATM$^{1/3}$)

FIGURE 10

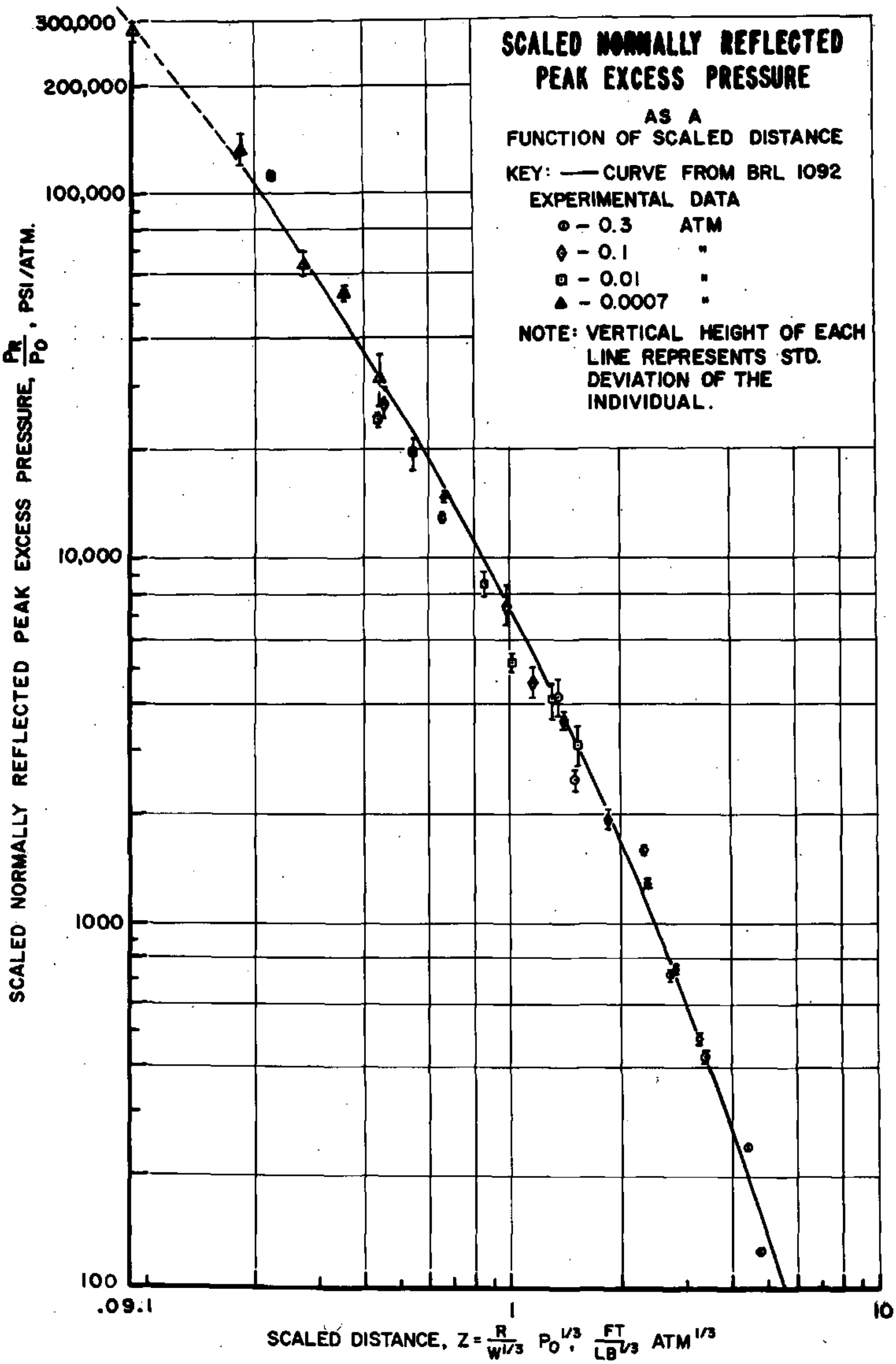

SCALED NORMALLY REFLECTED PEAK EXCESS PRESSURE
AS A FUNCTION OF SCALED DISTANCE
KEY: —— CURVE FROM BRL 1092
EXPERIMENTAL DATA
⊙ – 0.3 ATM
◊ – 0.1 "
□ – 0.01 "
▲ – 0.0007 "
NOTE: VERTICAL HEIGHT OF EACH LINE REPRESENTS STD. DEVIATION OF THE INDIVIDUAL.
300,000
200,000
100,000
10,000
1000
100
.09
.1
1
10
SCALED NORMALLY REFLECTED PEAK EXCESS PRESSURE, $\frac{P_R}{P_O}$, PSI/ATM.
SCALED DISTANCE, $Z = \frac{R}{W^{1/3}} P_O^{1/3}$, $\frac{FT}{LB^{1/3}}$ ATM$^{1/3}$

FIGURE 11

where P_S = side-on peak excess pressure (in psi)

P_R = normally reflected peak excess pressure (in psi)

p_o = ambient pressure (in psi)

$Y = P_S/p_o$ and is less than 20.

For values of Y greater than 20, air cannot be assumed to behave as an ideal gas. For these higher values, calculations by Shear and McCane[8] were used, in which air is treated as a real gas.

The altitude curves shown in Figure 8 are based on the results of the above equations, scaled for the effect of ambient pressure by the method of Sachs.

Average measured values of normally reflected peak excess pressure (of the initial shock front) for reduced ambient pressures of 0.3, 0.1, 0.01, and 0.0007 atmospheres are presented in Figure 9 together with portions of the curves from Figure 8. The theoretical curves for reduced ambient pressure and the experimental data agree favorably over the range of scaled distances in which experiments were conducted.

Both the theoretical curves and the experimental data presented in Figures 8 and 9, respectively, show that the pressure-distance curves for some of the reduced ambient pressures have ranges in which they lie slightly above the pressure-distance curves for higher ambient pressures. Hoffman[2] predicted this increase in pressure and its possible significance to military targets in his work on the effect of altitude on blast waves. By examination of Figure 8 it is evident that the increase in normally reflected peak pressure results from a combination of (1) the shape of the pressure-distance curve and (2) the direction in which the curve shifts when Sachs' scaling for altitude is applied. Scaling the sea level curve for higher altitudes results in the generation of a family of geometrically similar curves which are displaced both down and to the right. It happens that when this displacement is made some of the altitude curves (e.g., the one for 0.3 atmosphere) will slightly overlap the original sea level curve. Examination of the experimental results plotted in Figure 9 shows that in this limited range of scaled distance a slight increase in peak pressure is really observed, while at higher altitudes (e.g., 0.01 atmosphere ambient pressure) the peak pressure is less than for sea level.

The nondimensional curve shown in Figure 10 is included since similar data in the literature are presented in this manner. For theoretical work this presentation is often more convenient. Sachs' scaling theory is applied to the experimental data shown in Figure 10.

The average values of the experimental peak excess pressure are presented in Figure 11 with Sachs' scaling applied. It would appear from Figures 10 and 11 that Sachs' scaling theory is valid for predicting the peak pressure of the initial shock front within the ranges of scaled distances and ambient pressure in which tests were made.

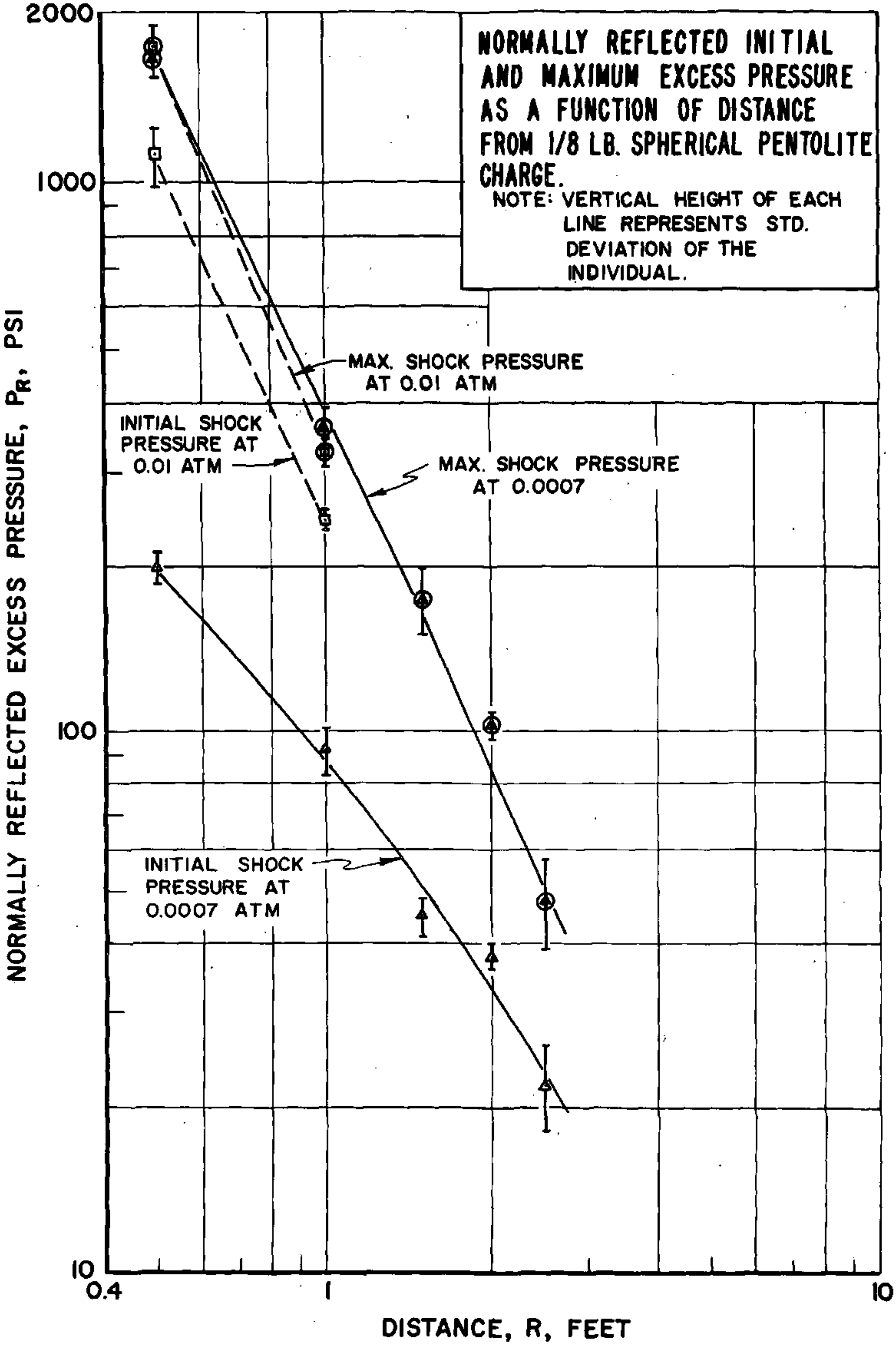
Maximum Pressure (as at Point B in Figure 7)

A tabulation of the maximum pressure by rounds is presented in Table I, under the ambient pressure and scaled distance conditions where they were observed (0.01 and 0.0007 atmospheres).

Both the initial and maximum pressures are plotted as a function of distance in Figure 12. This figure shows that at a reduced ambient pressure of 0.0007 atmospheres the second shock pressure was higher than the initial shock front for all scaled distances used in these findings. The two distances (0.5 and 1.0 feet) at 0.01 atmospheres, where the second pressure pulse is greater in magnitude than the initial shock pressure, are also included in Figure 12. Based on the limited data available at this time, it appears that occurrence of this phenomena is a function of both distance and ambient pressure. The magnitudes of the maximum shock pressures observed in ambient pressures of 0.01 and 0.0007 atmospheres suggest that at distances relatively close to the surface of the charge the maximum shock pressure may be independent of the ambient pressure.

In Figure 13 the observed maximum pressures are plotted with Sachs' scaling applied.

Findings indicate that Sachs' scaling is not valid for predicting the maximum pressure. From the data in Figure 13 and the characteristics of the recorded pressure-time histories, it appears that the curves representing the magnitude of the secondary pressure pulse will merge with the curve of the initial shock.



NORMALLY REFLECTED INITIAL AND MAXIMUM EXCESS PRESSURE AS A FUNCTION OF DISTANCE FROM 1/8 LB. SPHERICAL PENTOLITE CHARGE.
NOTE: VERTICAL HEIGHT OF EACH LINE REPRESENTS STD. DEVIATION OF THE INDIVIDUAL.
MAX. SHOCK PRESSURE AT 0.01 ATM
INITIAL SHOCK PRESSURE AT 0.01 ATM
MAX. SHOCK PRESSURE AT 0.0007
INITIAL SHOCK PRESSURE AT 0.0007 ATM
2000
1000
100
10
0.4
1
10
NORMALLY REFLECTED EXCESS PRESSURE, P_R, PSI
DISTANCE, R, FEET

FIGURE 12

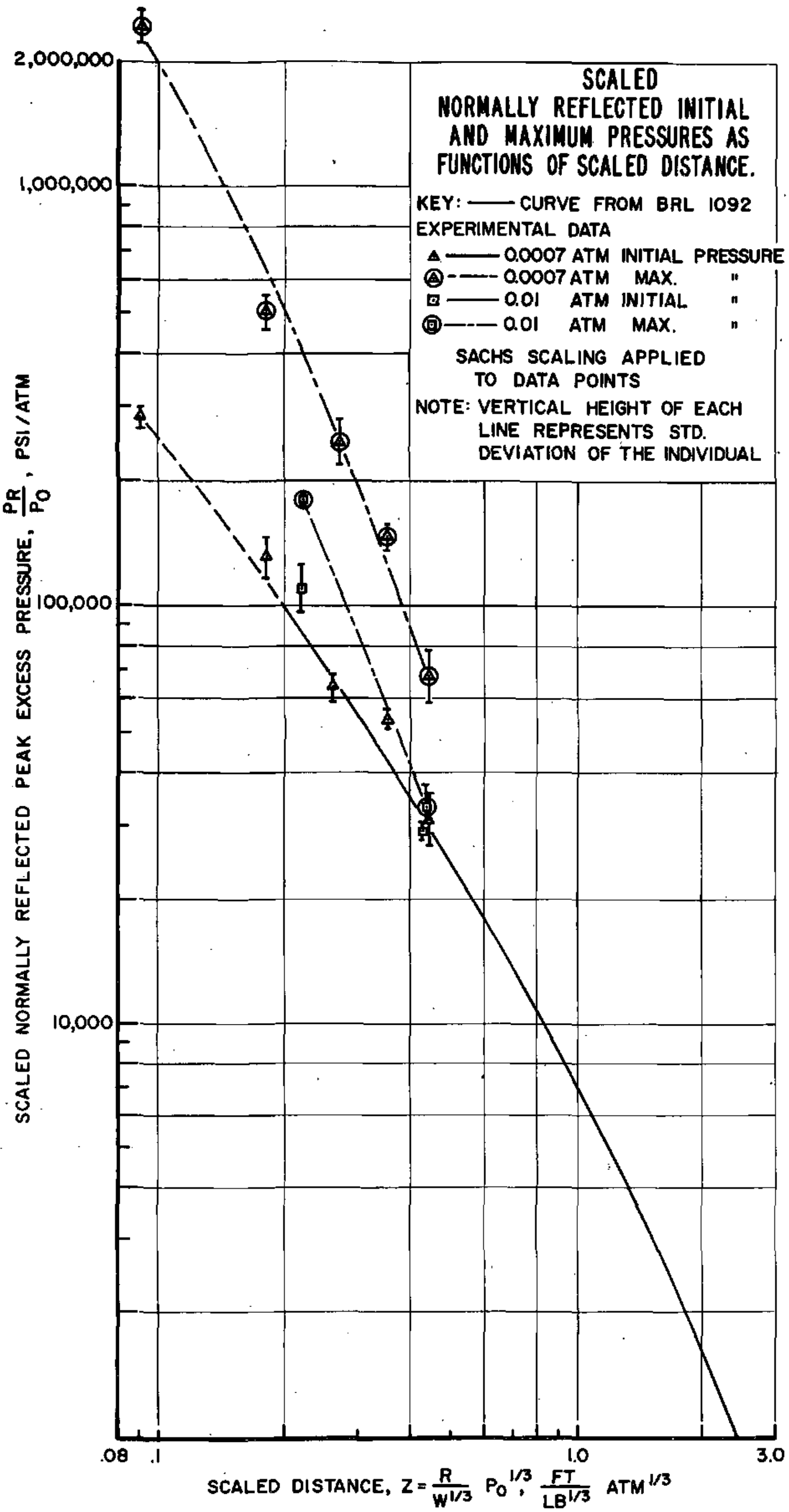

SCALED
NORMALLY REFLECTED INITIAL AND MAXIMUM PRESSURES AS FUNCTIONS OF SCALED DISTANCE.
KEY: —— CURVE FROM BRL 1092
EXPERIMENTAL DATA
0.0007 ATM INITIAL PRESSURE
0.0007 ATM MAX. "
0.01 ATM INITIAL "
0.01 ATM MAX. "
SACHS SCALING APPLIED TO DATA POINTS
NOTE: VERTICAL HEIGHT OF EACH LINE REPRESENTS STD. DEVIATION OF THE INDIVIDUAL
2,000,000
1,000,000
100,000
10,000
.08
.1
1.0
3.0
SCALED NORMALLY REFLECTED PEAK EXCESS PRESSURE, $\frac{P_R}{P_O}$, PSI / ATM
SCALED DISTANCE, $Z = \frac{R}{W^{1/3}} P_O^{1/3}, \frac{FT}{LB^{1/3}} ATM^{1/3}$

FIGURE 13

For military purposes, in which blast is used as a damaging agent against some type of structure, both the maximum pressure and the rate of pressure rise must be considered. If the form of the loading on a target structure is changed from that of the classical sea level shock wave to a more complicated pressure pulse (as in Figure 7), the analysis of structural response to blast may be greatly complicated.

Normally Reflected Positive Impulse

Average values of the normally reflected positive impulse measured in reduced ambient pressures of 0.3, 0.1, 0.01, and 0.0007 atmospheres are presented in Figure 14 with Sachs' scaling applied. The solid curve appearing in Figure 14 is computed from free-air blast data[3]. The dashed curve is from experimental data by Dewey, et al.[7], using the mechanical plug method. In general, the experimental data with altitude scaling applied are in good agreement with these other methods. This conclusion is a little surprising in view of the fact that the maximum pressure in the blast wave above 100,000 feet altitude was not predicted by Sachs' scaling, and yet the impulse measurements indicate that Sachs' scaling is still valid, even for altitudes greater than 100,000 feet. Impulse measurements by Olson, et al.[10], using the mechanical plug technique show that Sachs' scaling is applicable. Perhaps this scaling of impulse can be explained by Dewey's[7] interpretation of the mechanical plug results, which states that impulse is nearly independent of ambient pressure at small scaled distances.

Time of Arrival

Computed time-of-arrival measurements by Goodman[3] are presented as a solid curve in Figure 15. The experimental data, scaled by the method of Sachs, appear to be in very good agreement above a scaled distance of 0.5. Goodman's curve and the experimental data differ greatly at scaled distances of less than 0.5. The possibility exists that Sachs' theory is not valid in regions so close to the charge surface, but it is felt that additional experimental firings with other charge weights will be required to clarify this discrepancy.

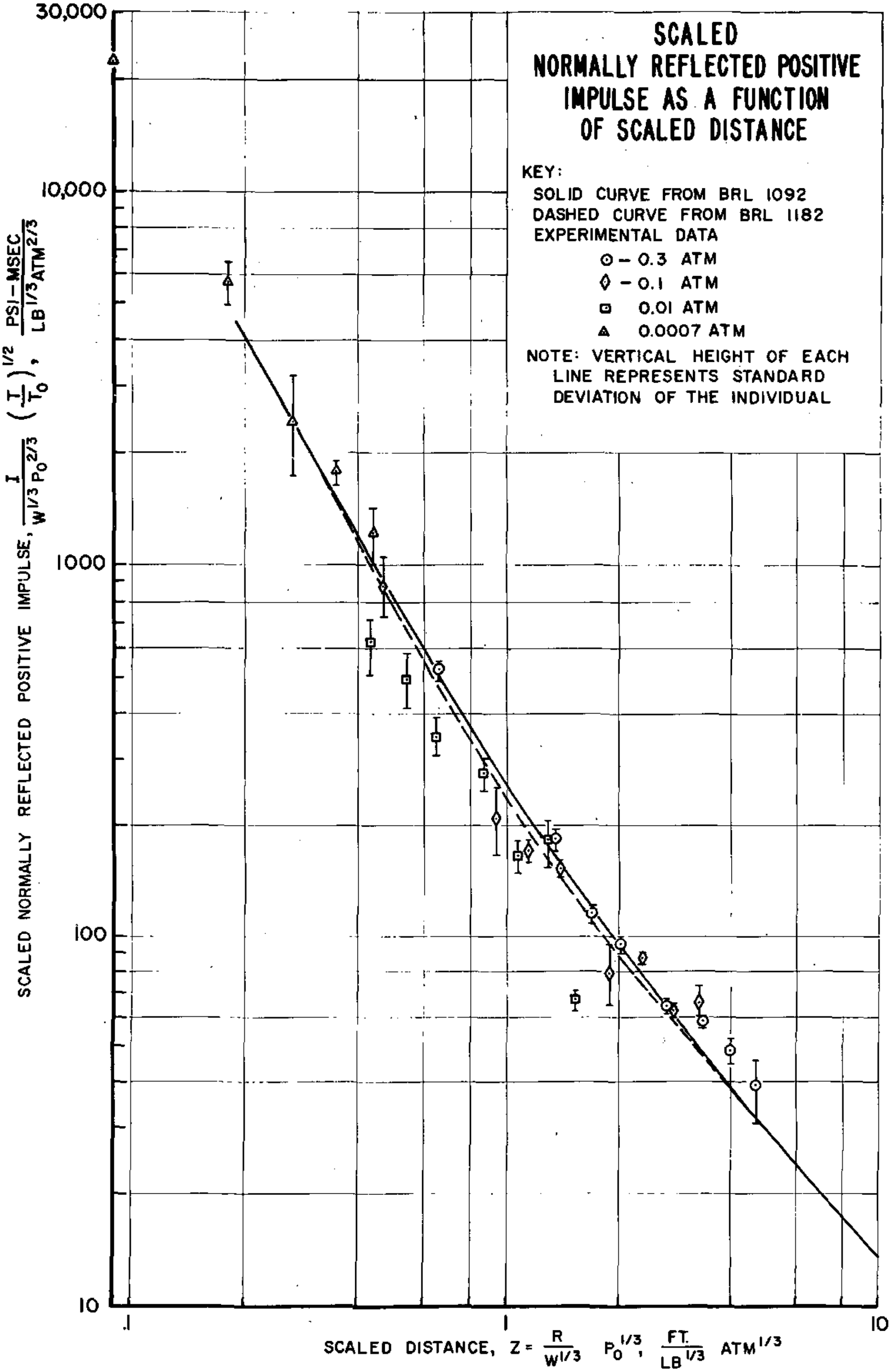

SCALED
NORMALLY REFLECTED POSITIVE
IMPULSE AS A FUNCTION
OF SCALED DISTANCE
KEY:
SOLID CURVE FROM BRL 1092
DASHED CURVE FROM BRL 1182
EXPERIMENTAL DATA
⊙ – 0.3 ATM
◊ – 0.1 ATM
▫ 0.01 ATM
△ 0.0007 ATM
NOTE: VERTICAL HEIGHT OF EACH
LINE REPRESENTS STANDARD
DEVIATION OF THE INDIVIDUAL
30,000
10,000
1000
100
10
.1
1
10
SCALED NORMALLY REFLECTED POSITIVE IMPULSE, $\frac{I}{W^{1/3} P_0^{2/3}} \left(\frac{T}{T_0}\right)^{1/2}$, $\frac{PSI-MSEC}{LB^{1/3} ATM^{2/3}}$
SCALED DISTANCE, $Z = \frac{R}{W^{1/3}} P_0^{1/3}$, $\frac{FT.}{LB^{1/3}}$ $ATM^{1/3}$

FIGURE 14

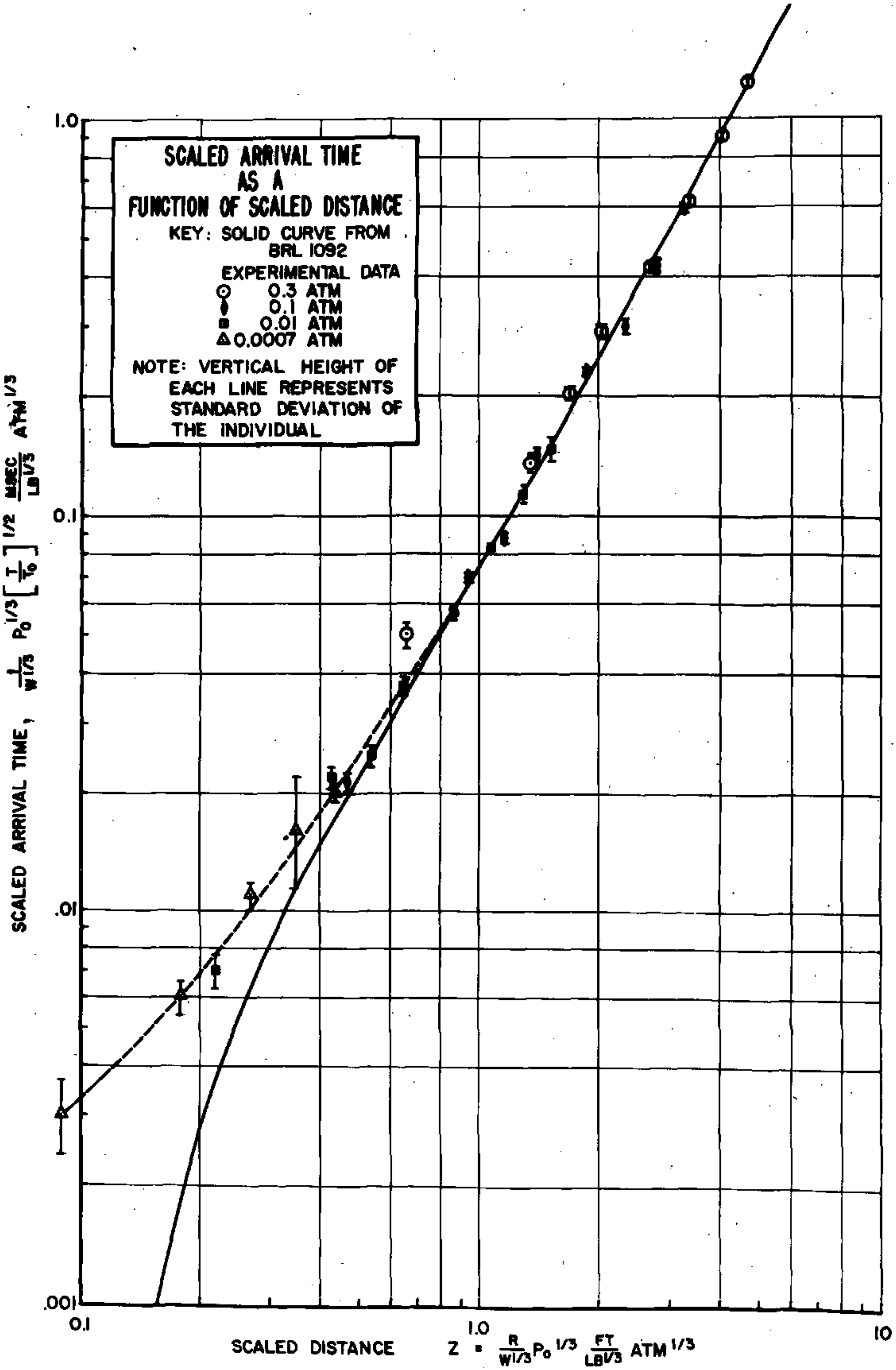

SCALED ARRIVAL TIME
AS A
FUNCTION OF SCALED DISTANCE
KEY: SOLID CURVE FROM BRL 1092
EXPERIMENTAL DATA
0.3 ATM
0.1 ATM
0.01 ATM
0.0007 ATM
NOTE: VERTICAL HEIGHT OF EACH LINE REPRESENTS STANDARD DEVIATION OF THE INDIVIDUAL
1.0
0.1
.01
.001
0.1
1.0
10
SCALED ARRIVAL TIME
SCALED DISTANCE

FIGURE 15

Normally Reflected Positive Duration

The scaled positive duration curve presented as a solid line in Figure 16 is from normally reflected measurements at sea level[5]. The experimental data are shown with Sachs' altitude scaling applied. In general, the agreement appears to be good and Sachs' scaling is applicable within this range of scaled distance and ambient pressure.

Side-on Peak Excess Pressures

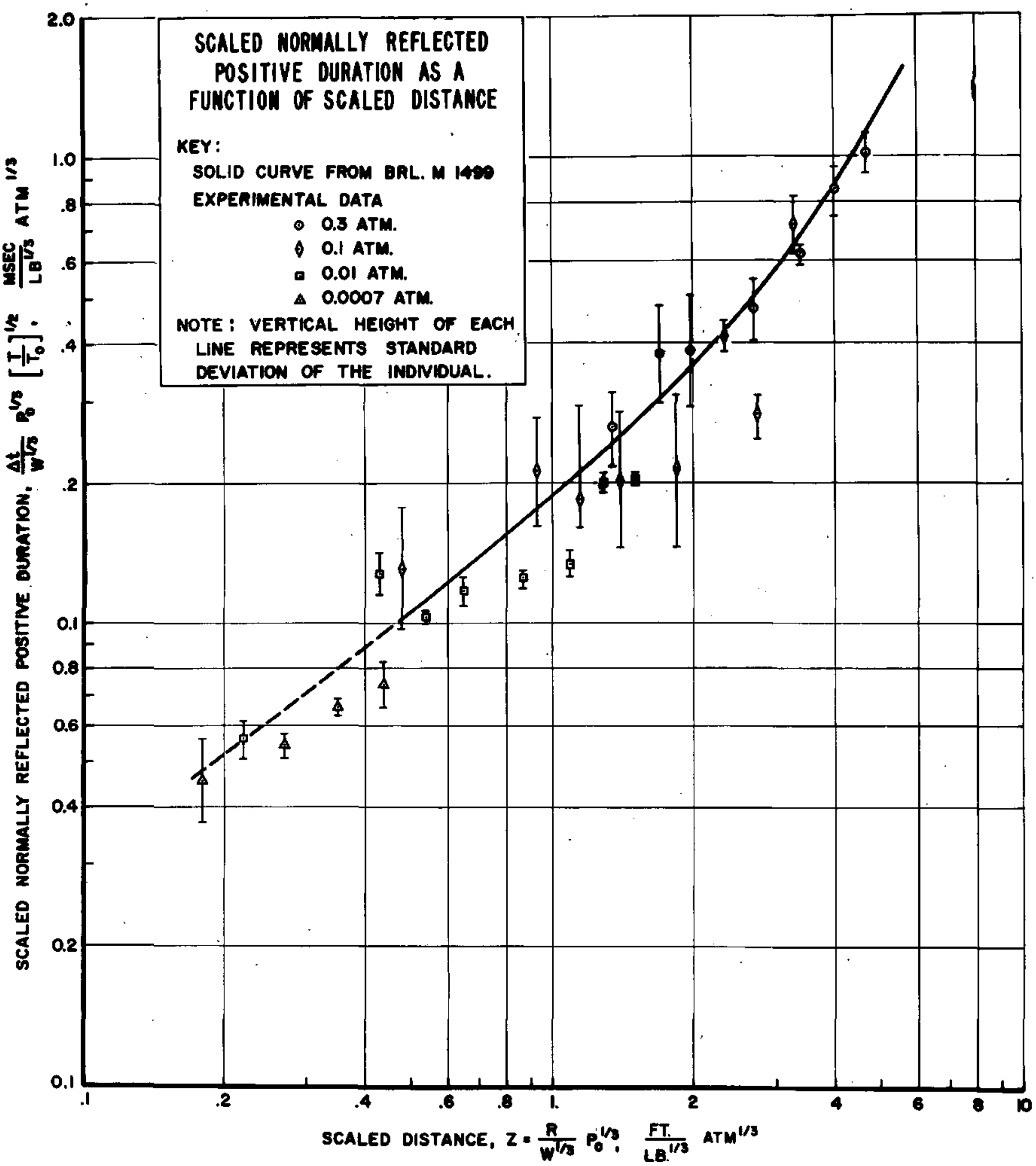
Side-on peak excess pressures computed from the measured values of the normally reflected peak excess pressure (using Equation (1)) appear in Figure 17 scaled for the effect of ambient pressure. The solid curve in Figure 17 is from Goodman's[3] compiled free-air blast data. The data appearing within the large circles in Figure 17 are from experimental firings at reduced ambient pressures by Dewey and Sperrazza[11] with scaling applied; these side-on peak excess pressures were obtained by two methods:

1. Calculating the peak excess pressure from velocity measurements using the Rankine-Hugoniot relation
2. Reading the peak excess pressure directly from pressure-time histories recorded with side-on pressure gages.

The agreement between these three sets of data is quite good where comparison can be made.

Calculated Shock Velocity

Calculated shock velocities are presented in Figure 18 and in Table 2 of the Appendix, along with a tabulation of the data by rounds. These velocities were computed from the measured arrival times at various distances and ambient pressures. The solid curve in Figure 18 is from Goodman's[3] compiled free-air blast data. The experimental data, in general, appear to be in good agreement with Goodman's computed curve. At positions close to the surface of the charge and in an ambient pressure of 0.007 atmospheres, the experimental data are somewhat scattered, but it is felt that this is probably a result of error in measurement rather than a failure of Sachs' scaling.



SCALED NORMALLY REFLECTED POSITIVE DURATION AS A FUNCTION OF SCALED DISTANCE
KEY:
SOLID CURVE FROM BRL. M 1499
EXPERIMENTAL DATA
0.3 ATM.
0.1 ATM.
0.01 ATM.
0.0007 ATM.
NOTE: VERTICAL HEIGHT OF EACH LINE REPRESENTS STANDARD DEVIATION OF THE INDIVIDUAL.
SCALED NORMALLY REFLECTED POSITIVE DURATION, $\frac{\Delta t}{W^{1/3}} P_0^{1/3} \left[\frac{T}{T_0}\right]^{1/2}$, $\frac{MSEC}{LB^{1/3}}$ ATM $^{1/3}$
2.0
1.0
.8
.6
.4
.2
0.1
0.8
0.6
0.4
0.2
0.1
.1
.2
.4
.6
.8
1.
2
4
6
8
10
SCALED DISTANCE, $Z = \frac{R}{W^{1/3}} P_0^{1/3}$, $\frac{FT.}{LB.^{1/3}}$ ATM $^{1/3}$

FIGURE 16

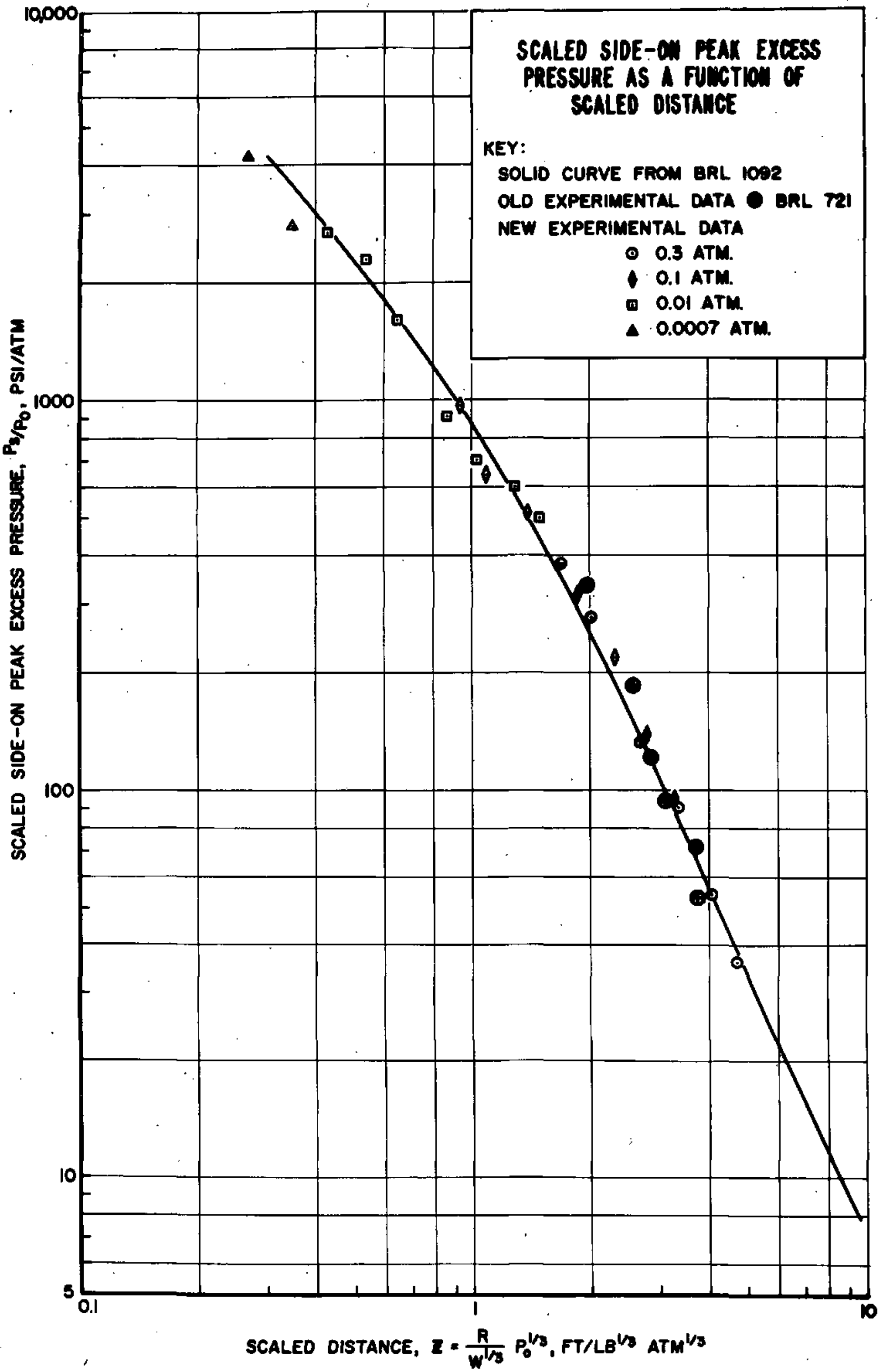

SCALED SIDE-ON PEAK EXCESS PRESSURE AS A FUNCTION OF SCALED DISTANCE
KEY:
SOLID CURVE FROM BRL 1092
OLD EXPERIMENTAL DATA ● BRL 721
NEW EXPERIMENTAL DATA
0.3 ATM.
0.1 ATM.
0.01 ATM.
0.0007 ATM.
10,000
1000
100
10
5
0.1
1
10
SCALED SIDE-ON PEAK EXCESS PRESSURE, P_s/P_0, PSI/ATM
SCALED DISTANCE, $Z = \frac{R}{W^{1/3}} P_0^{1/3}$, FT/LB$^{1/3}$ ATM$^{1/3}$

FIGURE 17

CALCULATED SCALED SHOCK WAVE VELOCITY
AS A FUNCTION OF SCALED DISTANCE

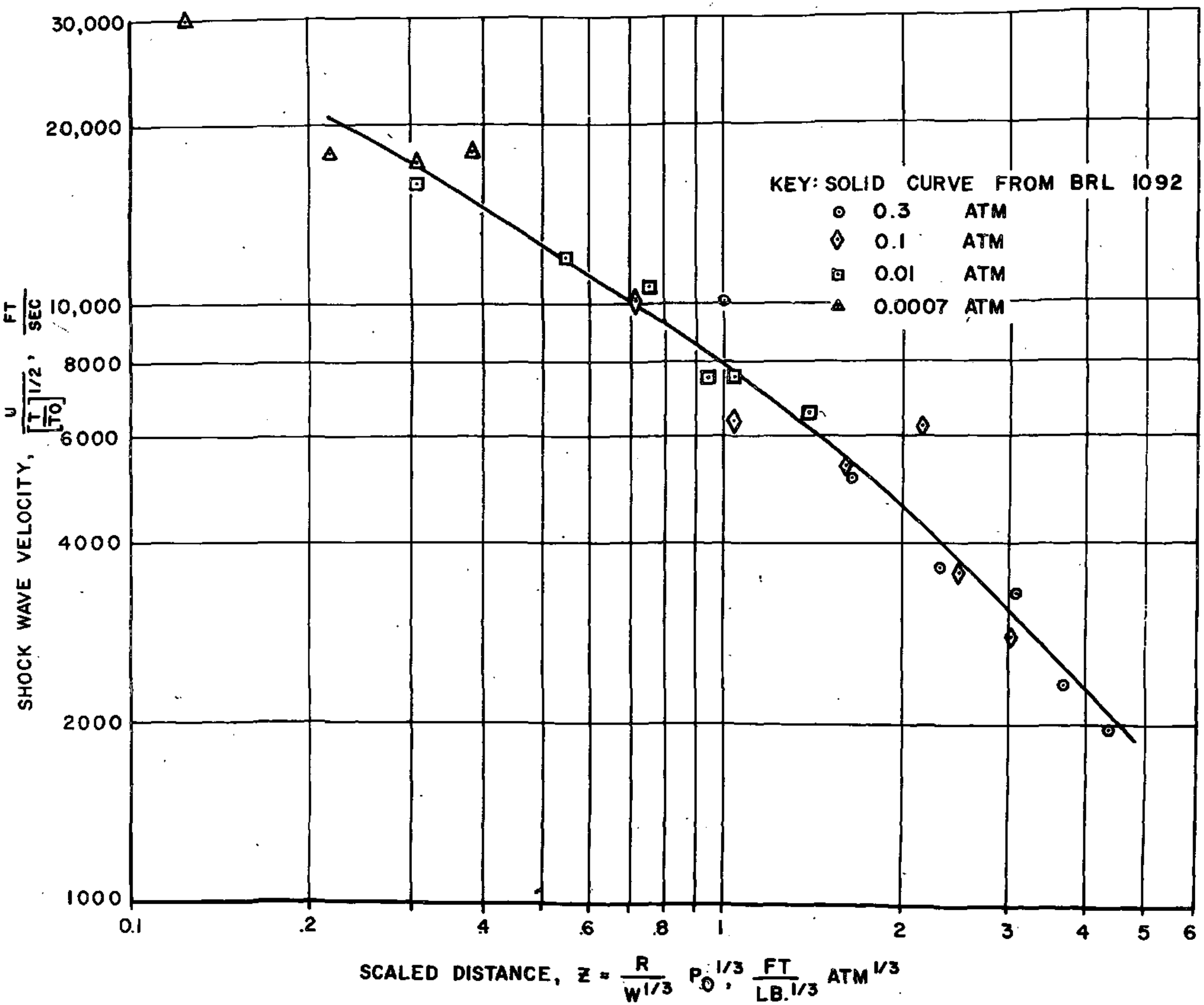


FIGURE 18

CONCLUSIONS

The results presented herein constitute an attempt to obtain quantitative data for various shock parameters at reduced ambient pressures close to the surface of an exploding charge. It is believed that these attempts were successful up to an altitude of 175,000 feet. However, above 105,000 feet a new form of pressure-time history has been observed which complicates scaling and measuring techniques.

The shape of the pressure-time history appears to be changing from its classical sea level shape to some new vacuum form. Even at an altitude of 175,000 feet the pressure-time history observed at positions close to the charge may be caused primarily by direct impingement of the explosive gases. For all practical purposes, the change from air shock as a damaging agent to the explosive gases has already occurred at these small radii.

Sachs' scaling was found to be valid for normally reflected peak pressures up to 105,000 feet and above <u>if the initial rise in pressure is used for scaling</u>, but Sachs' scaling <u>does not</u> predict the maximum excess pressure obtained under certain ambient pressure conditions and scaled distances.

Sachs' scaling appears to be valid for predicting the normally reflected positive impulse at the ambient pressures and scaled distances tested, even though the maximum pressure is not predictable by Sachs' scaling.

Maximum pressures obtained at 0.0007 and 0.01 atmospheres and at equivalent scaled distances are practically identical in magnitude. It may be that both the maximum pressure and the normally reflected positive impulse are independent of the ambient pressure close to the surface of the charge; i.e., the shock pressure-time curves for these ambient pressures are approaching the vacuum solution except for the initial shock jump at the front of the wave. Theoretically, the magnitude of the initial shock is more sensitive to ambient pressure, but goes to zero as ambient pressure goes to zero.

Side-on peak pressures computed from the initial shock of the normally reflected pressure-time history, as expected, follow Sachs' scaling. However, a modification in the form of the side-on pressure-time history probably would be observed if side-on measurements were made under the same conditions.

Sachs' scaling appears to be applicable for predicting the normally reflected positive duration within the ranges of scaled distances and ambient pressures that can be compared.

Arrival time appears to scale by Sachs' method at least to a scaled distance of 0.5 feet. The deviation from Goodman's curve at a scaled distance of 0.5 may be a failure of Sachs' scaling, but it is felt at this time that more data must be obtained close to the surface of the charge before a definite conclusion can be made. The calculated shock velocities are computed directly from arrival time measurements, so the difficulties encountered with arrival times also appear at the same scaled distances as in the calculated shock velocities.

FUTURE WORK

Measurements of normally reflected shock parameters at altitudes up to 300,000 feet and scaled distances between 7 feet per pound$^{1/3}$ and the surface of the charge are planned. Side-on measurements will also be made at reduced ambient pressures and various scaled distances.

Multiple photographs of normally reflected shock waves will be attempted at reduced ambient pressures to substantiate the piezoelectric transducer measurements through the velocity technique, and also to investigate the characteristics of the shock waves under altitude conditions. Pressure measurements will be taken in conjunction with these photographs to study the "fine structure" of the normally reflected shock wave under these conditions. It is felt that a theoretical and an experimental study of the "fine structure" of the shock wave will be necessary for proper interpretation of pressure-time histories recorded at altitudes above 250,000 feet.

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APPENDIX - EXPERIMENTAL DATA

TABLE 1

MEASUREMENTS OF NORMALLY REFLECTED SHOCK WAVES FROM EXPLOSIVE CHARGES AT HIGH ALTITUDE

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (°F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
313	P_o = 0.3	.122	34	3.5	4.70	45		
314		.122	35	3.5	4.70	35		
316		.122	36	3.5	4.70	42		
317		.122	37	3.5	4.70	42		
318		.122	38	3.5	4.70	41		
					Average	41.0	137	11
					Standard Deviation ±	3.7	12	
299	P_o = 0.3	.122	50	3.0	4.04	72		
300		.122	28	3.0	4.04	70		
301		.122	28	3.0	4.04	75		
302		.122	33	3.0	4.04	72		
303		.122	35	3.0	4.04	72		
					Average	72	240	16
					Standard Deviation ±	1.80	6.6	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
313	6.00	26.38	.678	.894	.957	1.262
314	11.67	51.36	.817	1.079	.974	1.286
316	8.68	38.24	.789	1.042	.974	1.287
317	8.83	38.95	.796	1.053	.974	1.288
318	8.98	39.64	.828	1.096	.975	1.290
Average		38.91		1.033		1.283
Standard Deviation	±	8.8		.08		.01
299	13.36	59.64	Lost	Lost	.696	.931
300	6.30	27.53	.595	.780	.713	.934
301	10.31	45.05	.760	.996	.696	.912
302	13.36	58.68	Lost	Lost	.706	.930
303	10.90	47.97	.642	.848	.705	.930
Average		47.77		.875		.927
Standard Deviation	±	13		.11		.009

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^{o}F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
293	P_o = 0.3	.122	42	2.5	3.37	130		
294		.122	42	2.5	3.37	130		
295		.122	47	2.5	3.37	138		
296		.122	42	2.5	3.37	126		
297		.122	47	2.5	3.37	136		
298		.122	49	2.5	3.37	126		
					Average	131	430	27
					Standard Deviation ±	5.2	17	
358	P_o = 0.3	.123	40	2.0	2.69	207		
359		.123	37	2.0	2.69	213		
360		.123	38	2.0	2.69	210		
361		.123	38	2.0	2.69	212		
362		.123	40	2.0	2.69	229		
					Average	214	720	40.4
					Standard Deviation ±	8.60	28	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\ \frac{T}{T_o}^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
293	12.70	56.25	.452	.601	.478	.634
294	12.88	57.04	.450	.598	.474	.629
295	13.37	59.51	.517	.690	.470	.628
296	12.82	56.78	.489	.649	.478	.634
297	12.93	58.25	.468	.625	.478	.638
298	13.28	59.22	.456	.610	.478	.640
Average		57.84		.629		.634
Standard Deviation	±	1.3		.03		.005
358	13.38	58.92	.366	.484	.330	.436
359	15.19	66.76	.359	.474	.330	.435
360	15.03	66.12	.354	.467	.330	.436
361	13.65	60.05	.365	.482	.330	.436
362	15.12	66.58	.383	.506	.332	.439
Average		63.69		.483		.436
Standard Deviation	±	3.8		.01		.002

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^{o}F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
424	P_o = 0.3	.120	40	1.5	2.03	490		
425		.120	40	1.5	2.03	516		
426		.120	45	1.5	2.03	490		
427		.120	45	1.5	2.03	507		
428		.120	45	1.5	2.03	497		
					Average	500	1660	83.0
					Standard Deviation ±	11	38	
429	P_o = 0.3	.120	45	1.25	1.70	733		
430		.120	45	1.25	1.70	818		
431		.120	49	1.25	1.70	672		
432		.120	52	1.25	1.70	746		
433		.120	81	1.25	1.70	665		
					Average	727	2420	115
					Standard Deviation ±	62	207	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\ \frac{T}{T_o}^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
424	21.84	96.91	.305	.407	Lost	Lost
425	19.15	84.97	.212	.282	.200	.264
426	20.70	92.31	.248	.332	.200	.265
427	22.46	103.13	.303	.405	.182	.242
428	20.62	91.96	.276	.369	.191	.254
Average		93.86		.359		.256
Standard Deviation	±	6.7		.05		.01
429	24.90	111.21	.315	.421	.147	.196
430	24.98	111.57	.275	.367	.134	.179
431	24.44	109.59	.274	.369	.139	.187
432	28.81	129.59	.213	.287	.147	.198
433	24.57	113.61	.243	.336	.130	.261
Average		115.11		.356		.204
Standard Deviation	±	8.2		.05		.03

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (°F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
462	P_o = 0.3	.121	33	1.0	1.35	1197		
463		.121	35	1.0	1.35	1050		
464		.121	36	1.0	1.35	1470		
465		.121	36	1.0	1.35	1407		
466		.121	59	1.0	1.35	1197		
467		.121	35	1.0	1.35	1092		
					Average	1236	4120	
					Standard Deviation ±	168	563	
455	P_o = 0.3	.121	42	0.5	0.66	4368		
456		.121	41	0.5	0.66	4368		
457		.121	44	0.5	0.66	4455		
458		.121	42	0.5	0.66	4452		
459		.121	44	0.5	0.66	4704		
					Average	4470	14,900	
					Standard Deviation ±	138	460	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}} \frac{T}{T_o}^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
462	40.84	179.00	.159	.210	.104	.115
463	46.32	203.47	.192	.254	.099	.110
464	37.55	165.11	.204	.270	.091	.101
465	39.15	172.14	.240	.318	.096	.106
466	43.32	194.76	.187	.253	.091	.103
467	43.39	190.60	.224	.296	.098	.108
Average		184.18		.267		.107
Standard Deviation	±	14.5		.04		.005
455	Lost	Lost	.156	.208	.034	.037
456	123.08	545.46	.158	.210	.037	.041
457	119.80	530.53	.157	.210	.043	.047
458	119.46	527.95	Lost	Lost	.035	.038
459	104.76	463.93	.152	.203	.039	.043
Average		516.97		.208		.041
Standard Deviation	±	36.2		.003		.004

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (°F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
309	P_o = 0.1	.122	45	3.5	3.28	45		
310		.122	38	3.5	3.28	48		
311		.122	32	3.5	3.28	45		
312		.122	32	3.5	3.28	48		
					Average	47	465	10
					Standard Deviation	± 1.7	17	
304	P_o = 0.1	.122	23	3.0	2.81	75		
305		.122	24	3.0	2.81	73		
306		.122	39	3.0	2.81	73		
307		.122	40	3.0	2.81	78		
308		.122	52	3.0	2.81	78		
					Average	75	750	14
					Standard Deviation	± 2.5	25	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\ \frac{T}{T_o}^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
309	7.91	73.23	Lost	Lost	.635	.567
310	6.06	55.75	.659	.605	.661	.606
311	6.19	56.60	.776	.708	.661	.603
312	8.78	80.21	.976	.891	.661	.603
Average		66.46		.735		.595
Standard Deviation	±	21.1		.14		.02
8 ft						
304	7.21	65.33	.482	.436	.478	.432
305	6.41	58.11	.401	.363	.378	.432
306	6.92	63.65	.436	.401	.478	.439
307	6.88	63.35	.454	.417	.478	.439
308	6.41	59.73	.435	.404	.478	.445
Average		62.03		.404		.437
Standard Deviation	±	3.0		.03		.005

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^{o}F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
287	P_o = 0.1	.122	39	2.5	2.34	135		
288		.122	70	2.5	2.34	132		
289		.122	32	2.5	2.34	126		
290		.122	32	2.5	2.34	132		
291		.122	38	2.5	2.34	126		
292		.122	39	2.5	2.34	126		
					Average	130	1300	22
					Standard Deviation ±	3.98	39	
346	P_o = 0.1	.122	50	2.0	1.87	200		
347		.122	51	2.0	1.87	182		
348		.122	74	2.0	1.87	190		
349		.122	53	2.0	1.87	200		
350		.122	59	2.0	1.87	218		
					Average	198	1980	32
					Standard Deviation ±	13	130	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\ \frac{T}{T_o}^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
287	9.10	83.82	.455	.417	.339	.312
288	9.42	89.39	.428	.405	.322	.305
289	9.20	84.21	.461	.420	.330	.301
290	9.60	87.84	.496	.453	.322	.294
291	9.56	88.02	.468	.430	.330	.303
292	8.77	80.77	.456	.418	.348	.319
Average		85.68		.424		.306
Standard Deviation	±	3.3		.02		.009
50						
346	12.08	112.03	.347	.322	.252	.233
347	5.37	49.85	.155	.144	.252	.234
348	5.30	50.29	.162	.153	Lost	Lost
349	5.33	49.58	.150	.139	.252	.235
350	12.67	118.44	.345	.323	.248	.232
Average		76.04		.216		.233
Standard Deviation	±	35.8		.097		.001

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (°F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} \; atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
333	P_o = 0.1	.121	60	1.5	1.41	350		
335		.121	40	1.5	1.41	378		
337		.121	52	1.5	1.41	392		
338		.121	52	1.5	1.41	357		
					Average	364	3640	52
					Standard Deviation ±	20	200	
264	P_o = 0.1	.121	45	1.25	1.16	406		
267		.121	45	1.25	1.16	448		
268		.121	47	1.25	1.16	504		
269		.121	49	1.25	1.16	413		
270		.121	47	1.25	1.16	448		
272		.121	37	1.25	1.16	490		
					Average	452	4520	65
					Standard Deviation ±	39	390	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
333	16.7	157.50	.309	.291	.156	.146
335	15.0	138.85	.267	.246	Lost	Lost
337	15.8	147.91	.147	.137	.157	.146
338	16.6	155.36	.180	.169	.152	.142
339	17.2	161.25	.183	.171	.157	.146
Average		152.17		.216		.145
Standard Deviation		± 8.9		.09		.002
264	18.09	167.35	.221	.204	.094	.087
267	17.63	163.14	.189	.175	.100	.093
268	20.61	191.09	.219	.204	.097	.090
269	19.15	177.91	.216	.201	.098	.091
270	15.71	145.66	.199	.185	.098	.091
272	18.19	167.12	.190	.174	.096	.088
Average		168.71		.190		.090
Standard Deviation		± 15.2		.02		.002

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^{o}F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
320	P_o = 0.1	.121	49	1.00	0.94	812		
321		.121	49	1.00	0.94	642		
322		.121	53	1.00	0.94	672		
323		.121	53	1.00	0.94	707		
324		.121	54	1.00	0.94	896		
					Average	742	7420	97
					Standard Deviation ±	106	1060	
448	P_o = 0.1	.121	36	0.5	0.47	2552		
449		.121	41	0.5	0.47	2772		
450		.121	46	0.5	0.47	2552		
451		.121	59	0.5	0.47	2200		
452		.121	49	0.5	0.47	3080		
453		.121	54	0.5	0.47	2904		
454		.121	45	0.5	0.47	2640		
					Average	2671	26,710	
					Standard Deviation ±	284	2840	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
320	12.70	118.42	.157	.146	.076	.070
321	15.40	143.40	.179	.166	.076	.070
322	26.60	248.95	.287	.268	.073	.068
323	28.80	269.35	.288	.269	.077	.072
324	26.20	245.31	.279	.261	.077	.072
Average		205.09		.222		.070
Standard Deviation	±	68.9		.06		.002
448	94.16	864.15	.127	.116	.026	.023
449	91.09	839.40	.213	.196	.026	.024
450	104.66	969.34	Lost	Lost	.026	.024
451	127.84	1198.42	.149	.140	.026	.024
452	75.76	703.81	.121	.113	.024	.023
453	Lost	Lost	.149	.139	.025	.023
454	74.93	693.28	.127	.117	.027	.025
Average		878.07		.137		.024
Standard Deviation	±	188.2		.03		.0007

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^{o}F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} \; atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
418	P_o = 0.01	.121	30	3.5	1.53	34		
419		.121	30	3.5	1.53	34		
420		.121	34	3.5	1.53	33		
421		.121	36	3.5	1.53	32		
422		.121	32	3.5	1.53	24		
					Average	31	3140	5
					Standard Deviation	± 4	420	
412	P_o = 0.01	.123	40	3.0	1.30	42		
413		.123	32	3.0	1.30	36		
414		.123	27	3.0	1.30	40		
415		.123	31	3.0	1.30	52		
416		.123	36	3.0	1.30	41		
417		.123	36	3.0	1.30	40		
					Average	42	4180	6
					Standard Deviation	± 5	533	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
418	1.55	65.75	.139	.059	.355	.150
419	1.57	66.79	.127	.072	.363	.154
420	1.59	67.72	.166	.070	.363	.154
421	1.60	68.28	.157	.067	.363	.154
422	1.38	58.65	.142	.060	.329	.140
Average		65.40		.066		.150
Standard Deviation	±	3.9		.006		.006
412	5.45	231.58	.327	.139	.265	.113
413	3.89	164.11	.207	.088	.250	.108
414	3.67	154.04	.295	.124	.278	.117
415	4.81	202.72	Lost	Lost	.278	.117
416	3.83	162.24	.298	.127	.278	.118
417	3.86	163.51	.347	.147	.278	.118
Average		179.70		.125		.115
Standard Deviation	±	30.6		.02		.004

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^{o}F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
363	P_o = 0.01	.123	52	2.5	1.07	53		
364		.123	55	2.5	1.07	50		
365		.123	62	2.5	1.07	54		
366		.123	47	2.5	1.07	48		
					Average	51	5100	7
					Standard Deviation ±	3	300	
353	P_o = 0.01	.122	50	2.0	0.87	75		
354		.122	57	2.0	0.87	92		
355		.122	60	2.0	0.87	81		
356		.122	60	2.0	0.87	78		
					Average	82	8200	9
					Standard Deviation ±	7	700	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}$
363	3.87	166.48	.271	.117	.198	.085
364	3.94	170.00	.272	.117	.198	.085
365	3.28	142.49	.277	.119	Lost	Lost
366	4.20	179.76	.242	.104	.199	.085
Average		164.68		.114		.085
Standard Deviation	±	15.7		.004		.000
353	5.73	246.00	.307	.132	.135	.058
354	7.35	317.77	.280	.122	.137	.059
355	6.05	262.33	.295	.129	.137	.059
356	6.18	267.96	.287	.125	.133	.058
Average		273.52		.127		.058
Standard Deviation	±	30.9		.004		.0009

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (°F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Measured Normally Reflected Peak Pressure (psi)	Scaled Normally Reflected Peak Pressure (psi/atm)	Calculated Scaled Side-on Peak Pressure (psi/atm)
340	P_o = 0.01	.121	44	1.5	0.65	129		
341		.121	43	1.5	0.65	126		
342		.121	49	1.5	0.65	124		
344		.121	50	1.5	0.65	131		
345		.121	44	1.5	0.65	126		
					Average	127	12,700	16
					Standard Deviation ±	3	300	
273	P_o = 0.01	.121	51	1.25	0.54	182		
274		.121	47	1.25	0.54	202		
275		.121	51	1.25	0.54	202		
276		.121	53	1.25	0.54	180		
277		.121	46	1.25	0.54	235		
278		.121	42	1.25	0.54	185		
279		.121	37	1.25	0.54	180		
					Average	195	19,500	23
					Standard Deviation ±	20	2000	

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
340	7.10	305.43	.279	.120	.094	.040
341	7.37	316.73	.314	.134	.082	.035
342	9.55	412.92	.268	.117	.090	.039
344	8.61	372.64	.272	.118	.086	.037
345	7.08	304.58	.268	.115	Lost	Lost
Average		342.46		.121		.038
Standard Deviation	±	48.3		.008		.002
273	9.68	418.32	.244	.105	.056	.024
274	12.70	546.62	.237	.102	.060	.026
275	11.07	478.40	.260	.112	.056	.024
276	8.10	350.75	.240	.104	.060	.026
277	9.72	417.93	.249	.107	.060	.026
278	14.16	606.38	.240	.103	.060	.026
279	14.23	606.90	.253	.108	.056	.024
Average		489.33		.106		.025
Standard Deviation	±	100.		.003		.0009

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^oF)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Pressure at Shock Front: Measured Normally Reflected Peak Pressure (psi)	Pressure at Shock Front: Scaled Normally Reflected Peak Pressure (psi/atm)	Pressure at Shock Front: Calculated Scaled Side-on Peak Pressure (psi/atm)	Maximum Pressure After Shock Front: Measured Maximum Normally Reflected Pressure (psi)	Maximum Pressure After Shock Front: Scaled Maximum Normally Reflected Pressure (psi/atm)
	P_o = 0.01									
326	0.01	.121	43	1.00	0.43	240			350	
327	0.01	.121	50	1.00	0.43	235			266	
328	0.01	.121	60	1.00	0.43	250			406	
329	0.01	.121	51	1.00	0.43	255			Lost	
330	0.01	.121	68	1.00	0.43	Lost			294	
331	0.01	.121	66	1.00	0.43	265			336	
					Average	249	24,900	27	330	33,000
					Standard Deviation ±	12	1,200		54	3,300
435	0.01	.121	50	0.5	0.22	1148			1505	
436	0.01	.121	53	0.5	0.22	1260			1785	
437	0.01	.121	29	0.5	0.22	980			Lost	
438	0.01	.121	24	0.5	0.22	1365			1853	
439	0.01	.121	26	0.5	0.22	875			1820	
440	0.01	.121	42	0.5	0.22	1225			1997	
					Average	1142	114,200	-	1784	178,400
					Standard Deviation ±	184	18,400		173	17,300

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
326	10.94	469.17	.346	.148	.050	.021
327	13.22	575.30	.296	.128	.052	.023
328	16.79	732.41	.275	.120	.052	.023
329	13.74	594.03	.278	.120	.050	.022
330	13.52	594.29	.316	.139	.050	.022
331	17.14	751.92	.312	.137	.052	.023
Average		619.37		.132		.022
Standard Deviation	±	106.9		.011		.0006
435	55.64	518.42	.154	.067	.017	.007
436	79.90	746.72	.121	.052	.019	.008
437	85.90	784.21	.134	.057	.017	.007
438	87.81	797.54	.138	.058	.016	.006
439	83.44	759.40	.129	.054	.018	.007
440	85.45	789.74	.139	.060	.015	.006
Average		732.67		.058		.007
Standard Deviation	±	106.9		.005		.0006

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^oF)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Pressure at Shock Front: Measured Normally Reflected Peak Pressure (psi)	Pressure at Shock Front: Scaled Normally Reflected Peak Pressure (psi/atm)	Pressure at Shock Front: Calculated Scaled Side-on Peak Pressure (psi/atm)	Maximum Pressure After Shock Front: Measured Maximum Normally Reflected Pressure (psi)	Maximum Pressure After Shock Front: Scaled Maximum Normally Reflected Pressure (psi/atm)
407	P_o = .0007	.123	70	2.5	0.44	20			57	
408		.123	41	2.5	0.44	18			38	
409		.123	47	2.5	0.44	22			53	
410		.123	48	2.5	0.44	28			55	
411		.123	47	2.5	0.44	20			35	
					Average	22	31,429	1.70	48	68,571
					Standard Deviation ±	4	5,350		10.3	14,678
400	P_o = .0007	.123	65	2.0	0.35	40			106	
401		.123	65	2.0	0.35	40			99	
402		.123	67	2.0	0.35	35			93	
403		.123	68	2.0	0.35	Lost			Lost	
404		.123	69	2.0	0.35	35			105	
405		.123	77	2.0	0.35	38			110	
					Average	38	54,286	2.0	103	147,140
					Standard Deviation ±	2	2,597		6.6	9,499

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
407	3.55	952.83	.390	.070	.117	.021
408	4.19	1075.40	.404	.071	.114	.020
409	5.31	1368.78	.406	.072	.112	.020
410	4.48	1158.30	.477	.084	.117	.021
411	4.88	1516.14	.485	.086	.121	.021
Average		1214.29		.076		.021
Standard Deviation	±	226.8		.008		.0007
400	7.49	1969.10	.363	.065	.082	.015
401	6.77	1781.86	.390	.070	.093	.017
402	7.13	1877.00	.380	.068	.099	.018
403	8.09	Lost	.378	.068	.095	.017
404	6.49	1714.82	.368	.067	.086	.015
405	6.36	1693.10	.381	.069	.082	.015
Average		1807.18		.068		.016
Standard Deviation	±	115.4		.002		.001

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (°F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Pressure at Shock Front: Measured Normally Reflected Peak Pressure (psi)	Pressure at Shock Front: Scaled Normally Reflected Peak Pressure (psi/atm)	Pressure at Shock Front: Calculated Scaled Side-on Peak Pressure (psi/atm)	Maximum Pressure After Shock Front: Measured Maximum Normally Reflected Pressure (psi)	Maximum Pressure After Shock Front: Scaled Maximum Normally Reflected Pressure (psi/atm)
393	P_o = .0007	.123	55	1.5	0.27	50			175	
394		.123	72	1.5	0.27	42			196	
395		.123	65	1.5	0.27	48			132	
396		.123	65	1.5	0.27	40			156	
398		.123	60	1.5	0.27	42			182	
399		.123	69	1.5	0.27	48			200	
					Average	45	64,286	3	174	248,570
					Standard Deviation ±	4	5,195		26	36,858
368	P_o = .0007	.121	50	1.0	0.18	104			355	
376		.121	65	1.0	0.18	80			300	
384		.121	45	1.0	0.18	80			390	
385		.121	64	1.0	0.18	90			360	
386		.121	59	1.0	0.18	100			390	
387		.121	40	1.0	0.18	100			Lost	
					Average	92	131,429	3	360	514,280
					Standard Deviation ±	12	15,576		37	52,559

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
393	11.72	3057.20	.306	.054	.069	.012
394	14.40	3818.19	.399	.072	.060	.011
395	9.56	2523.29	.291	.052	.069	.012
396	7.74	2038.67	.331	.059	.060	.011
398	5.37	1405.06	.311	.056	.055	.010
399	6.57	1737.05	.328	.059	.060	.011
Average		2429.91		.059		.011
Standard Deviation	±	895.9		.007		.001
368	25.43	6617.63	.257	.046	.039	.007
376	18.35	4846.76	.290	.052	.034	.006
384	Lost	Lost	.267	.047	.030	.005
385	Lost	Lost	.249	.045	.032	.006
386	22.58	5928.63	.276	.049	.034	.006
387	21.08	5429.67	.252	.044	.034	.006
Average		5705.67		.047		.006
Standard Deviation	±	751.7		.003		.0005

TABLE 1 (Cont'd.)

Round Number	Ambient Pressure (atm)	Charge Weight (lb)	Ambient Temp. (^{o}F)	Distance from Gage to Charge (ft)	Scaled Distance $\left(\frac{ft}{lb^{1/3}} atm^{1/3}\right)$	Pressure at Shock Front: Measured Normally Reflected Peak Pressure (psi)	Pressure at Shock Front: Scaled Normally Reflected Peak Pressure (psi/atm)	Pressure at Shock Front: Calculated Scaled Side-on Peak Pressure (psi/atm)	Maximum Pressure After Shock Front: Measured Maximum Normally Reflected Pressure (psi)	Maximum Pressure After Shock Front: Scaled Maximum Normally Reflected Pressure (psi/atm)
441	P_o = .0007	.121	42	0.5	0.09	210			1853	
442		.121	53	0.5	0.09	210			Lost	
443		.121	54	0.5	0.09	210			1680	
444		.121	39	0.5	0.09	192			1540	
445		.121	46	0.5	0.09	175			1715	
446		.121	55	0.5	0.09	192			Lost	
447		.121	60	0.5	0.09	210			Lost	
					Average	200	285,710	-	1697	2,424,286
					Standard Deviation ±	14	19,990		128	183,712

TABLE 1 (Cont'd.)

Round Number	Measured Normally Reflected Positive Impulse (psi-msec)	Scaled Normally Reflected Positive Impulse $\left[\frac{\text{psi-msec}}{\text{lb}^{1/3}\ \text{atm}^{2/3}}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Normally Reflected Positive Duration (msec)	Scaled Normally Reflected Positive Duration $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$	Measured Arrival Time (msec)	Scaled Arrival Time $\left[\frac{\text{msec}}{\text{lb}^{1/3}}\ \text{atm}^{1/3}\left(\frac{T}{T_o}\right)^{1/2}\right]$
441	97.07	25,111	.138	.024	.014	.002
442	91.41	23,918	.128	.023	.016	.003
443	91.54	23,968	.123	.022	.016	.003
444	91.45	23,584	.132	.023	.015	.003
445	91.72	23,823	.124	.022	.016	.003
446	91.14	23,887	.123	.022	.015	.003
447	89.97	23,696	.131	.023	Lost	
Average		23,998		.023		.003
Standard Deviation	±	1,387		.0009		.0004

TABLE 2

CALCULATED SCALED SHOCK VELOCITY

Ambient Pressure (atm)	Distance from Charge (ft)	Scaled Distance $\frac{ft}{lb^{1/3}}$ $atm^{1/3}$	Average Scaled Arrival Time $\frac{msec}{lb^{1/3}}$ $atm^{1/3}\left(\frac{T}{T_o}\right)^{1/2}$	Calculated Scaled Shock Velocity $\frac{U}{\left(\frac{T}{T_o}\right)^{1/2}}$ (ft/sec)
P_o = 0.3	0.50	0.66	.041*	
		1.00**		10,147
	1.00	1.35	.107*	
		1.69**		4,564
	1.50	2.03	.256*	
		2.36**		3,666
	2.00	2.69	.436*	
		3.04**		3,434
	2.50	3.37	.634*	
		3.77**		2,287
	3.00	4.04	.927*	
		4.37**		1,854
	3.50	4.70	1.283*	
P_o = 0.1	0.50	0.47	.024*	
		0.71**		10,217
	1.00	0.94	.070*	
		1.05**		6,267
	1.50	1.41	.145*	
		1.74**		5,227
	2.00	1.87	.233*	
		2.10**		6,438
	2.50	2.34	.306*	
		2.57**		3,588
	3.00	2.81	.437*	
		3.04**		2,975
	3.50	3.28	.595*	

TABLE 2 (Cont'd.)

Ambient Pressure (atm)	Distance from Charge (ft)	Scaled Distance $\frac{ft}{lb^{1/3}}$ $atm^{1/3}$	Average Scaled Arrival Time $\frac{msec}{lb^{1/3}}$ $atm^{1/3}\left(\frac{T}{T_o}\right)^{1/2}$	Calculated Scaled Shock Velocity $\frac{U}{\left(\frac{T}{T_o}\right)^{1/2}}$ (ft/sec)
P_o = .01	0.50	0.22	.007*	
		0.32**		14,000
	1.00	0.43	.022*	
		0.54**		13,750
	1.50	0.65	.038*	
		0.76**		11,000
	2.00	0.87	.058*	
		0.97**		7,407
	2.50	1.07	.085*	
		1.19**		7,667
	3.00	1.30	.115*	
		1.43**		6,571
	3.50	1.53	.150*	
P_o = .0007	0.50	0.09	.003*	
		0.13**		30,000
	1.00	0.18	.006*	
		0.22**		18,000
	1.50	0.27	.011*	
		0.31**		16,000
	2.00	0.35	.016*	
		0.39**		18,000
	2.50	0.44	.021*	

* From Table 1

** Scaled distance at center of the interval for which the shock velocity is calculated.

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Normally reflected shock parameters including peak excess pressure, first positive impulse, positive duration and arrival time at scaled distances between 1 and 7 feet per pound$^{1/3}$ and ambient pressures of 0.3, 0.1, 0.01, and 0.0007 atmospheres are presented. Sachs' scaling theory was applied to these parameters. It was found that Sachs' scaling is valid for predicting the magnitude of the first shock appearing in the pressure-time history. As the ambient pressure is reduced the magnitude of this first shock decreases; however, at ambient pressures in the vicinity of 0.01 atmosphere the initial shock is followed by a relatively slow-rising pressure pulse, the peak of which exceeds the peak of the first shock. The peak pressure of this secondary pulse is not predictable by Sachs' scaling. It is indicated that at very low ambient pressures the initial shock will disappear entirely.

Spherical charges of Pentolite (50/50, TNT/PETN) with a nominal weight of 1/8 pound were used for these experiments.

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