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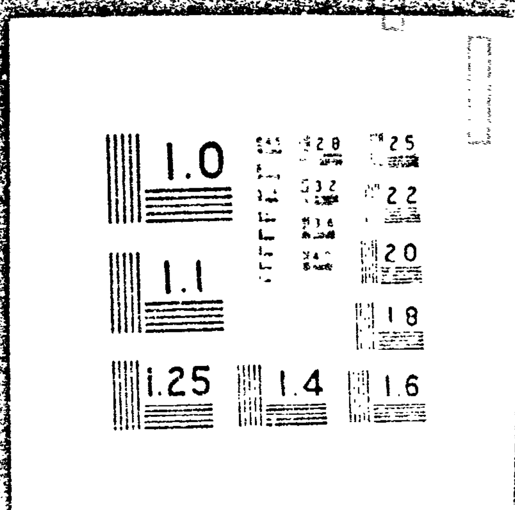

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WT-906

OPERATION CASTLE--PROJECT 1.3

Report to the Scientific Director

DYNAMIC PRESSURE MEASUREMENTS

C. D. Broyles
M. L. Merritt

Sandia Corporation
Albuquerque, New Mexico

[redacted]

GENERAL SHOT INFORMATION

	Shot 1	Shot 2	Shot 3	Shot 4	Shot [illegible]	Shot 6
DATE	1 March	27 March	7 April	25 April	5 May	14 May
CODE NAME (Unclassified)	Bravo	Romeo	Koon	Union	Yankee	Nectar
TIME*	06:40	06:25	06:15	06.05	06 05	06:15
LOCATION	Bikini, West of Charlie (Namu) on Reef	Bikini, Shot I Crater	Bikini, Tare (Eninman)	Bikini, on Barge at Intersection of Arcs with Radii of 6900 from Dog (Yurochi) and 3 Statute Miles from Fox (Aomoen)		Eniwetok, IVY Mike Crater, Flora (Elugelab)
TYPE	Land	Barge	Land	Barge	Barge	Barge
HOLMES & NARVER COORDINATES	N 170,617 17 E 76,163 98	N 170,635 05 E 75,950 46	N 100,154 50 E 109,799 00	N 161,698 83 E 116,800 27	N 161,424 43 E 116,688,15	N 147,750 00 E 67,790 00

* APPROXIMATE

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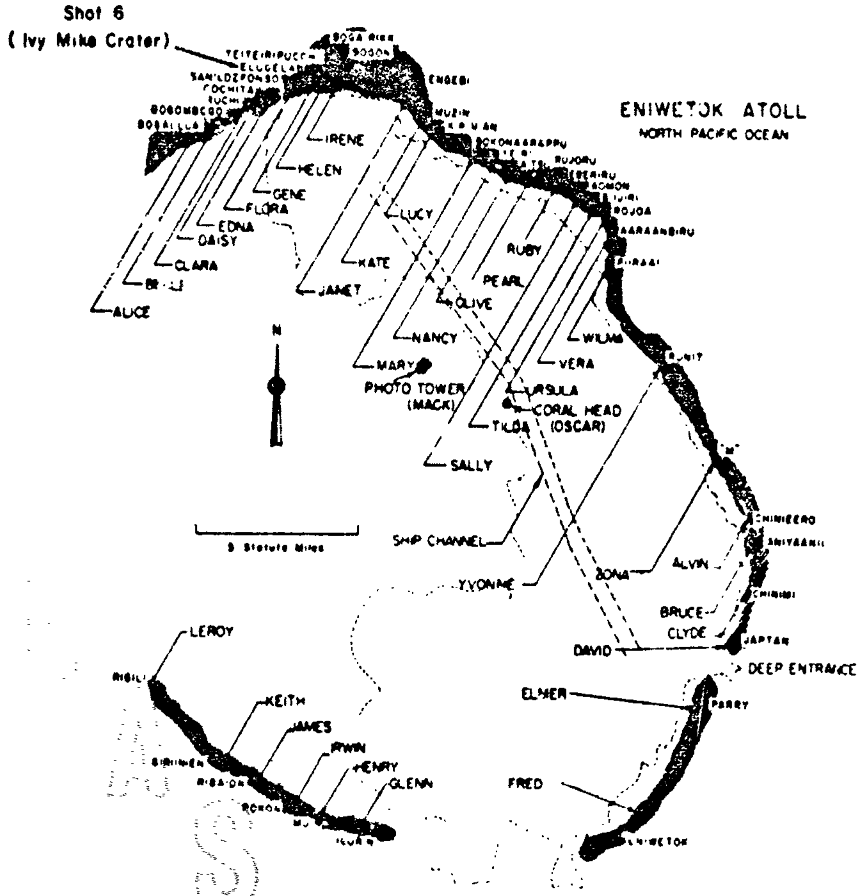
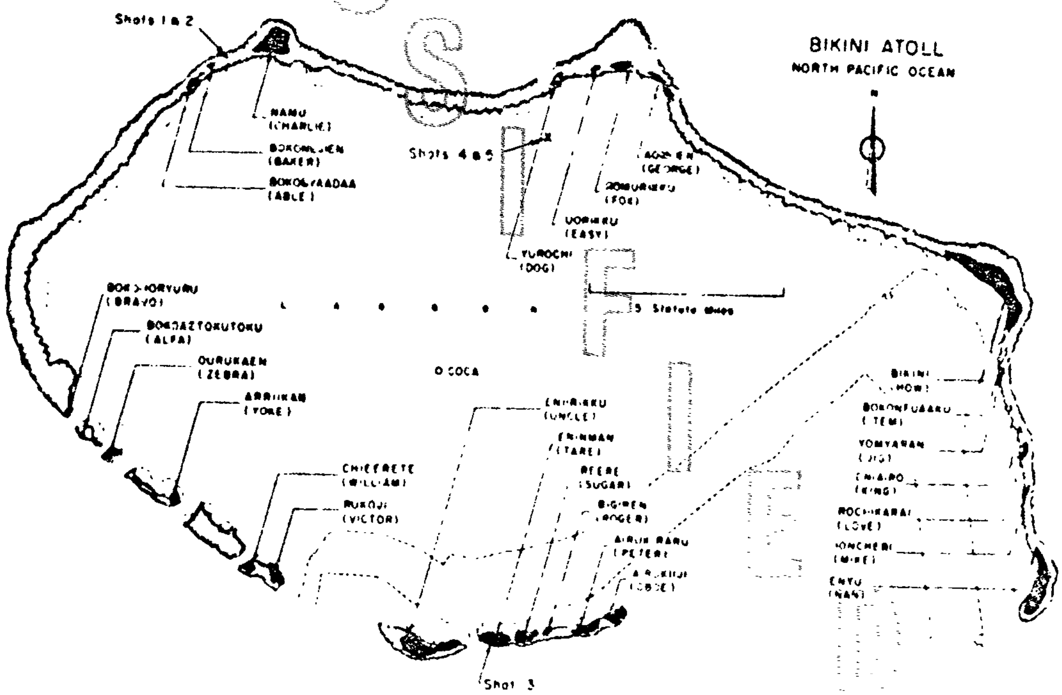

Shot 6
(Ivy Mike Crater)
ENIWETOK ATOLL
NORTH PACIFIC OCEAN
ENGEBI
IRENE
HELEN
GENE
FLORA
EDNA
DAISY
CLARA
ALICE
JANET
LUCY
KATE
RUBY
PEARL
OLIVE
NANCY
MARY
PHOTO TOWER
(MACK)
WILMA
VERA
URSULA
CORAL HEAD
(OSCAR)
TILDA
SALLY
N
5 Statute Miles
SHIP CHANNEL
YVONNE
ZONA
ALVIN
BRUCE
CLYDE
DAVID
JAPTAN
DEEP ENTRANCE
PARRY
ELMER
FRED
LEROY
KEITH
JAMES
IRWIN
HENRY
GLENN


Shots 1 & 2
BIKINI ATOLL
NORTH PACIFIC OCEAN
N
NAMU
(CHARLIE)
(BAKER)
(ABLE)
Shots 4 & 5
(GEORGE)
(FOX)
(EASY)
YUROCHI
(DOG)
5 Statute Miles
(BRAVO)
(ALFA)
(ZEBRA)
(YOKE)
(UNCLE)
(TARE)
(SUGAR)
(ROGER)
(PETER)
(WILLIAM)
(VICTOR)
BIKINI
(HOW)
(ITEM)
(JIG)
(KING)
(LOVE)
(MIKE)
(NAN)
Shot 3

[redacted]

FOREWORD

This report is one of the reports presenting the results of the 34 projects participating in the Military Effects Tests Program of Operation Castle, which included six test detonations. For readers interested in other pertinent test information, reference is made to WT—934, Summary of Weapons Effects Tests, Military Effects Program. This summary report includes the following information of possible general interest: (1) an overall description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the six shots; (2) discussion of all project results; (3) a summary of each project, including objectives and results; and (4) a complete listing of all reports covering the Military Effects Tests Program.

[redacted]

ABSTRACT

The objectives of Project 1.3 were to spot-check the theoretical relationship between dynamic pressure and overpressure in the 10-to-40-psi overpressure range and to evaluate a group of gages measuring various blast parameters.

The one measurement of dynamic pressure in Shot 6 agreed with that implied by the overpressure; in this case the shock had traveled 800 feet over land immediately before reaching the gage. In Shots 4 and 5 measurements of dynamic pressure by the gage group were all high; in this case the gages were near the water's edge. These latter records also showed peculiar waveforms, indicating that the shock had picked up water and/or dust.

The force plate and density gage seem to be suitable for field use, but their response to dust must yet be studied.

[redacted]

CONTENTS

FOREWORD 6

ABSTRACT 7

CHAPTER 1 INTRODUCTION 11
- 1.1 Objectives 11
- 1.2 Background 11

CHAPTER 2 EXPERIMENT DESIGN 13
- 2.1 Instruments. 13
- 2.2 Gage Layout. 13
  - 2.2.1 Dynamic Pressure. 14
  - 2.2.2 Gage Evaluation 15
- 2.3 Changes in the Experiment 15

CHAPTER 3 RESULTS 16
- 3.1 Presentation of Data 16
- 3.2 Discussion 16
  - 3.2.1 Dynamic Pressure. 16
  - 3.2.2 Gage Evaluation 16

CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS 23
- 4.1 Conclusions. 23
- 4.2 Recommendations 23

APPENDIX LIST OF ABBREVIATIONS 24

REFERENCES 26

TABLES
- 3.1 Dynamic Pressure Results 17
- 3.2 Overpressure Results 17
- 3.3 Density Results. 17
- 3.4 Total Pressure Results 18
- 3.5 Comparison of Measured with Calculated Dynamic and Total Pressure. 18

FIGURES
- 2.1 Correction factors for pitot gage, q-tube, and force plate 14
- 3.1 Dynamic pressure versus time, Shots 4, 5, and 6 . . . 19
- 3.2 Overpressure versus time, Shots 4, 5, and 6. 20
- 3.3 Density ratio versus time, Shots 3 and 4 20
- 3.4 Total pressure versus time, Shots 4, 5, and 6 (force plate) 21

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3.5 Comparison of force plate with pitot tube and q-tube. 22
A.1 Idealized wave form illustrating notation 24

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Chapter 1
INTRODUCTION

1.1 OBJECTIVES

The principal objective of Project 1.3 was to study the dynamic pressure-time characteristics of shock waves produced by high-yield surface bursts.

Blast damage to military targets is due to winds in the shock wave as well as to overpressures; in fact, damage to such targets as towers, bridges, and trucks is much better related to dynamic pressure than to overpressure. Since the extent of damage is related to the time history of dynamic pressure as well as to its peak value, measurements as a function of time are needed. Such measurements will also serve as a check on the theoretical relation between peak values of overpressure and dynamic pressure.

Another objective was to evaluate a group of gages for use on future studies of blast winds and other parameters associated with the precursor.

1.2 BACKGROUND

Dynamic pressure measurements have been made at Operations Tumbler-Snapper (Reference 1), Ivy (Reference 2), and Upshot-Knothole (Reference 3). Measurements where no precursor existed have been made both in regular and Mach reflection regions. In the Mach region, for air bursts and surface bursts, measured values of the peak dynamic pressure, q, have been in fairly good agreement with values calculated from the measured overpressure, using the theoretical relation (Reference 2):

$$q = \frac{1}{2} \rho u^2 = 2.5 \, \Delta P^2/(7P_o + \Delta P) \qquad (1.1)$$

Where: ρ = density.
u = particle velocity.
ΔP = overpressure.
P_o = ambient pressure.

However, measurements have been made only at overpressures below 20 psi, and in a few cases the values measured were somewhat higher than the calculated values. It is believed that these high values have the same explanation as that proposed below for high values in the precursor.

Only in Upshot-Knothole have measurements been made of dynamic pressure in the precursor. Although many of the gage towers were destroyed,

[redacted]

so that most records were incomplete, the records did show that the measured values of q were two to twenty times those calculated from the overpressure using the above relationship. The explanation for these high values as developed experimentally and theoretically (Reference 3) is that dust as well as air registers on the kind of gage used. Subject to rather broad limitations, dust carried along by the blast registers as $\rho_{dust}u^2$, whereas, air registers as $1/2\ \rho_{air}u^2$. It is a matter of experience that, at both the Nevada Test Site (NTS) and the Pacific Proving Grounds (PPG), a precursor is a dust-loaded blast wave.

Since this problem of dust interaction is not at all well understood, experiments were continued after Upshot-Knothole at Sandia Corporation to better define the interaction of dust with gages and structures. At the same time it was suggested that a set of data including overpressure, temperature, density, and at least two dynamic pressure measurements using gages with different responses to dust would give more insight into the nature of the precursor and would allow the effects of the air and the dust to be separated. The various gages being evaluated are a result of this suggestion.

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Chapter 2
EXPERIMENT DESIGN

2.1 INSTRUMENTS

The pitot-static gage was the best calibrated dynamic pressure gage and had been most widely used in the past. Therefore it was selected as the standard instrument for dynamic pressure measurements. The pitot gage also offered the advantage of measuring both dynamic pressure and the overpressure and both the positive and negative phases. Because of the shortage of recording channels no pitot gage could be included in the group of gages being studied. Since the differential pressure q-tube had been previously compared to the pitot gage it was considered the standard in this group.

The group of gages consisted of the following:

1. A resistance wire temperature gage, similar in principle to one used previously (Reference 1) but modified by mounting it in a side-on baffle and by using a blower to draw a continuous flow of air past the sensing wire.

2. A centripetal density gage (Reference 3) modified by doubling the rotor speed and mounting in a smaller baffle. An element to measure overpressure was also included.

3. A differential pressure q-tube.

4. A drag q-tube, identical in dimensions to the differential type, but instrumented to record the deflection of the sensing element instead of the difference in pressure between the centers of the front and back of the element.

5. A force plate, in which a large diaphragm-type pressure gage (Carlson-Wiancko Earth Pressure gage (Reference 4)) with a 7 3/8-inch diameter sensitive area was mounted in a 13-inch diameter baffle and used head-on into the blast to measure the total or stagnation pressure.

These gages have been tested in the laboratory, but the combination of high thermal radiation, zero time transients, long duration of the shock wave, and climatic conditions in actual bursts required that they also be tested in such bursts. The pitot gages and q-tubes have been calibrated in the wind tunnel (Reference 3), and Figure 2.1 gives the correction factors to obtain dynamic pressure from measured differential pressures. A model of a force plate was also tested, and the complete calibration will be presented elsewhere (Reference 6). Figure 2.1 also includes the correction factor for head-on orientation.

2.2 GAGE LAYOUT

All gages for this project were placed six feet above ground surface. This height was chosen as a compromise between the need to be far enough above ground to eliminate interference between the ground and the gage and the necessity of having a gage mount strong enough to withstand the high dynamic pressures to be measured.

2.2.1 Dynamic Pressure. The plan for this experiment did not call for complete coverage of q-time vs. distance, but for spot checks at selected positions in the 10-to-40-psi range of overpressures.

For Shot 3, three pitot gages were placed at distances corresponding to expected overpressures of 15 to 35 psi. It was expected that if a precursor formed, the closest gage (Station 130.03) would be in it; there-

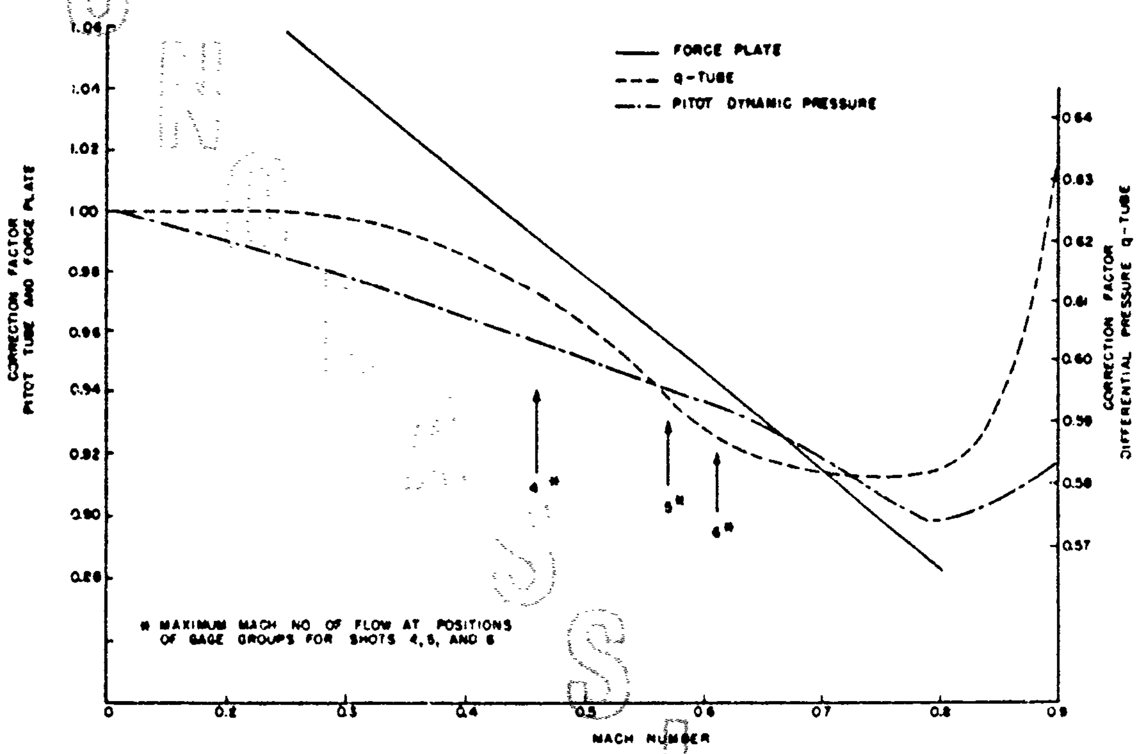

Figure 2.1 Correction factors for pitot static gage, q-tube, and force plate.

fore a temperature and a density gage were added to this station to aid in interpretation of results.

On arrival at the site it was discovered that the Echo shot (later canceled) gave an opportunity to measure dynamic pressures over two kinds of surfaces. Only one-half of Pearl Island had been cleared, the other half having been left in its native state of vegetation. Stations 130.04 and 130.05, each consisting of a pitot gage and a temperature gage, were installed at about equal distances from ground zero, one in the cleared area and one in the vegetation. This choice of gages was expected to measure the different amounts of heating of the air and the different amounts of dust picked up by the shock resulting from the differences in surface. These two stations were expected to be in a precursor if one formed.

[redacted]

2.2.2 Gage Evaluation. Only one group of the gages described in Section 2.1 was set up, Stations 131 and 130.07 next to each other on George Island of northern Bikini. Operation plans called for four nearby barge shots giving four trials of the gage group at overpressures ranging from 8 to 21 psi. In approaching the gages the shock would travel over water except for the last 20 to 30 feet, so that a fairly ideal shock was expected for the study.

2.3 CHANGES IN THE EXPERIMENT

Operation Castle was notable for the fluidity of its plans made necessary by the weather and the fact that it was primarily a weapons development test. To set forth these changes and their effect on Project 1.3, a list of the shots in the order in which they were fired follows:

Shot 1 was fired as scheduled. Although no participation was planned by Project 1.3, the force plate already installed on George Island was activated.

Shot 2 was moved from its position off Dog Island to the same place as Shot 1, thus removing one of the chances to test the gage group. The force plate was operated but again at an overpressure of only 3 psi, not at the higher value desired for the test.

Shot 3 was detonated at its planned position but was so much smaller in yield than expected that the resultant dynamic pressures were not in the range desired.

At this stage of the operation, Echo, the second shot on which dynamic pressure measurements were planned, was canceled.

Shot 4, the second shot on which the gage-group study was planned, went as scheduled, and measurements were made as intended.

Shot 5, another shot for which the gage study was planned, went as expected and some measurements were obtained. The water wave from Shot 4 had washed away the battery box containing the power supply for the density gage and the temperature-gage blower. Because of the high radiation-contamination level and the short time available between shots, these could not be reinstalled, so the density gage and the temperature-gage blower could not be run.

Shot 6, another shot on which it had been planned to make the gage study, was moved from Bikini to the Ivy Mike crater at Eniwetok. Because of previous inability to obtain desired data for this project and for Project 1.2a, a blast line was set up for this new position. Construction problems and the limited time available allowed only one station, consisting of a pitot gage and a force plate, at an overpressure level of 21.5 psi.

[redacted]

Chapter 3
RESULTS

3.1 PRESENTATION OF DATA

Data obtained are presented in Figures 3.1 through 3.4 and in Tables 3.1 through 3.4, grouped according to the quantity measured.

3.2 DISCUSSION

3.2.1 Dynamic Pressure. The first objective of Project 1.3 was not fully achieved because Echo shot was canceled and Shot 3 was so much smaller in yield than expected that the dynamic pressures resulting were too small to be read accurately.

On Shots 4 and 5 measured values of dynamic pressure and total or stagnation pressure were higher than those implied by the overpressure (Table 3.5), and waveforms were much distorted. For instance, on Shot 5 the dynamic pressure versus time records had a hump immediately after the initial rise (Figure 3.1), the overpressure-time record (Figure 3.2) had a dip at the same place, and the total pressure-time record (Figure 3.4) was essentially straight. Evidently the shock wave was not an ideal shock but seems to be one carrying with it water droplets and/or dust particles.[1] The point of measurement was fairly close to the water's edge.

On the other hand on Shot 6, measurements of dynamic pressure and total pressure were in good agreement with the values implied by the overpressure, and waveforms were only slightly rounded (Figures 3.1, 3.2, and 3.3). At the point of measurement the shock had traveled the last 800 feet over land.

This observation that a shock wave was less ideal over a water surface than over a land surface stands in direct contrast to previous suppositions.

3.2.2 Gage Evaluation. Although the gages were not in the ideal shock desired, some information about gage operation was obtained.

The force plate seems to have the required rise time of from 1 to 3 msec, and the ringing is not too objectionable. On Shot 1 this gage drifted badly before shock arrival because of heating by thermal radiation, but on subsequent shots the whole gage was covered by three or four sheets of 1-mil aluminum foil, and the drift was much smaller.

The drag q-tube, while otherwise behaving as expected, showed excessive ringing at its natural frequency of about 500 cps. The pressure-time insert in Figure 3.1 for this gage has this ringing smoothed out in order

[1] Photography shows that the shock wave in traveling across water kicks up water spray which would follow the front at about this time interval (Reference 7).

[redacted]

TABLE 3.1 DYNAMIC PRESSURE RESULTS

For definition of symbols, see Appendix.

Shot	Station	Gage	GR	t_a	q_1	Δt_1	q_2	Δt_2
			ft	sec	psi	sec	psi	sec
3	130.03	Pitot	8,200	4.568			0.28	
3	130.02	Pitot	8,800	5.040			0.43	
3	130.01	Pitot	10,900	6.766			0.15	
4	131	q-Tube Diff. Pres.	15,430	5.683	5.3	0.001	7.0	0.04
4	131	q-Tube Drag	15,430	5.683	5.9	0.001	7.5	0.04
5	131	q-Tube Diff. Pres.	15,660	4.860	9.9	0.001	13.0	0.019
5	131	q-Tube Drag	15,660	4.860	8.2	0.001	13.3	0.058
6	132	Pitot	8,240	2.635	8.0	0.001	8.5	0.009

TABLE 3.2 OVERPRESSURE RESULTS

For definition of symbols, see Appendix.

Shot	Station	Gage	GR	t_a	ΔP_1	Δt_1	ΔP_2^{+} [a]	Δt_2^{+}	t^{+}	ΔP_m^{-}	Δt_m^{-}	t^{-}	I^{+}	I^{-}	I^{+}/I^{-}
			ft	sec	psi	sec	psi	sec	sec	psi	sec	sec	psi-sec	psi-sec	
3	130.03	Pitot	8,200	4.568	2.2	0.002	3.6	0.025	2.54	0.28	4.73	5.9	3.1	0.8	3.9
3	130.02	Pitot	8,800	5.040	2.7	0.003	3.3	0.02	2.82	0.35	4.1	5.7	3.2	0.6	5.4
3	130.01	Pitot	10,900	6.766	1.53	0.001	2.1	0.03	2.10	0.38	4.23	6.8	2.0	1.5	1.33
4	131	Density	15,430	5.683	14.0	0.001	14.6	0.003	4.06	2.2	8.8	27.0	21.0	25.0	0.84
5	131	Density	15,660	4.860	23.3	0.001	18.8	0.09							
6	132	Pitot	8,240	2.635	15.2	0.002	21.0	0.011	2.26	2.3	5.2	20.0	14.0	19.0	0.74

[a] These are the maximum pressures reached after the initial rise; in all except Shot 5 these are also the maximum pressures reached (see Figure 3.2).

TABLE 3.3 DENSITY RESULTS

For definition of symbols, see Appendix.

Shot	Station	GR	t_a	$(\rho/\rho_o)_1$	Δt_1	$(\rho/\rho_o)_2^{+}$	Δt_2^{+}	t^{+}	$(\rho/\rho_o)_m^{-}$	Δt_m^{-}	t^{-}	$(\rho/\rho_o)_2$ Calculated from ΔP
		ft	sec		sec		sec	sec		sec	sec	
3	130.03	8,200	4.568	1.17	0.005	1.22	0.01	1.5	0.93	3.3	8.0	1.17
4	131	15,430	5.683	1.82	0.005	1.89	0.025	3.1	0.78	7.6	21.2	1.57

[redacted]

TABLE 3.4 TOTAL PRESSURE RESULTS

Shot	Station	GR	t_a	ΔP_1	Δt_1	ΔP_2^+	Δt_2^+	t^+	ΔP_m^-	Δt_m^-	t^-
		ft	sec	psi	sec	psi	sec	sec	psi	sec	sec
1	130.07	54,140	33.34	2.94	0.002	3.14	0.33	9.8			33
2	130.07	54,350	34.63	2.3	0.003	2.60	0.40	8.3	0.45	18	33
4	130.07	15,430	5.683	22.5	0.001	22.5	0.001	3.1	3.0	8	19
5	130.07	15,660	4.860	31.0	0.001	31.0	0.001	4.2			
6	132	8,240	2.635	28.5	0.002	30.5	0.008	1.56			

TABLE 3.5 COMPARISON OF MEASURED WITH CALCULATED DYNAMIC AND TOTAL PRESSURE

Shot	Gage	Ground Range	ΔP^a Over-pressure	q Calcu-lated	q_1 Meas-ured	q_2 Meas-ured	Total Pressure	Total Pressure	Total Pressure
		ft	psi	psi	psi	psi	$\Delta P+q_{cal}$	$\Delta P+q_{meas}$	Force Plate
4	Diff. Pres. q	15,462	14.0	4.3	5.3		18.3	19.3	22.5
			14.0	4.3		7.0	18.3	21.0	22.5
4	Drag q	15,462	14.0	4.3	5.9		18.3	18.9	22.5
			14.0	4.3		7.5	18.3	21.5	22.5
5	Diff. Pres. q	15,659	23.3	10.7	9.9		34.0	33.2	31.0
			18.8	7.3		13.0	26.1	31.8	31.0
5	Drag q	15,659	23.3	10.7	8.2		34.0	31.5	31.0
			18.8	7.3		13.3	26.1	32.1	31.0
6	Pitot Static	8,238	21.0	8.9	8.5		29.9	29.5	30.5

[a]The values of overpressure listed are those occurring at the same time as the dynamic pressures listed.

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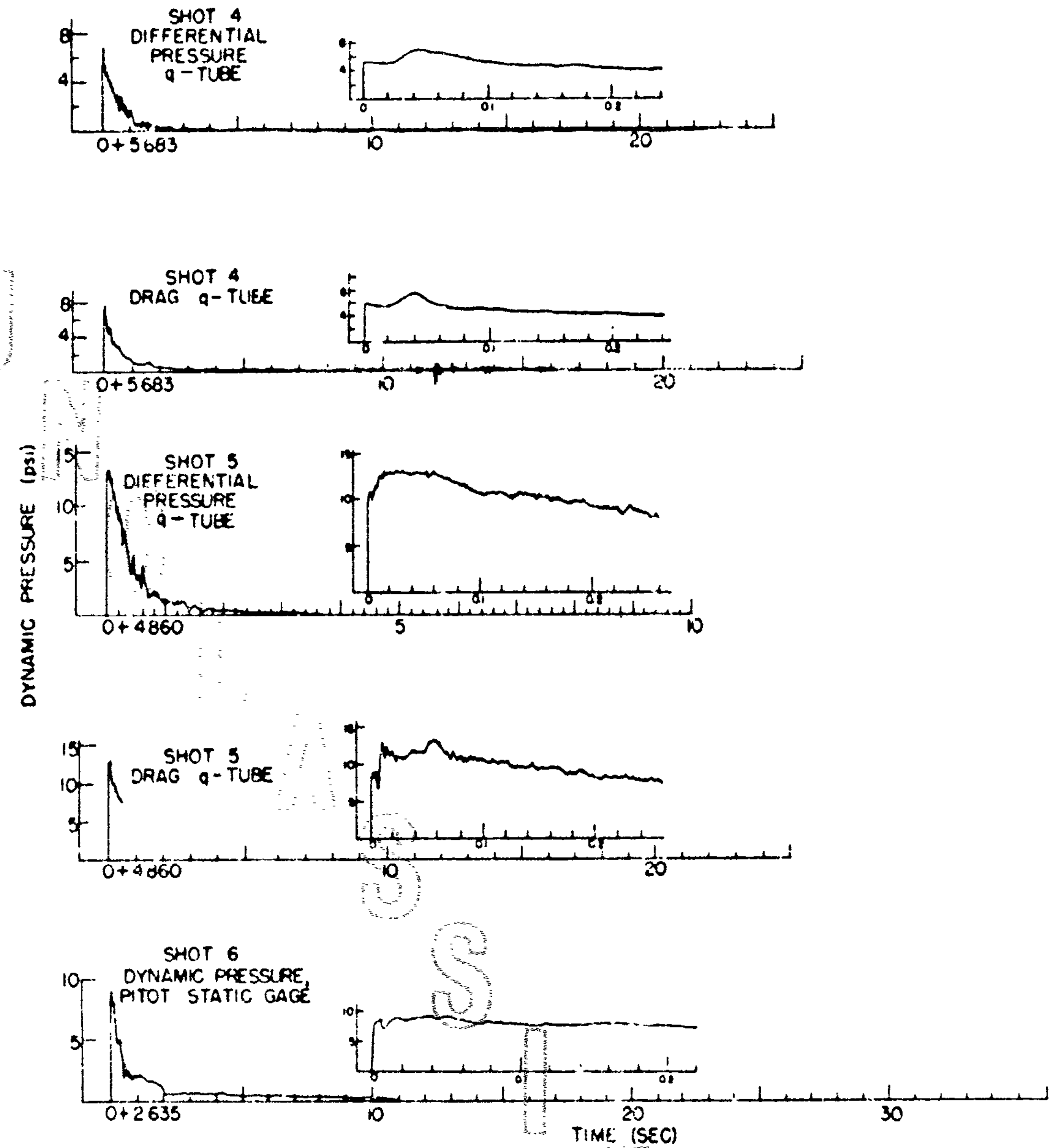

Figure 3.1 Dynamic pressure versus time, Shots 4, 5, and 6.

to see the true form at all. The amplitude of the ringing was up to 80 percent of the signal amplitude. Since it does not appear that this ringing can be damped out with the present design nor that its frequency can be raised to such a value that it will not be objectionable, it must be concluded for now that this gage is not suitable for its proposed use.

Figure 3.5 compares total pressure measured by the force plate to that measured by three types of dynamic pressure gages. Here the noise and high-frequency ringing of the gages has been smoothed out. A 50-cps ringing of the force plate is much more prominent on Shot 6 than on the other shots. The correspondence of the total pressures is very good on Shots 4 and 6, although the force plate differs from the q and ΔP measure-

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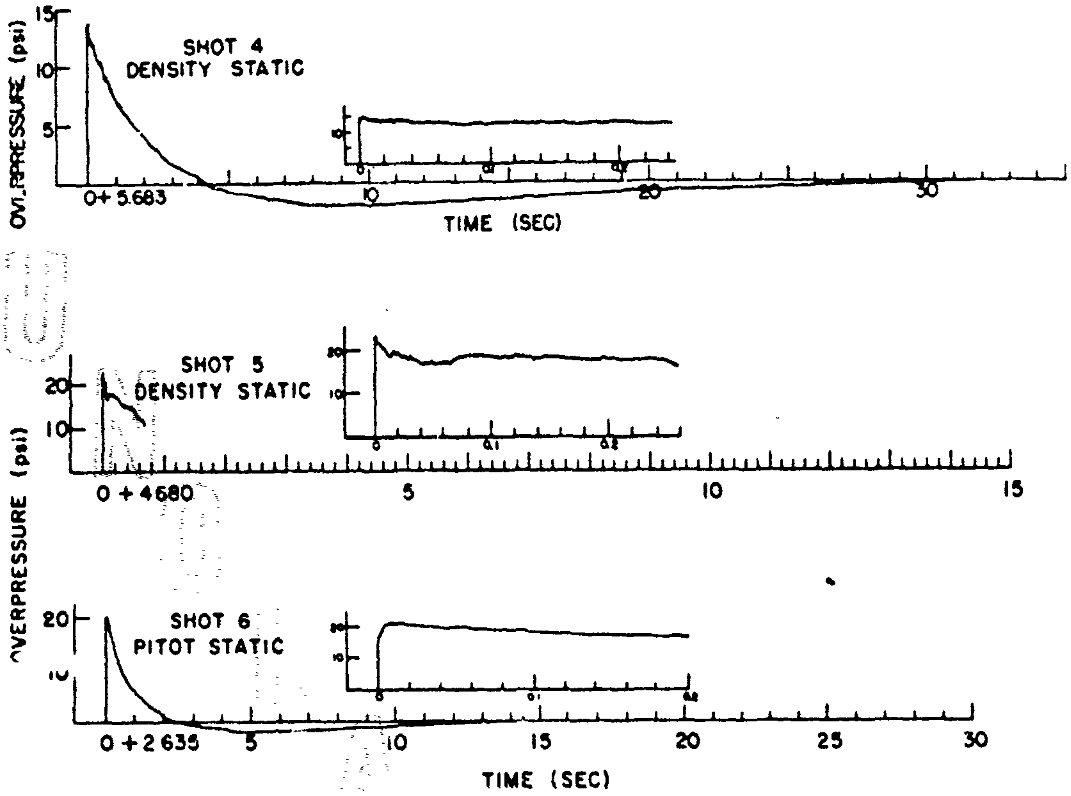

Figure 3.2 Overpressure versus time, Shots 4, 5, and 6.

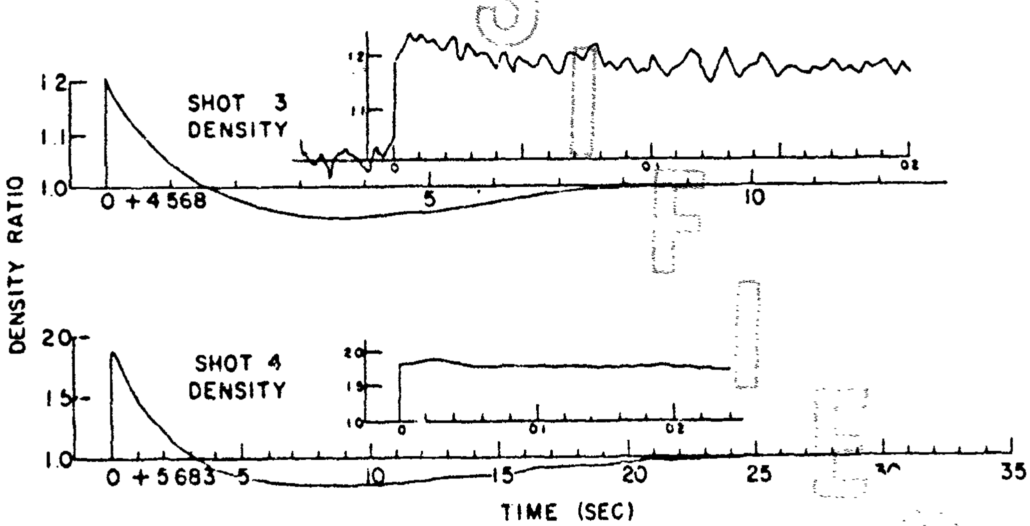

Figure 3.3 Density ratio versus time, Shots 3 and 4.

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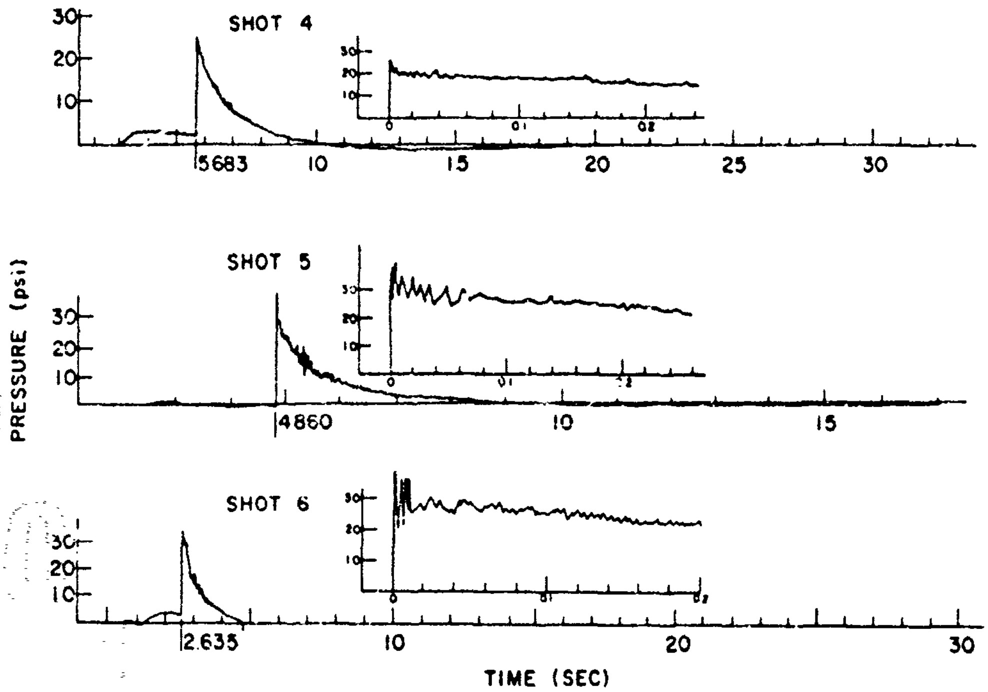

Figure 3.4 Total pressure versus time, Shots 4, 5, and 6 (force plate).

ments by slightly more than the expected accuracy (5 percent) of the individual records. The 2-msec dip in the q and ΔP record of Shot 5 appears to be a real signal from the q record, although the differential pressure q-tube does not show it. The similar dip in the force plate record for Shot 6 is probably coincidental since it seems to result, at least partially, from the 50-cps ringing of the force plate.

The density gage operated very satisfactorily on Shot 3 at an over-pressure of about 4 psi, the measured compression ratio (ratio of shock density to ambient density) being in good agreement with that inferred from the overpressure. On Shot 4 it gave a high value as did all other gages. This may mean that in some way it registers water or dust in the air. Laboratory tests in still air show that the gage responds to dust, but that in shock flow the dust goes by the opening and does not contribute significantly to the gage output. In Figure 3.3 the density-time insert is a true tracing of the record on Shot 3. For Shot 4 the gage oscillations have been smoothed out.

The temperature gage was installed principally to provide information about any changes in air temperature before shock arrival but with the hope that it might operate at least part way through the shock. However, it was so fragile that the resistance wire (1/2-mil Nilvar) broke for no apparent cause. This occurred just before Shot 4, so that the gage was not operated on that shot. The battery power for the blower could not be reinstalled in time for Shot 5 so that the thermal radiation had a chance to heat the air stagnated around the element, and no valid measurement was obtained on this shot either.

[redacted]

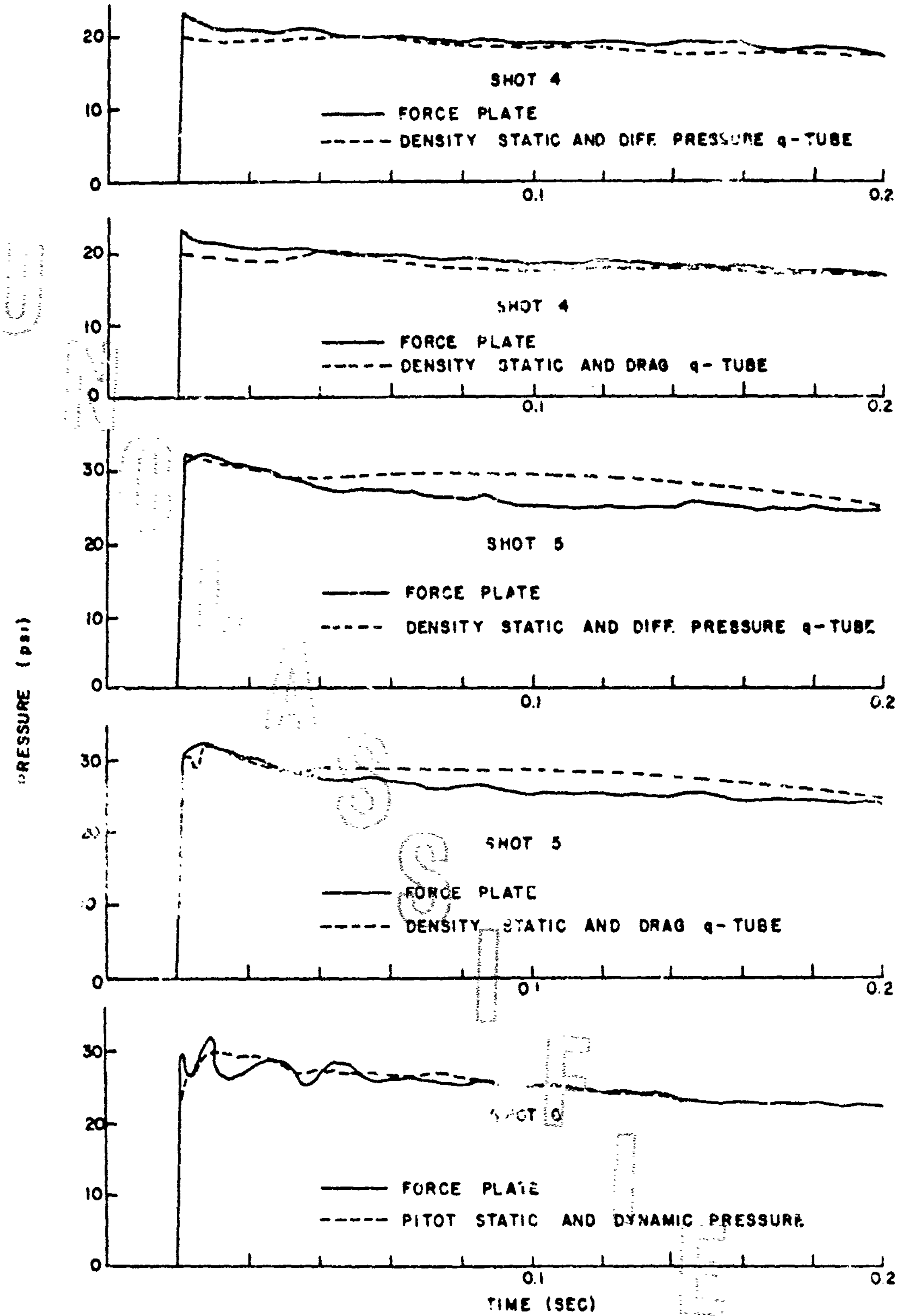

Figure 3.5 Comparison of force plate with pitot tube and q-tube.

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Chapter 4
CONCLUSIONS and RECOMMENDATIONS

4.1 CONCLUSIONS

The one successful measurement of dynamic pressure made specifically to check the relation between dynamic pressure and overpressure was in good agreement with the theoretical relation. This measurement was made on Shot 6 at an overpressure of 21.5 psi and at a position such that the shock wave had had 800 feet of travel over land immediately in front of the gage. Measurements were also obtained on Shots 4 and 5 in connection with the gage evaluation study at overpressures of 14 and 20 psi and at a position such that the shock wave had traveled entirely over water except for the last 20 to 30 feet. These records gave higher values of dynamic and total pressure than implied by the overpressure, and had distorted waveforms. Such nonideal behavior suggests that the shocks had picked up water and/or dust in their travel; this was not expected of shock waves over water, a supposedly ideal surface.

From the gage study it seems that the force plate and the density gage are suitable for field use. The density gage responds at least partially to material other than air carried by the shock wave and this response requires further investigation if it is to be used in the presence of dust. Further use of the resistance wire temperature gage or of the drag-type q-tube is not recommended.

On Shot 4 both q-tubes indicate the hump in dynamic pressure, but this is not at all clearly evident in the force-plate record; however, on Shot 5, the hump in dynamic pressure corresponds to the dip in overpressure so that no hump in total pressure would be expected. On Shot 5 the sum of the overpressure and dynamic pressure exceeds the force plate reading behind the front. If the force-plate scale were increased or the density static scale decreased, the values at 0.1 second after shock arrival could be matched and, as in Shot 4, have the force plate readings slightly higher just behind the front but thereafter about equal to the sum of the dynamic pressure and overpressure.

4.2 RECOMMENDATIONS

The comparison of propagation of a precursor wave over sandy soil and over vegetation (proposed on the canceled Shot Echo) should be carried out when suitable test conditions become available.

Further measurements of the dynamic pressures from surface bursts should be made to cover the range of pressures planned for Shot 3 but not realized because of the small yield.

Appendix

LIST OF ABBREVIATIONS

ΔP = Overpressure, the difference between the ambient and the absolute pressure in a shock wave.

- ΔP_2^+ = Maximum ΔP in the positive phase.
- ΔP_m^- = Maximum ΔP in the negative phase.
- ΔP_i = Initial rise of overpressure (or total pressure).

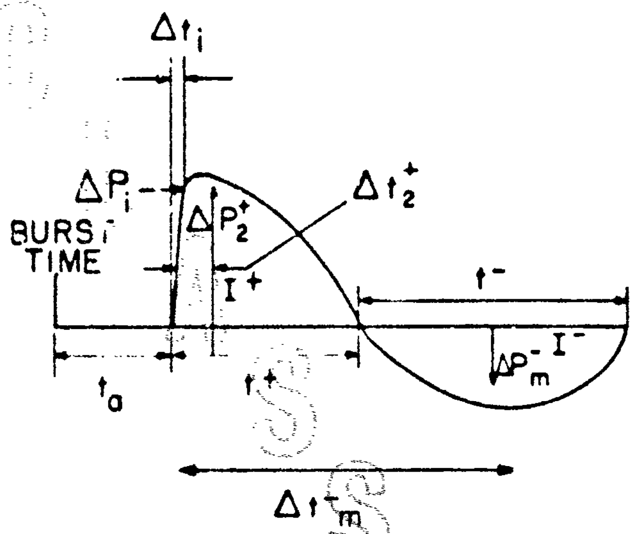

Figure A.1 Idealized waveform illustrating notation.

Δt = Time interval between time of shock arrival and time of a quantity being measured.

- Δt_2^+ = Time to maximum in the positive phase of quantity being measured.
- Δt_m^- = Time to maximum in the negative phase of quantity being measured.
- Δt_i = Initial rise time of overpressure or other quantity being measured.

GR = Ground range, the distance from shot point to gage.

I = Impulse, the integral of overpressure with time.

P_o = Initial ambient pressure.

[redacted]

q = Dynamic pressure; in clean air $q = 1/2\ \rho u^2$.

q_1 = Initial rise of dynamic overpressure.

q_2 = The maximmm dynamic pressure in the positive phase.

t_a = Arrival time after zero time of shock wave at gage.

t^+ = Duration of positive phase.

t^- = Duration of negative phase.

u = Particle velocity of air in the shock wave.

(ρ/ρ_o) = Density ratio.

[redacted]

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