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MEMORANDUM REPORT NO. 1818

BASIC AIR BLAST MEASUREMENTS FROM A 500-TON TNT DETONATION PROJECT 1.1 OPERATION SNOWBALL

by

R. E. Reisler
J. H. Keefer
L. Giglio-Tos

December 1966

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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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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

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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REReisler/JHKeefer/LGiglio-Tos/cr
Aberdeen Proving Ground, Md.
December 1966

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PROJECT 1.1 OPERATION SNOWBALL

ABSTRACT

This report presents free field blast data obtained by instruments positioned at selected distances from the center of a 500-ton hemispherical surface charge of TNT. Measured values of shock arrival time, overpressure, duration of positive phase of the shock wave, impulse, and dynamic pressure are plotted as functions of distance and are compared with predicted values. Pressure-time histories obtained at pressure levels of 300, 90, 30 and 15 psi are compared with predicted wave shapes. Measured data in the low and moderate pressure regions compare favorably with predicted values.

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LIST OF SYMBOLS

q	dynamic air pressure
P_s	peak overpressure
P_t	total head pressure
P_o	ambient pre-shock static pressure sea level
P_a	ambient pre-shock static pressure test site
W	charge weight (lb)
T_a	temperature (ambient)
S_p	pressure scaling factor
S_d	distance scaling factor
S_t	time scaling factor
S_I	impulse scaling factor

1. INTRODUCTION

The mission of Project 1.1 was to conduct studies of the air blast phenomena resulting from the explosion of a 500-ton hemispherical charge during Operation Snowball. Operation Snowball was the name given to a coordinated test program under the guidance of The Technical Cooperation Program (TTCP). The test was held at the Suffield Experimental Station, (SES), Alberta, Canada in 1964 and participants included project groups from Canada, the United Kingdom, and the United States.

The charge consisted of 30,678 blocks of TNT, each block measuring 12 x 12 x 4 inches with an average weight of 32.6 pounds. The blocks were stacked on a base consisting of four layers of 3/4-inch plywood on a 1-foot bed of sand. When assembled, the charge, shown in Figure 1.1, has a radius of 17 feet. Figure 1.2 shows the detonation of the charge.

1.1 Objectives

The objectives of the project were:

a. To predict, measure, and analyze the air blast phenomena from a multi-ton TNT detonation.

b. To provide such free-field blast parameter information for interested projects.

c. To integrate these results with existing information on blast phenomena.

d. To provide instrumentation support for associated participating projects.

1.2 Background and Theory

The Ballistic Research Laboratories (BRL), have participated in large-scale explosive tests under Defense Atomic Support Agency sponsorship for more than a decade. In recent years participation has been in the three large-scale High Explosive (HE) tests conducted at SES in 1959, 1960 and 1961. The collection of basic air-blast data from the 500-ton explosion, a first in "extra large" HE detonations, is a natural continuation in the process of data acquisition and analysis of the blast

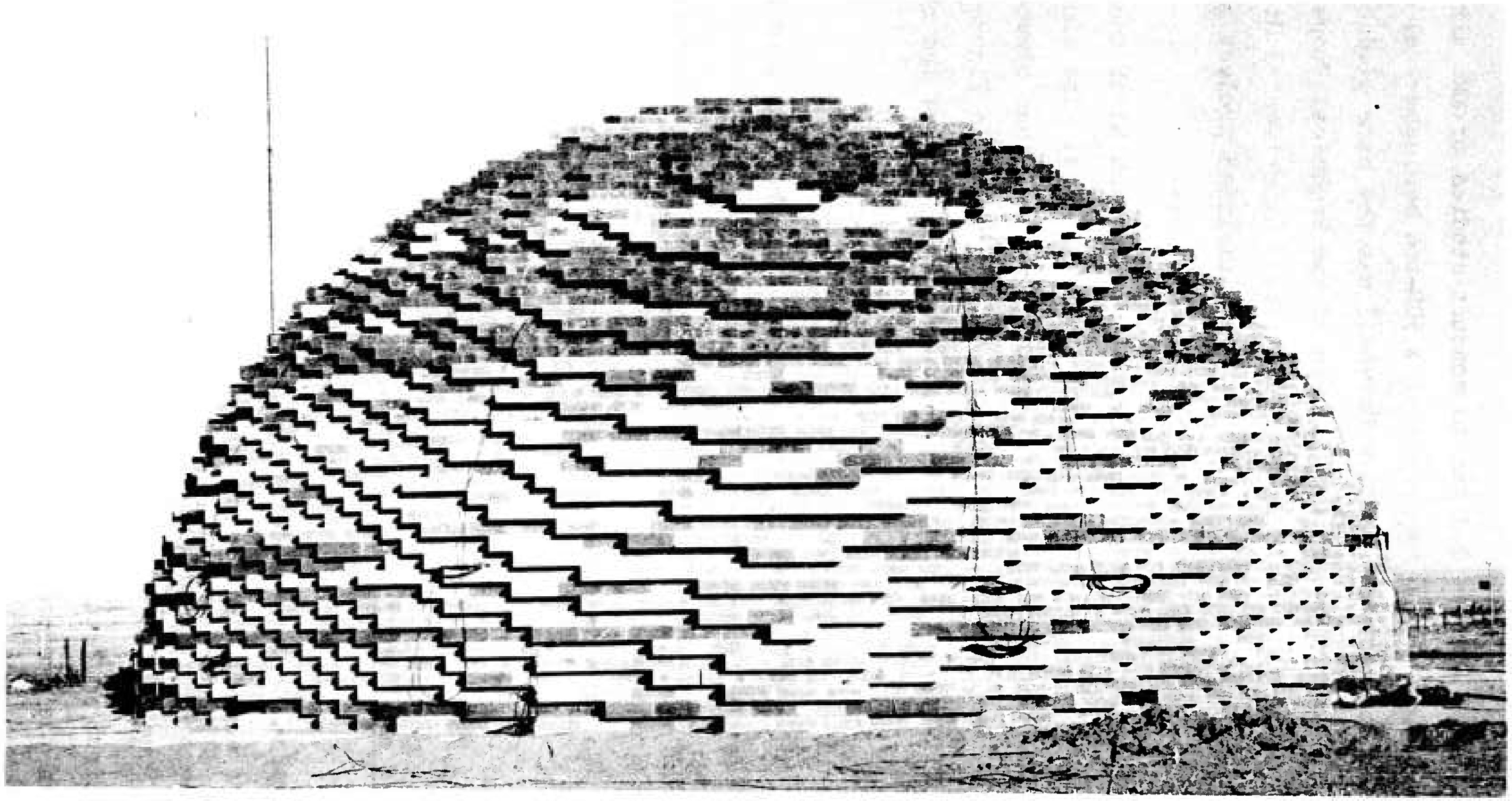

Figure 1.1 Stacked 500-Ton Charge

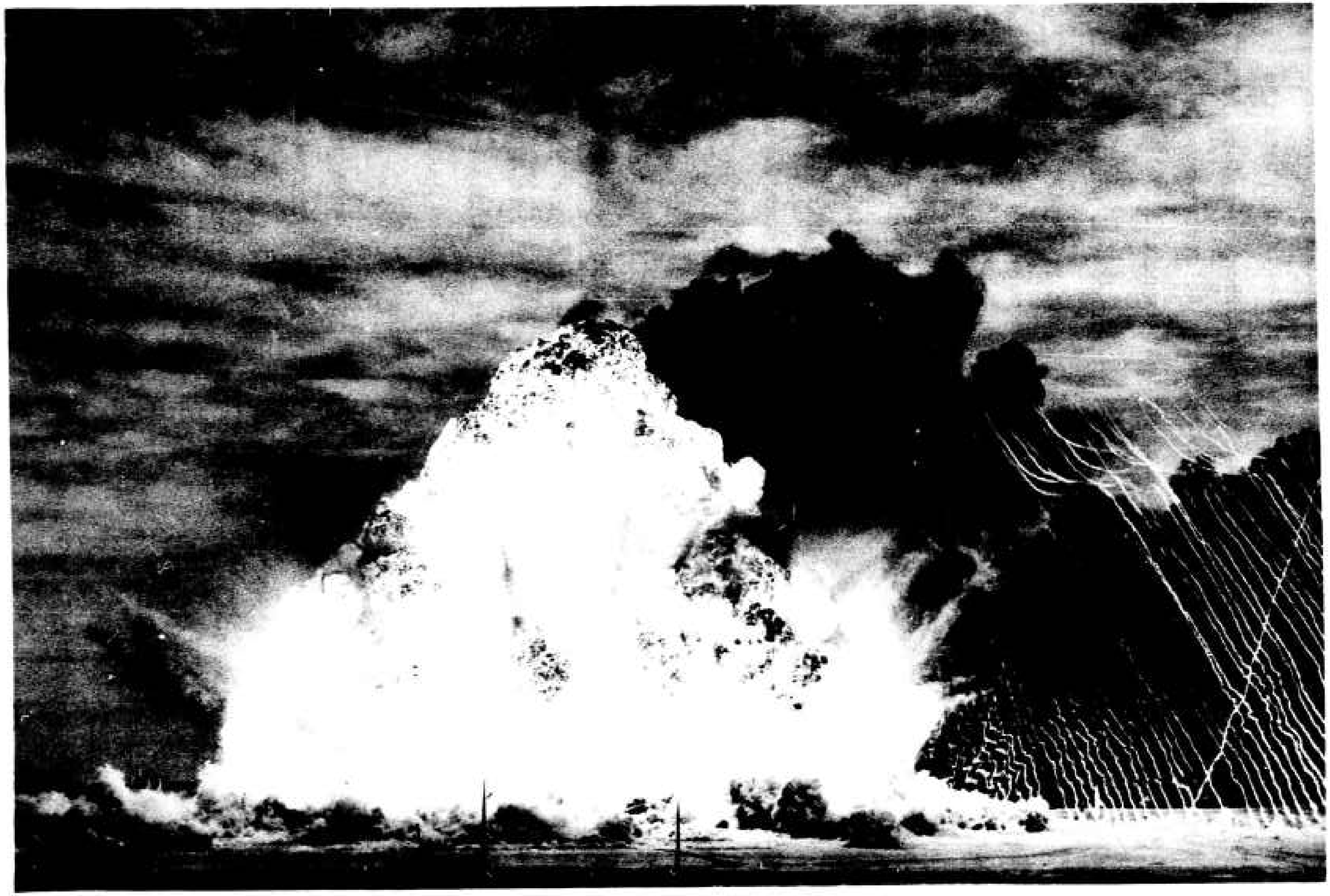

Figure 1.2 Detonation of 500-Ton Charge

phenomena. A thorough understanding of the air-blast parameters is imperative for an analysis of the effect of blast loading. Dynamic blast effects from the explosion can be used to better understand the blast effects from nuclear detonations. Thus, information gained from Snowball can be used for current analysis relating to structures loading, vehicle damage, and correlation with nuclear test results.

Theoretical calculations concerning the formation and propagation of air blast waves associated with a TNT charge and their comparison with similar phenomena from a point source explosion in air have been accomplished by several authors. Presented in DASA Report No. 1249[1*] is a summary by George Stalk in which it is stated that: "The HE source represents a fairly low temperature, high density gas and performs much like the energy transfer associated with a moving piston. The pressure-distance decay rate increases as the analogous piston energy is depleted until at greater distances the HE curve becomes quite similar to a point source curve." Additional details of the wave propagation may be found in reports by Dr. H. L. Brode of the Rand Corporation.[2]

The data recorded by the experimenters participating in the 5-ton, 20-ton, and the 100-ton shots at SES in 1959, 1960, and 1961 were used to provide predictions of the overpressure parameters for the 500-ton shot. Two hundred and seventy-three data points were used in a combination of two least squares fits to obtain the pressure-distance curve. Selected records from the three previous tests were used to make the positive phase and the positive impulse predictions.

Peak dynamic pressure versus distance was of considerable interest to those experimenters concerned with drag sensitive targets. Based on an assumption that a classical wave shape would be recorded at pressures less than 400 psi, the dynamic pressure was calculated from the following

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**Superscript numbers denote references which may be found on page 61.*

well-known relationship:

$$q = \frac{5}{2} \frac{(P_s)^2}{7 P_o + P_s}$$

which is derived from the Rankine-Hugoniot equations.

Predictions of wave form were made using the technique developed by Brode in Reference 2. Pressure levels of 300, 90, 30, 15, and 5 psi were selected as representative of the pressure spectrum; special emphasis was placed on the 30-and 5-psi regions so that the results could be compared with similar data from the United Kingdom (U.K.) projects.

2. PROCEDURES

Project 1.1 set up pressure measurement instrumentation at 29 sites. Electronic and self-recording pressure instrumentation systems were used at 22 stations located on an established blast line in the northeast sector of the test area. The blast line began with the closest station at 50 feet (3,000 psi) and extended to a station at 1450 feet (5 psi) as illustrated in Figure 2.1. An instrument shelter, constructed below grade, was located at 960 feet to house the electronic recording equipment. All control signals and signal cables to the instrument stations emanated from the recording shelter.

Because of the great distances from ground zero, stations 23 and 24 were not located on the blast line, but were established along the main access road to the test site. Instrumentation at these sites was manually initiated by personnel at observation areas. Station 26 was located at the main laboratory at SES approximately 35 miles from the test area. Three positions were located in a pasture near the town of Hilda, 25 miles East of the test area. Gages were taken to the area on the morning of the detonation by Canadian Air Force helicopter. Figure 2.2 shows the location of these very low pressure stations.

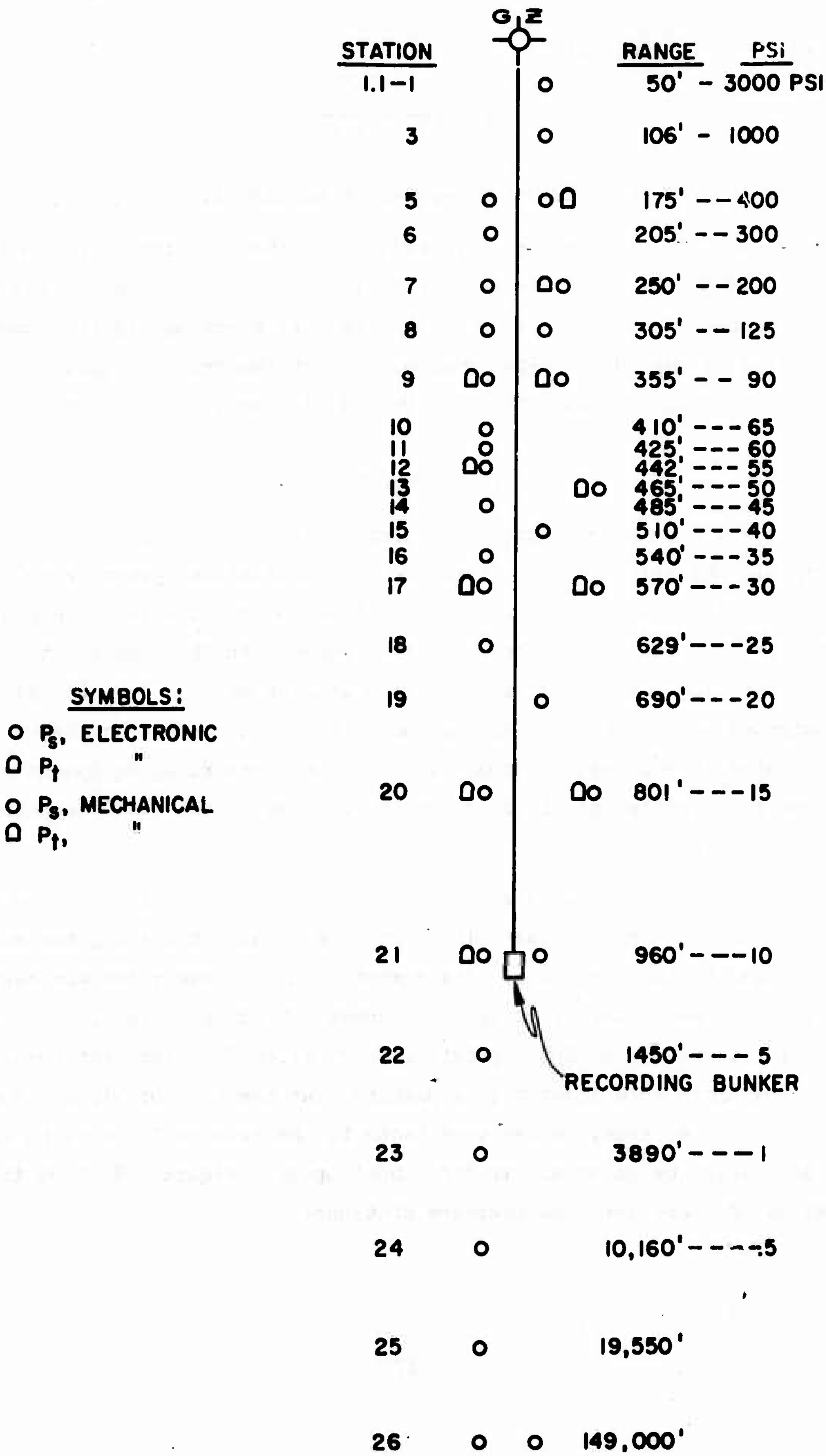


Figure 2.1 Blast Line Layout

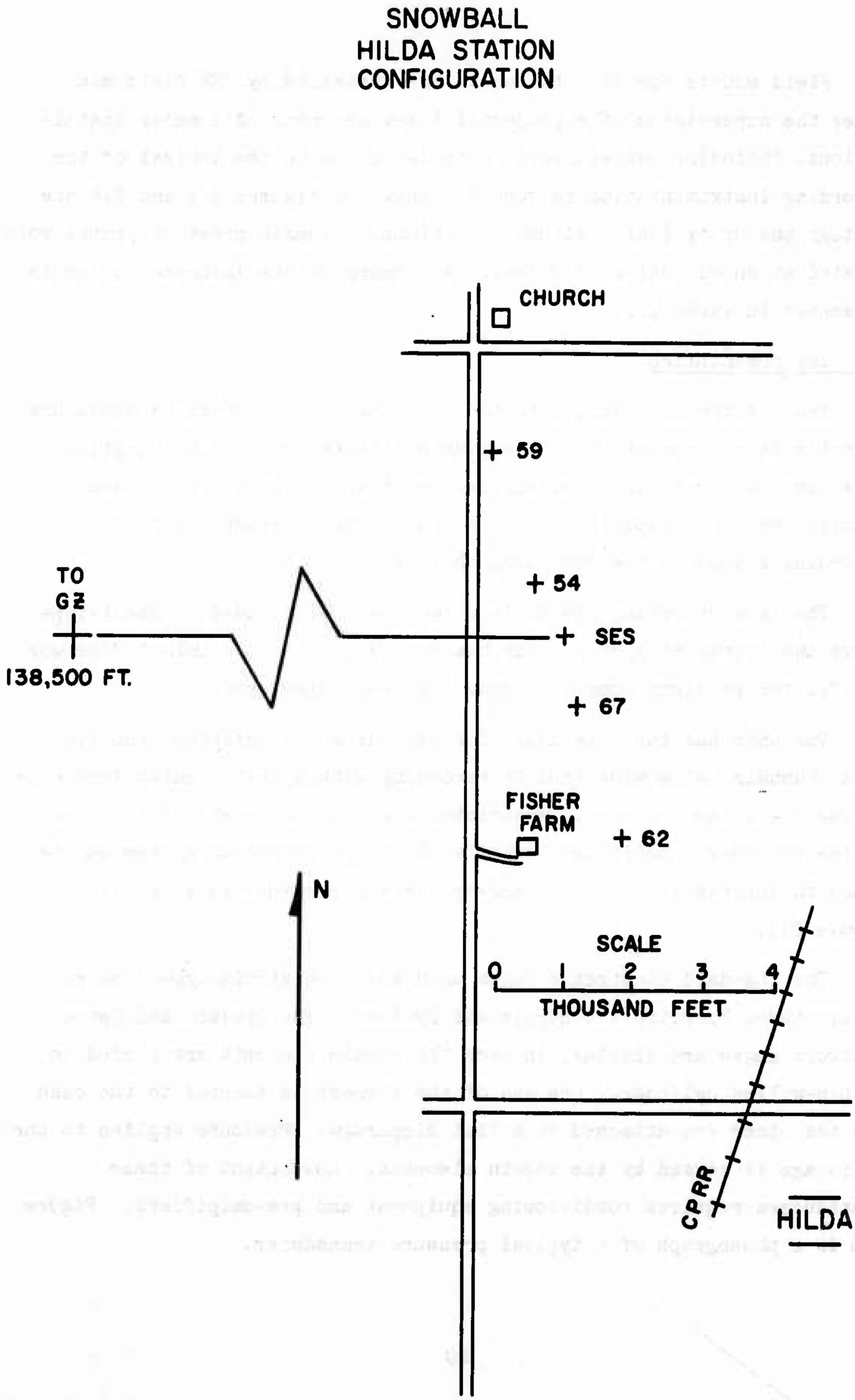


Figure 2.2 Very Low Pressure Layout, Hilda Site

Field mounts for all the gages were installed by SES field men under the supervision of a project 1.1 advance man. All major installations, including cables, were installed prior to the arrival of the recording instrumentation personnel. Shown in Figures 2.3 and 2.4 are photographs of typical instrument stations. Dynamic pressure probes were located at an elevation of 3 feet. A summary of the instrumentation is presented in Table 2.1.

2.1 Instrumentation

The electronic instrumentation consisted of 0 - 10 kc FM miniature magnetic tape recorders and Consolidated Electrodynamics Corporation 20-kc and 3-kc recording systems used with strain gage type pressure transducers. Low capacitance cable coupled the transducers to the recording system in the recording shelter.

The tape recording system is unique in that it uses a Cobelt-tape drive and transport system which has been designed to eliminate the wow and flutter problems common to many tape recording systems.

The unit has the capability for recording one reference and six data channels using wide band FM recording with a 54-kc center frequency giving 0 - 10-kc response. Associated logic units provide for control of the recorder. Additional details about the recording system may be found in Reference 3 and a photograph of the recorder is shown in Figure 2.5.

The standard electronic gages used were the strain-type sensors manufactured by Detroit Controls and Dynisco. The Dynisco and Detroit Controls gages are similar; in each the strain elements are bonded to a thin-walled cylinder. One end of the element is secured to the case and the other end attached to a flat diaphragm. Pressure applied to the diaphragm is sensed by the strain elements. Low output of these transducers requires conditioning equipment and pre-amlpifiers. Figure 2.6 is a photograph of a typical pressure transducer.

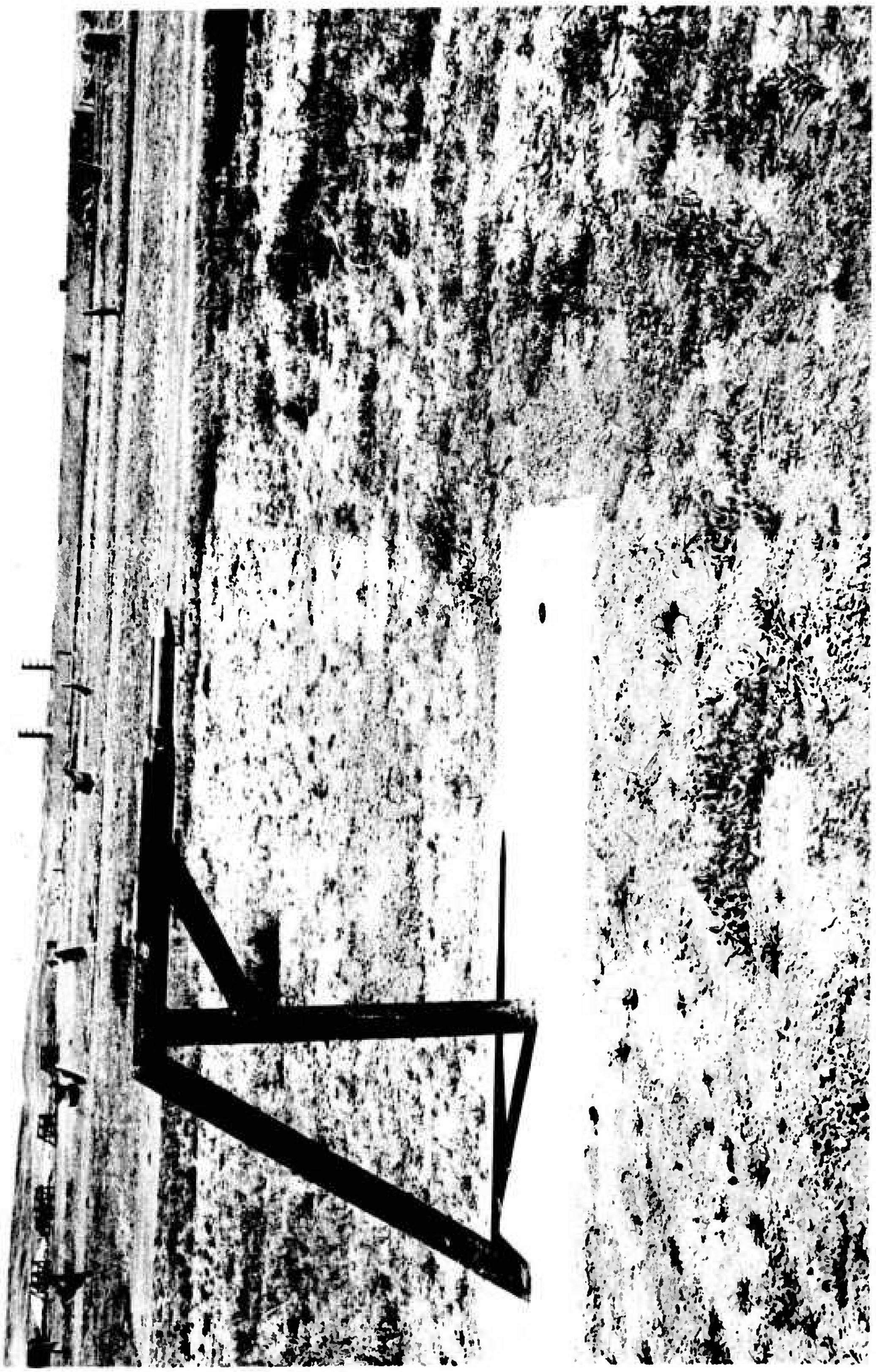


Figure 2.3 Electronic Pressure Gage Station

Figure 2.4 Installation of Self-Recording Gage

Table 2.1 Summary of Project Instrumentation

A. BLAST LINE

System	Type	No. of Channels
Electronic System E and Tape	Ground Baffle	13
	Probe	6
Self-Recording	Ground Baffle	19
	Probe	5

B. PROJECT SUPPORT

System	Type	No. of Channels	Project
Electronic System D		20	1.16
Electronic System D and E		16	1.6
Electronic System E and Tape		10 (4 included in Blast Line)	4.1
Self-Recording	P_s	3	1.10
Self-Recording	P_s	3	3.4
Self-Recording	P_s	1	1.2
Self-Recording	P_s	3	1.6

SUMMARY TOTAL

Electronic Channels: 61

Self-Recording Channels: 34

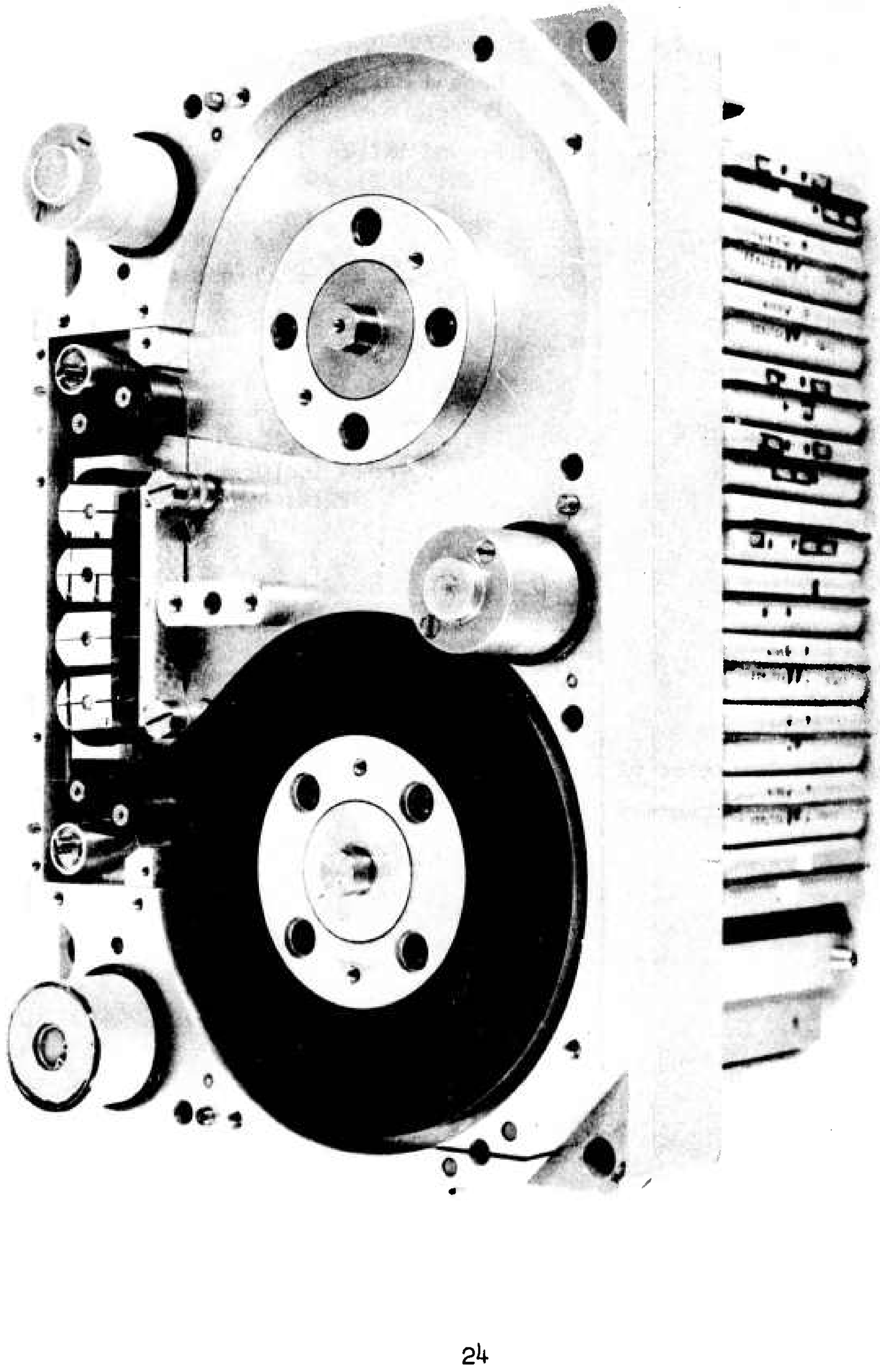


Figure 2.5 Miniature Magnetic Tape Recorder

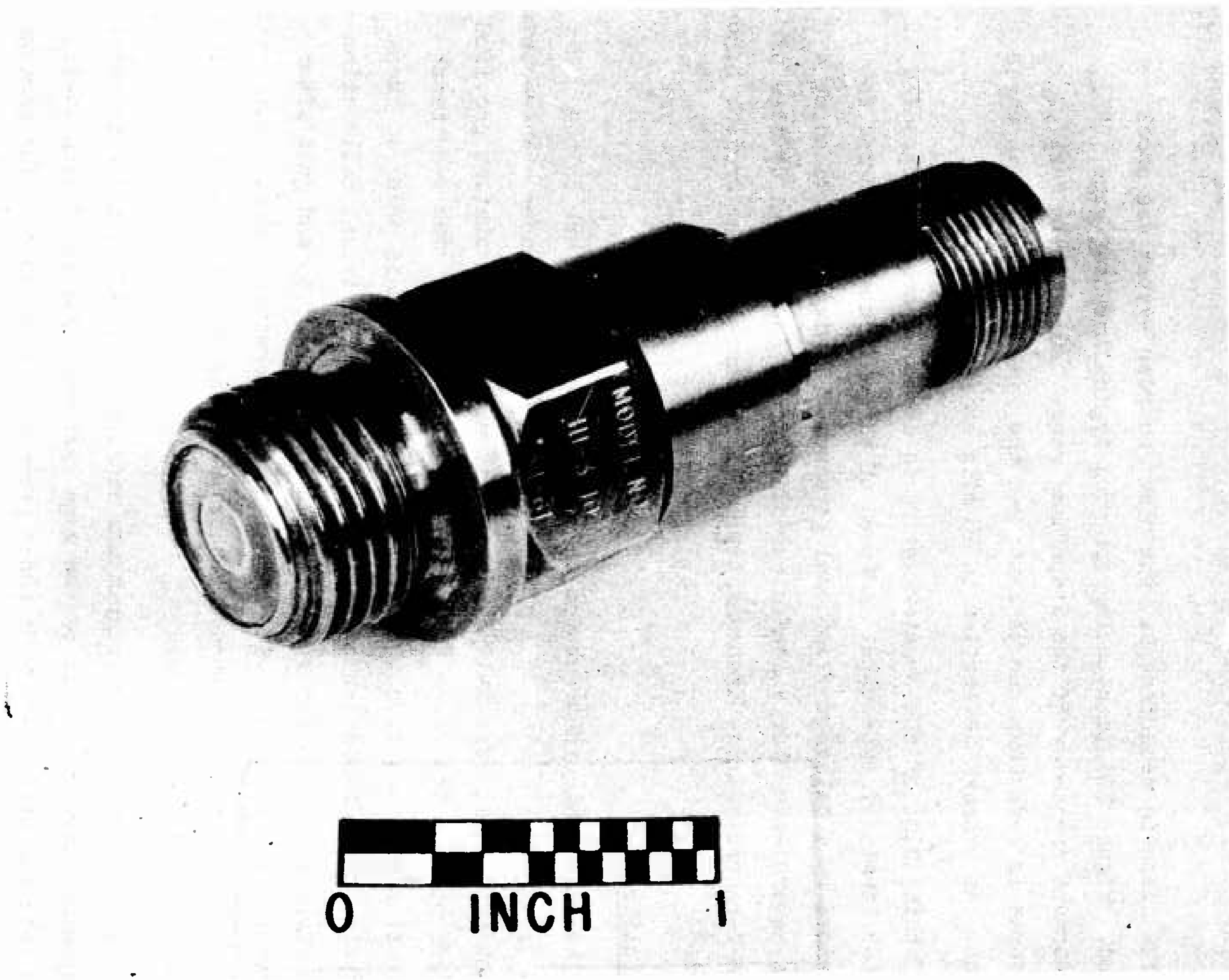


Figure 2.6 Typical Strain Type Pressure Transducer

The self-recording pressure gage has a single metal diaphragm sensor. A stylus mounted to this sensor scribes a record on the metal tape of a negator spring motor-recorder system or on a metal disk driven by a DC motor.

For close-in measurements, the disk recorder system was shock mounted. Figure 2.7 is a photograph of a typical negator gage (PNS). The resonant frequency of the diaphragms range from 1 kc to 7 kc; hysteresis is less than one percent; and the linearity is one to three percent. An average deflection is 20 mils at rated pressure.

Running time of the negator spring is 10 to 20 seconds depending upon the length of tape used. A speed of three inches per second is maintained by a balanced frictional governor. Timing is provided by a 50 cps square wave electromechanical oscillator. Additional details of the self-recording gage instrumentation is presented in the Project 1.3b report.[4]

2.2 Calibration

The electronic instrumentation was calibrated in place in the field by the application of a static force to the transducer. Where this was not practical, especially with certain drag instrumentation provided for Project 1.6, the force was simulated electrically. The resultant calibration was read from the oscillogram and plotted in order to check the system characteristics prior to acceptance. Electrical calibration steps were applied to the recording media just prior to and just after the event for correlation with the earlier calibration. Static calibration of the self-recording diaphragm sensors was done in the laboratory prior to installation in the gages.

A shock tube testing program was conducted at BRL in order to check the dynamic characteristics of the gage systems. The air driven 24-inch shock tube was used to provide shock pressures up to 30 psi; for pressures greater than 30 psi, the detonation driven shock was used.[5] Schematics of the two tubes are shown in Figures 2.8 and 2.9 which indicate the location of the test sections. Every electronic gage and sample self-recording sensors of each range were tested.

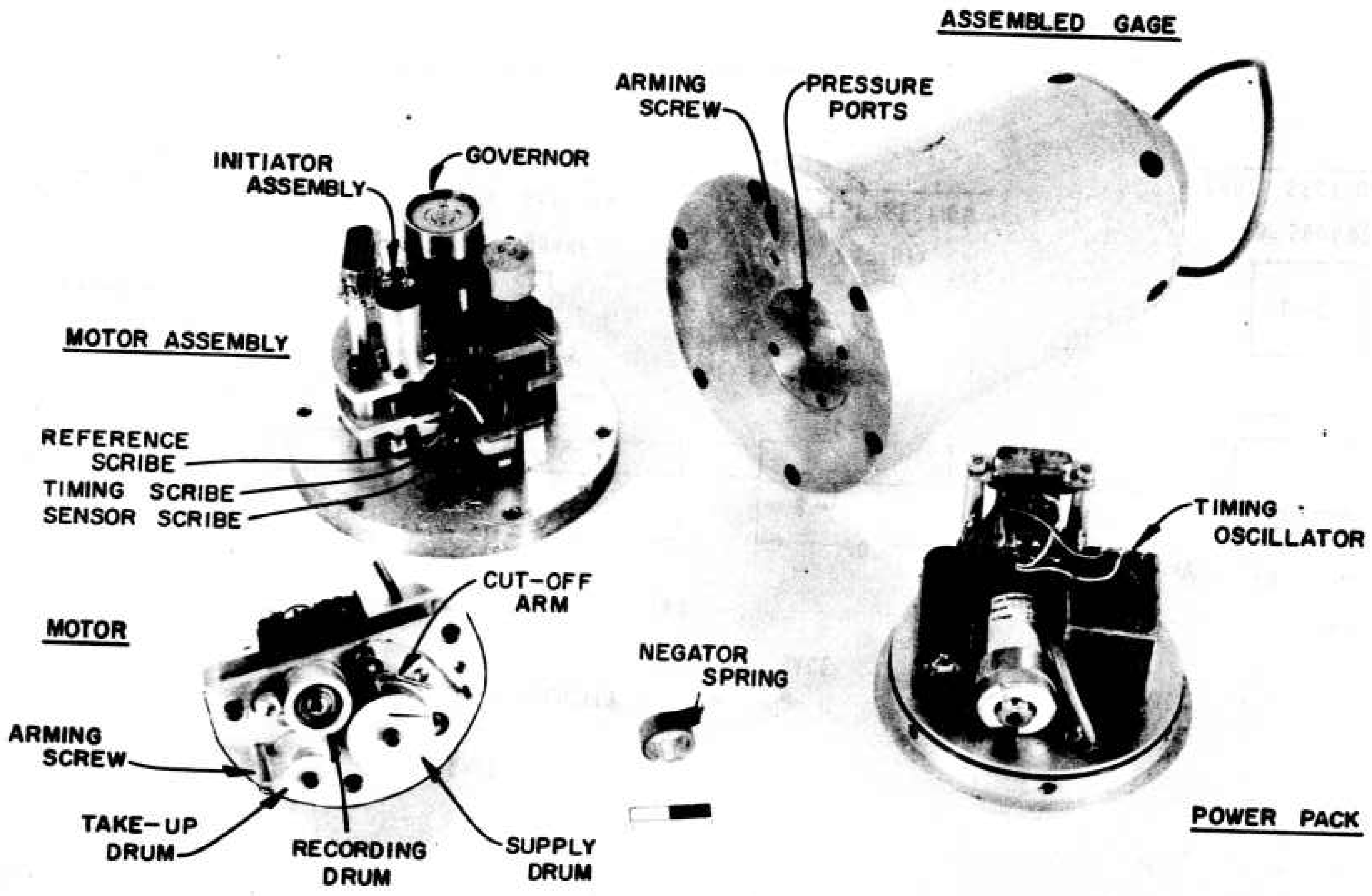


Figure 2.7 Exploded View of Self-Recording Pressure Gage

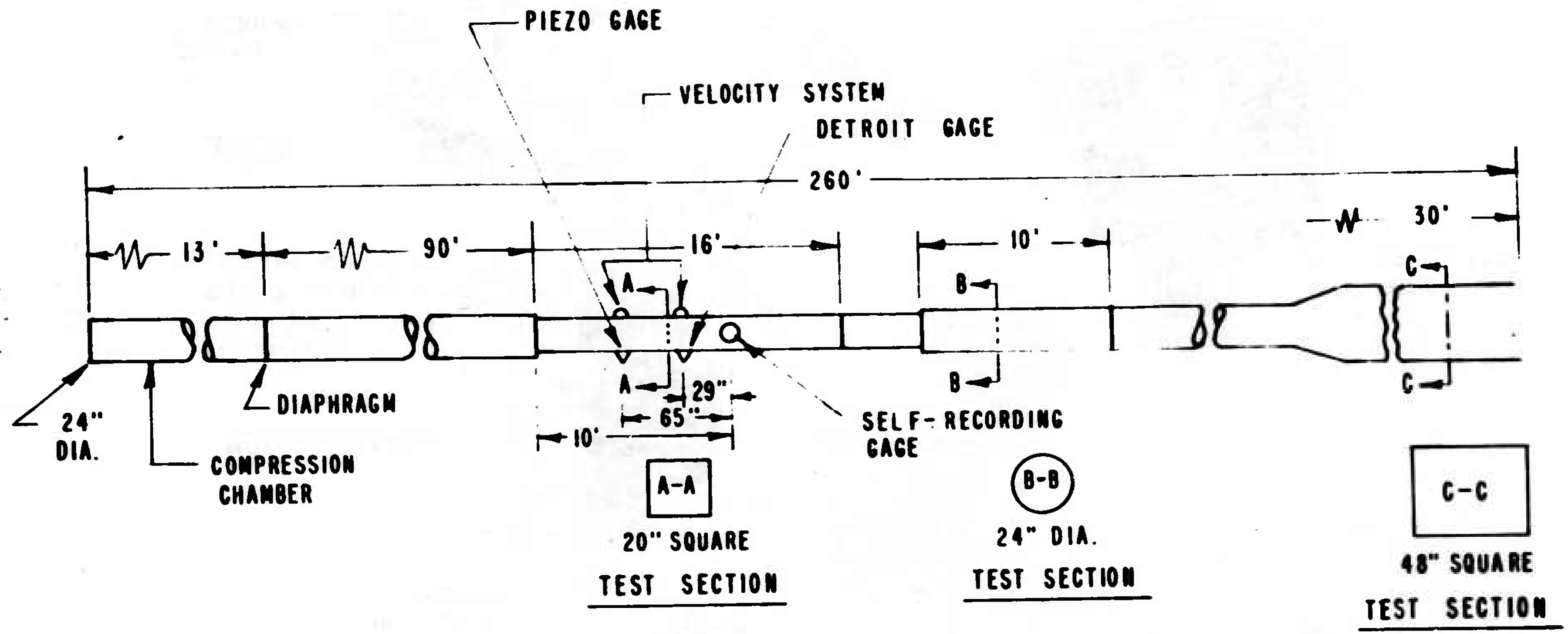


Figure 2.8 BRL 24" Shock Tube

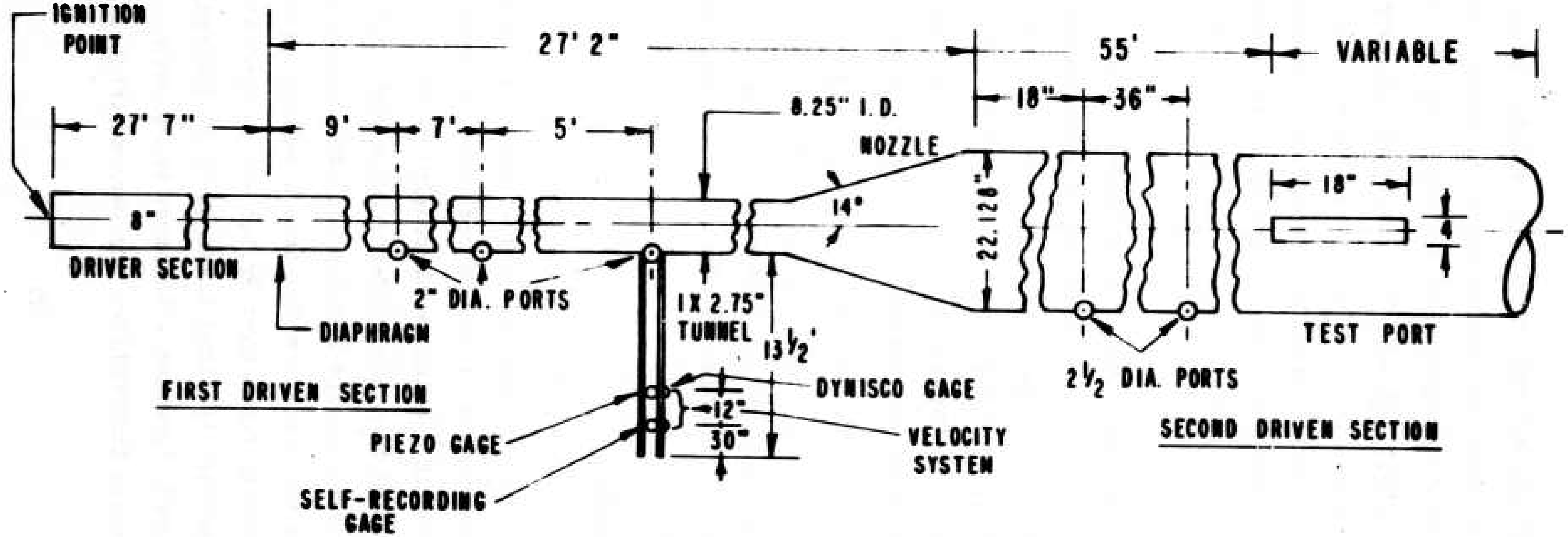


Figure 2.9 Detonation Driven Shock Tube

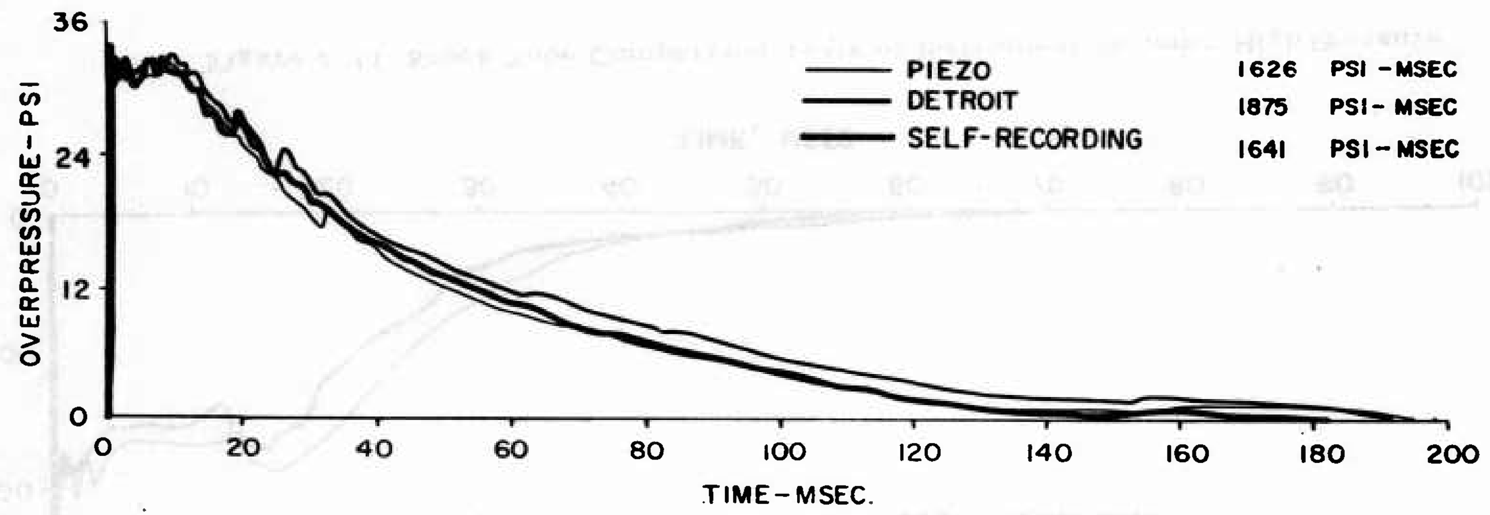
In order to obtain information on the reliability of gage systems, a series of comparison shots was conducted in the shock tubes. The levels of pressure at the test sections were 30, 100, 160, and 200 psi. The electronic pressure gages and the self-recording pressure gages to be used at these same levels in the field were tested. The identical recording system used in the field was employed. A piezoelectric transducer was used along with the velocity system of the shock-tube facility to provide control data. Figures 2.10 and 2.11 show the results of the comparison tests.

In the gas driven shock tube a side tunnel (1 inch x 2 3/4 inch) was used in order to reduce the vibration effects transmitted through the wall of the tube to the gage systems. The reduction of such effects is especially important for the self-record system. As may be seen from the figures, a classical wave was not produced. This was due primarily to the incomplete mixture and detonation of gases in the driver section.

As an additional comparison indicating the reliability of the systems, the data obtained from self recording and electronic sensors on a 20-ton surface shot were plotted and are presented in Figure 2.12. The loss of data due to the longer rise time of the self-recording gage is seen in the 300-psi record.

2.3 Record Processing

The records obtained by the electronic recording systems appear as oscillograms for visual reading at the laboratory on Universal Telereader equipment. X-Y measurements of the record trace are converted to digital form by magnetic reading heads coupled to the cross-wire system in the reader. Records from the self-recording gages are read with the aid of a toolmaker's microscope modified to use magnetic reading heads. Output signals from the heads are fed into a Telecordex accumulator and thence to an IBM Summary Punch Card System and an automatic typewriter. These cards, representing readings taken at short intervals throughout the span of the record, together with cards representing calibration steps and time interval information, are used as input for the BRL



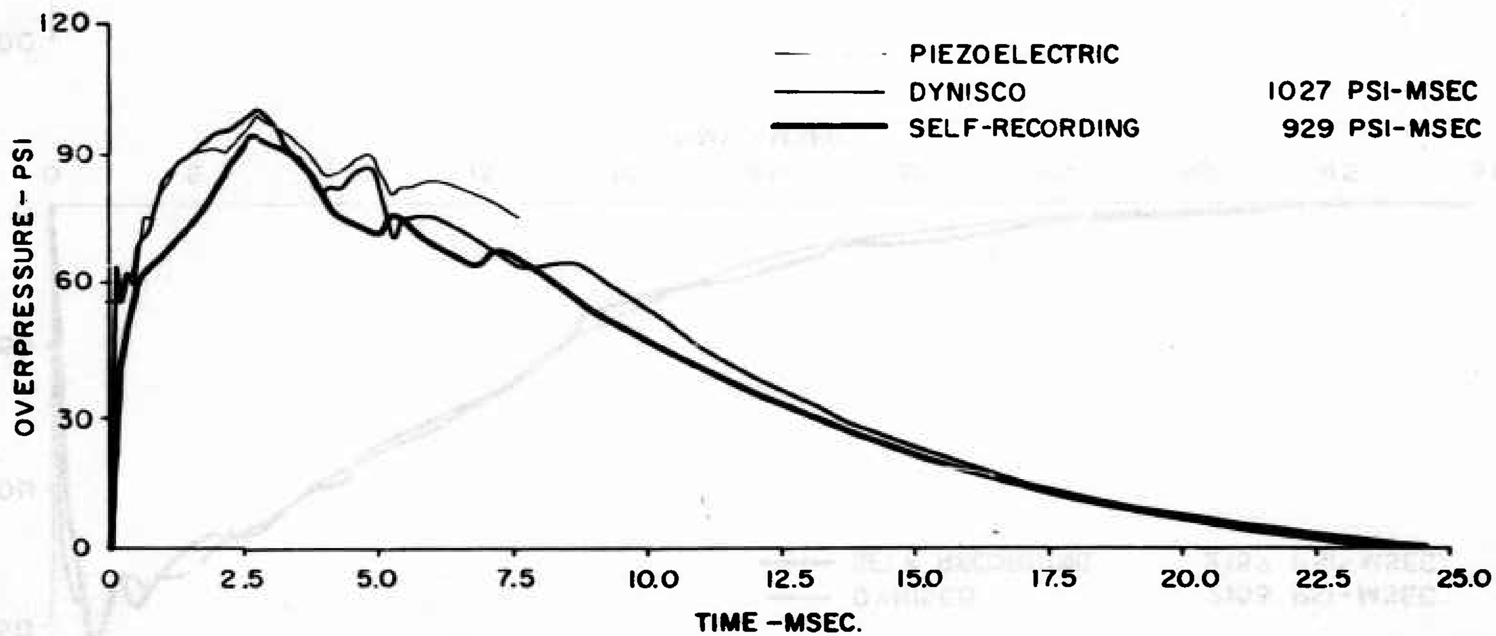


Figure 2.10 Shock Tube Comparison Tests of Instrument Systems, Low Pressure

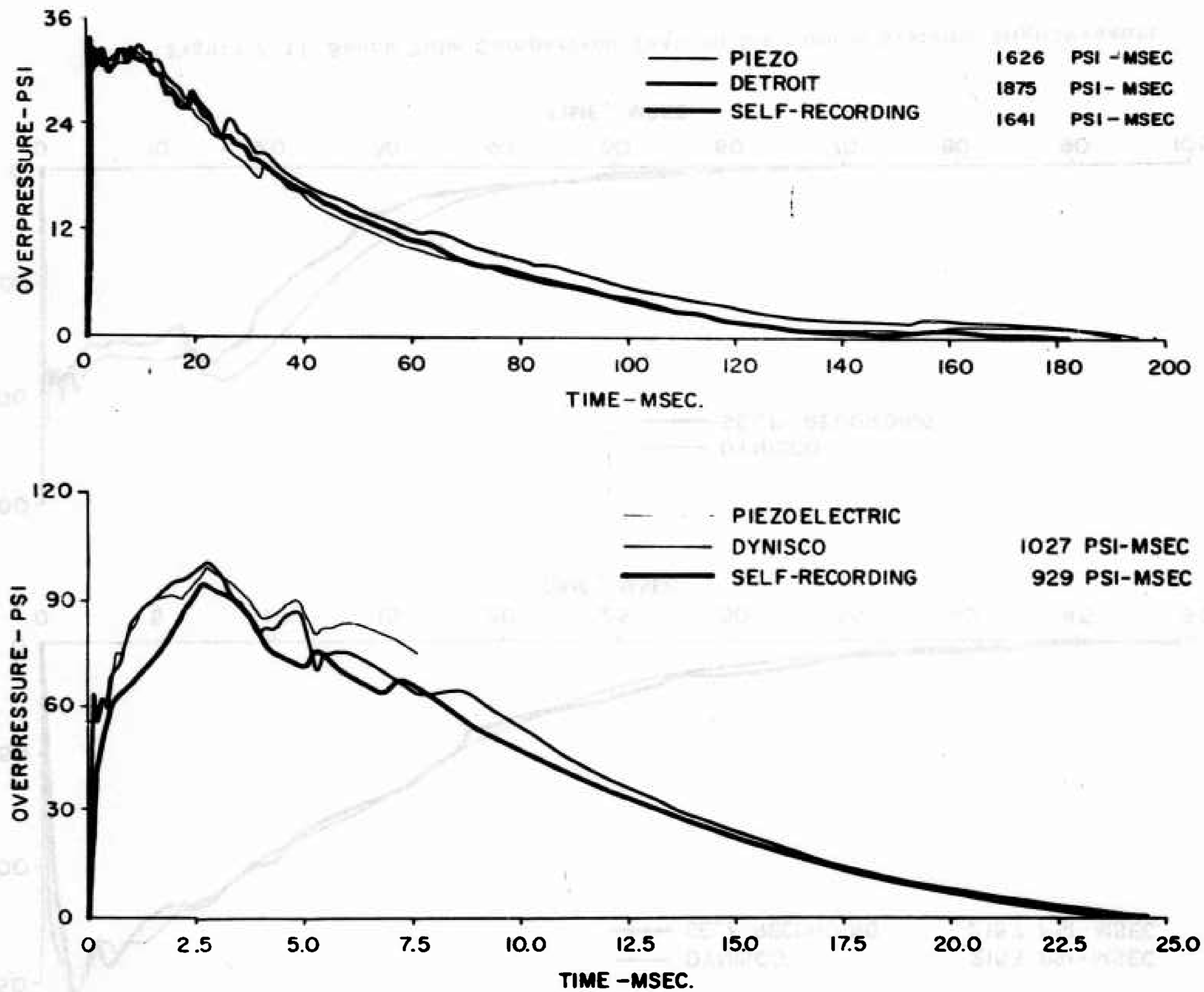


Figure 2.10 Shock Tube Comparison Tests of Instrument Systems, Low Pressure

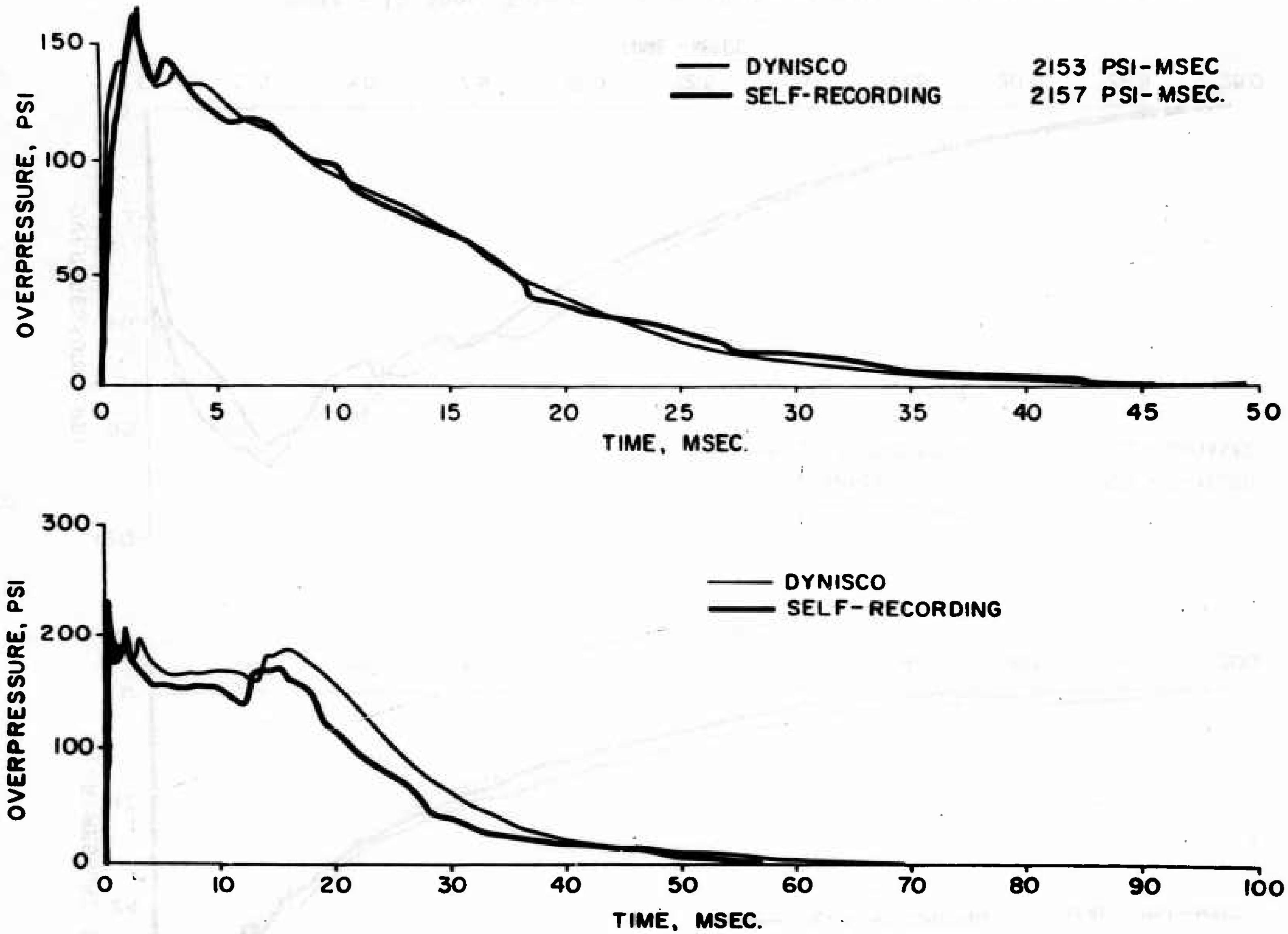


Figure 2.11 Shock Tube Comparison Tests of Instrument Systems, High Pressure

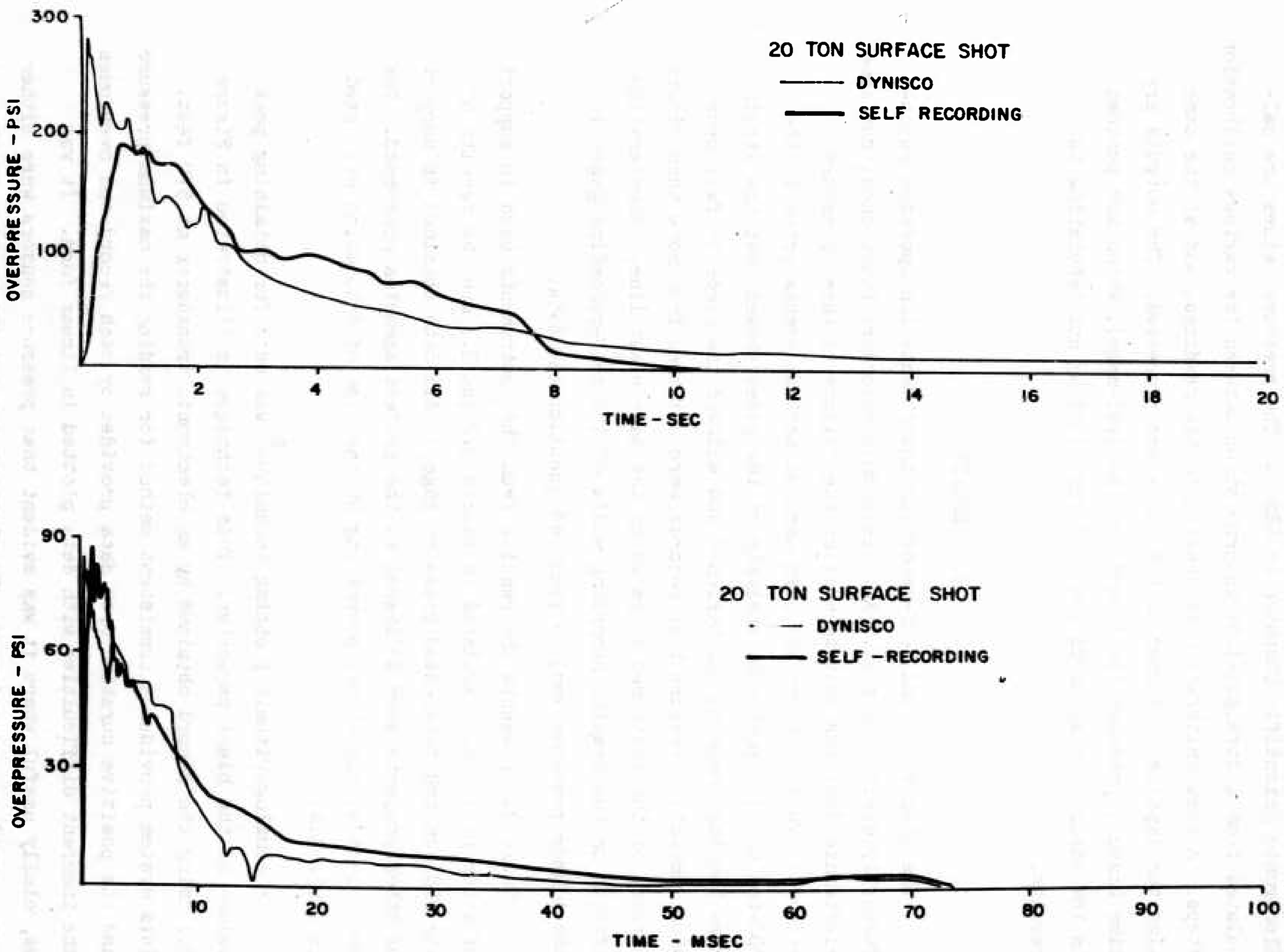


Figure 2.12 Field Comparison of Instrument Systems, 20-Ton Surface Shot

Electronic Scientific Computer (BRLESC). The pressure values are calculated from a straight-line interpolation between the various calibration steps. A time calibration is applied to the readings, and at the same time the impulse is summed as the cards are processed. The outputs are time (msec), pressure (psi), and impulse (psi-msec), which are punched on IBM cards. These cards are used for plotting and tabulating the results.

3. RESULTS

The electronic and self-recording instrumentation operated satisfactorily during the test. All electronic recorders functioned, but some electronic data was lost because of the failure of three pressure sensors. These sensors had been used on several events prior to the 500-ton shot; a post-shot analysis of the gages showed that the strain gage bonding compound had hardened and allowed the gages to fail upon shock impact. Pressure time records were obtained from more than ninety percent of the instruments placed on the main blast line. Acceleration effects on the negator recording media of the self-recording gages in the higher pressure regions produced questionable data.

Table 3.1 presents the results from the instruments used in support of other projects. Tabulated in Tables 3.2 and 3.3 are the results of the side-on and total-head pressure gages. All data obtained in support of other projects were delivered to the project agencies concerned. The meterological conditions prevailing at the time of detonation are noted in Table 3.4.

A semilogarithmic plotting technique[6] was used for obtaining peak values of the blast parameter. This technique is illustrated in Figure 3.1 using the record obtained by an electronic transducer at 570 feet. This system provides a consistent method for reading the maximum pressure and the positive duration from data provided by each record and overcomes the inherent difficulties with data plotted in linear form. It was especially useful where it was evident that pressure sensors were either over-damped or under-damped. By plotting the initial portion of the

Table 3.1 Results, Support Instrumentation

Project	Station	Distance (ft)	Location	Gage	Remarks
4.3	15	510	Foxhole A	Strain	Good Record
			Foxhole B	Strain	Good Record
	16	540	Foxhole A	Strain	Good Record
			Foxhole B	Strain	Good Record
	17	570	Foxhole A	Strain	Good Record
			Foxhole B	Strain	Good Record
3.4		365	Gnd. Baffle	SR	Good Record
	11	425	Gnd. Baffle	SR	Good Record
	14	482	Gnd. Baffle	SR	Good Record
1.6	13	465	M-113	SR	Poor Record
	17	570	M-113	SR	Fair Record
	20	800	M-113	SR	Good Record
1.10	(16 Ft - 10 psi)		Radome	SR	Good Record
	(7 1/2 Ft - 10 psi)		Radome	SR	Good Record
	(7 1/2 Ft - 5 psi)		Radome	SR	Peak Record
1.6		15 Channels Instrumented	-	15 Records Obtained	
1.16		20 Channels Instrumented	-	15 Records Obtained	

Note: Foxhole A Station Adjacent to Blast Line

Table 3.2 Results of Side-On Instrumentation

Bearing	Sta.	Ground Range	Sensor	Arrival Time (msec)	Max. Over-Pressure (psi)	Positive Duration (msec)	Overpressure Impulse (psi-msec)	Remarks
055310	1	50	ELW7-1	2.1	2327	19.0	4110	Good Record
083245	2	81	ELW8-7	4.6	1245	17.5	2214	Good Record
050050	3	106	ELW7-7	7.8	541	14.5	1602	Max. Pressure Questionable
			ELW9-7	-	875	-	-	Questionable Duration
090115	4	130	ELE4-1	11.6	-	-	-	Gage Failure
070315	5	175	ELW7-5	18.3	387	-	776	Record Fails to Return to Zero
			ELE5-2	-	350	28.5	1780	Good Record
100930	-	-	SR62-2	-	-	-	-	Questionable Record
104840	6	205	SR62-3	-	190	42.0	1434	Questionable Max. Pressure
081350	7	250	ELW8-5	33.1	215	-	372	Fails to Return to Zero
102240	-	-	SR42-2	-	200	-	339	Poor Record
101000	8	305	ELE5-1	49.8	135	155	2506	Good Record
			ELW9-1	-	125	132	2615	Good Record
			SR42-4	-	125	-	-	Questionable Duration
090330	9	355	ELW9-6	63.8	-	-	-	Gage Failure
101500	-	-	SR22-5	-	90	130	2200	Good Record
103420	-	-	SR22-2	-	84	135	1958	Good Record
101210	10	410	SR12-1	-	60	106	1425	Gage Underdamped
105540	-	-	SR12-5	-	60	108	2020	Questionable Pertubation in Decay 45-70 msec.
103830	11	425	SR12-2	-	53	122	1313	Good Record

Table 3.2 Results of Side-On Instrumentation (Continued)

Bearing	Sta.	Ground Range	Sensor	Arrival Time (msec)	Max. Over-Pressure (psi)	Positive Duration (msec)	Overpressure Impulse (psi-msec)	Remarks
101350	12	442	SR12-3	-	47.0	-	-	Fails to Return to Zero
105515	-	-	SR12-7	-	48.0	98	1230	Gage Overdamped, Record Extrapolated
070420	13	465	ELW7-6	108.0	50.5	135	1397	Good Record
104545	14	485	SR50-4	-	37.0	98	1036	Good Record
103150	15	510	ELE4-3	128.4	35.0	155	1416	Good Record
105720	16	540	SR50-1	-	40.4	-	-	Peak Only
	17	570	ELE4-8	160.4	35.0	156	1236	Good Record
104710	-	-	SR50-8	-	37.0	126	1038	Good Record
094740	18	630	SR50-7	-	30.0	125	952	Good Record
103915	19	690	ELW8-2	221.6	21.0	200	1029	Good Record
	20	800	ELW9-5	292.4	14.5	175	830	Good Record
104115	-	-	SR25-8	-	12.0	230	971	Good Record
105830	-	-	SR25-3	-	13.7	210	925	Good Record
	21	960	ELW8-6	399.0	10.0	222	750	Good Record
080050	-	-	SR10-1	-	9.8	230	815	Good Record
	22	1450	SR 721	-	5.2	275	499	Good Record
	23	3890	SR 649	-	1.2	400	212	Light Stylus Pressure Center Record Otherwise Good Record
Tech OP	24	10160	SR1813	-	0.31	520	87.5	Good Record
Non Tech OP	25	19550	SR	-	-	-	-	No Record, Gage Malfunction
SES	26	149,000	SR	-	-	-	-	Nc Record, No Apparent Shock Rec'd at SES
HILDA	27	138,500	SR	-	0.075	-	-	-

Table 3.3 Results of Total Head Instrumentation

Station No.	Ground Range (ft)	Sensor	Arrival Time (msec)	Maximum Pressure (psi)	Positive Duration (msec)	Remarks
5	175	W7-3	18.2	1700	-	Fair Record
7	250	W8-5	33.7	735	56.0	Good Record
9	355	W9-2	63.4	245	-	Poor Record-Gage failing at shock arr.
		SR41-3 Total	-	227	24.0	Poor Record
		22-4 Side-on	-	64	47.0	Good Record
12	443	SR22-7 Total	-	94	100.0	Poor Record-Not plotted
		12-4 Side-on	-	-	-	No Record
13	465	W7-2	108.3	99	130.0	Good Record
17	570	E4-7	160.2	69.2	117.8	Good Record
		SR12-6 Total	-	61.5	155.0	Good Record
		50-9 Side-on	-	333.0	129.0	Good Record
20	801	W9-3	292.5	17.2	-	Fair Record-Fails to return to zero
		SR25-5 Total	-	19.1	170.0	Good Record
		25-6 Side-on	-	-	-	No Record
21	961	SR25-7 Total	-	12.6	220.0	Good Record
		10-5 Side-on	-	9.0	220.0	Good Record

Table 3.4 Table of Meteorological Conditions

A. GENERAL DATA

Firing Date: 17 July 1964

Time: 1058 MST

Site: Watching Hill Blast Range, SES

Relative Humidity at 1 meter elevation, 3300 Ft. From GZ: 41 percent

Atmospheric Pressure 3300 Ft. From GZ: 13.60 psi

Estimated Temperature and Wind Profile at zero

Height (ft)	Temperature (F)	Wind Speed (mph)
6	76.0	4
20	73.0	5
50	72.5	-
100	72.0	5.5
200	71.5	-
300	70.0	-
400	69.5	-
500	69.0	6.0
600	68.5	-
700	68.0	6.5

Table 3.4 (Continued)

B. Data for sound ray trajectories

Elevation Ft.	Sound Speed Due Temp. Ft/Sec	Wind* Direction Deg.	Vector Direction Δ Deg.	Wind Speed Ft/Sec	Component Wind Speed Ft/Sec	Temperature C	Resultant Sound Vel Ft/Sec
0	1135	90	0	7	7	+24	1142
259	1132	11	79	5	1	+22	1133
896	1124	19	71	7	2	+19	1126
2149	1118	44	46	12	9	+15	1127
3802	1108	72	18	14	13	+10	1121
5248	1100	91	1	20	20	+ 6.4	1120
6582	1094	86	4	34	34	+ 3.1	1128
8481	1097	96	6	49	48	+ 4.7	1145
10292	1093	81	9	53	52	+ 2.8	1145
11392	1089	75	15	62	60	+ 0.8	1149
12526	1086	81	9	66	65	- 0.9	1154
13731	1082	83	7	68	67	- 2.5	1149
14948	1079	84	6	72	72	- 4.1	1151
16205	1076	87	3	76	76	- 5.8	1152
17480	1070	87	3	76	76	- 8.4	1146

* Direction towards which wind is blowing

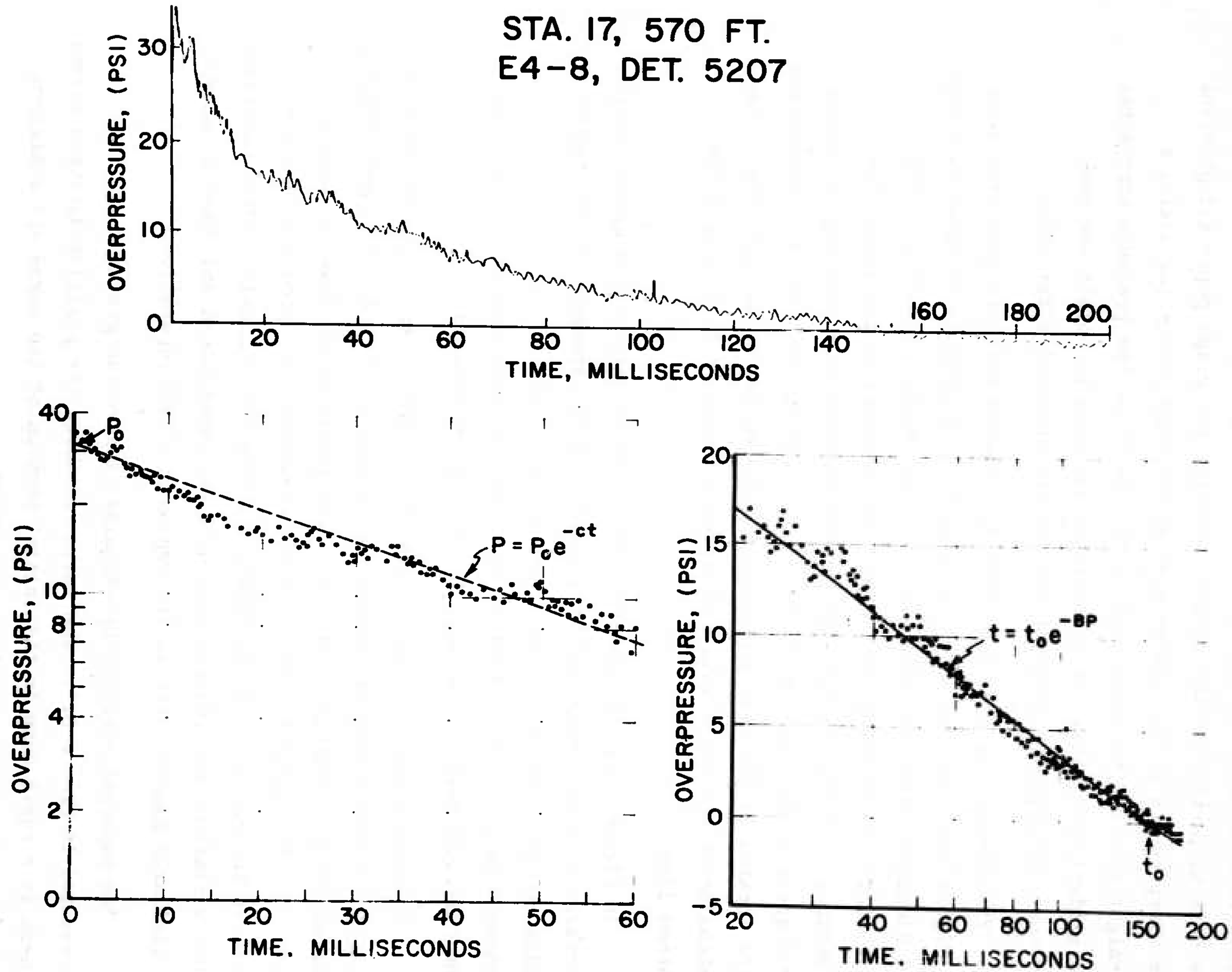


Figure 3.1 Linear and Semilogrithmic Plots of a Typical Overpressure Time Record

record on semilogarithmic graph paper a straight line can be drawn through the initial portion of the record. Turning the graph paper and plotting the overpressure on the linear portion and time on the log scale, a straight line can be drawn through the record as the pressure approaches the ambient condition. This technique was used to obtain the peak pressure and positive duration for all the Snowball blast data.

The measured arrival time data is compared with the predicted data in Figure 3.2. Data obtained by Projects 1.4 (Effects of Blast on Actual and Simulated Missiles, BRL) and 3.4 (Body Motion of Buried Arches, Naval Civil Engineering Laboratory) are included in the plot. The transducers of Project 3.4 were surface mounted on a line approximately 60 degrees to the west of the Project 1.1 blast line; the 1.4 transducers were located to the east approximately 25 degrees of the 1.1 line. The extension of the curve into the close-in region is indicated by the dashed line.

In Figure 3.3, the measured over pressure data versus ground range compared with the predicted data indicate good agreement in the region below 300 psi. Above 300 psi, the predicted data are less than the measured data. In this region, photo-optical data provided by SES, was the only information available for making predictions.

Positive duration measurements shown plotted versus ground range in Figure 3.4 show a marked departure from that predicted. A longer duration was measured at Station 2 (81 feet from ground zero) than at Station 3 (106 feet from ground zero). Longer durations than predicted are also seen in the region of shock separation from the fireball. After observing this variation, the 100-ton test data was re-examined and found to accept a similarly shaped curve in the region of shock separation.

The measured overpressure-impulse data versus ground range are presented in Figure 3.5. The curve resembles the positive duration curve; there is a rapid drop in the initial portion of the curve and a maximum occurs in the region of shock separation.

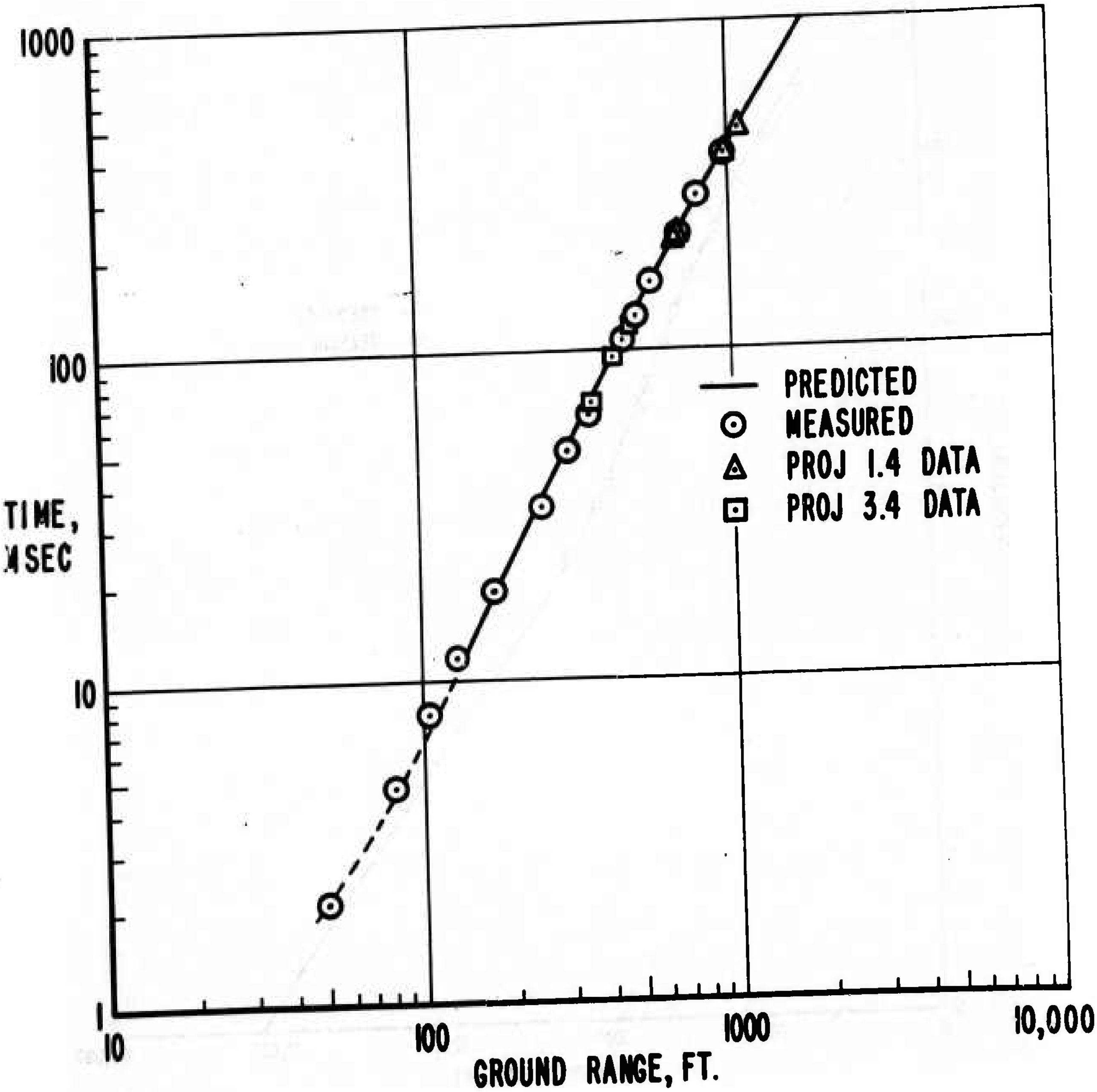


Figure 3.2 Predicted and Measured Arrival Time versus Ground Range

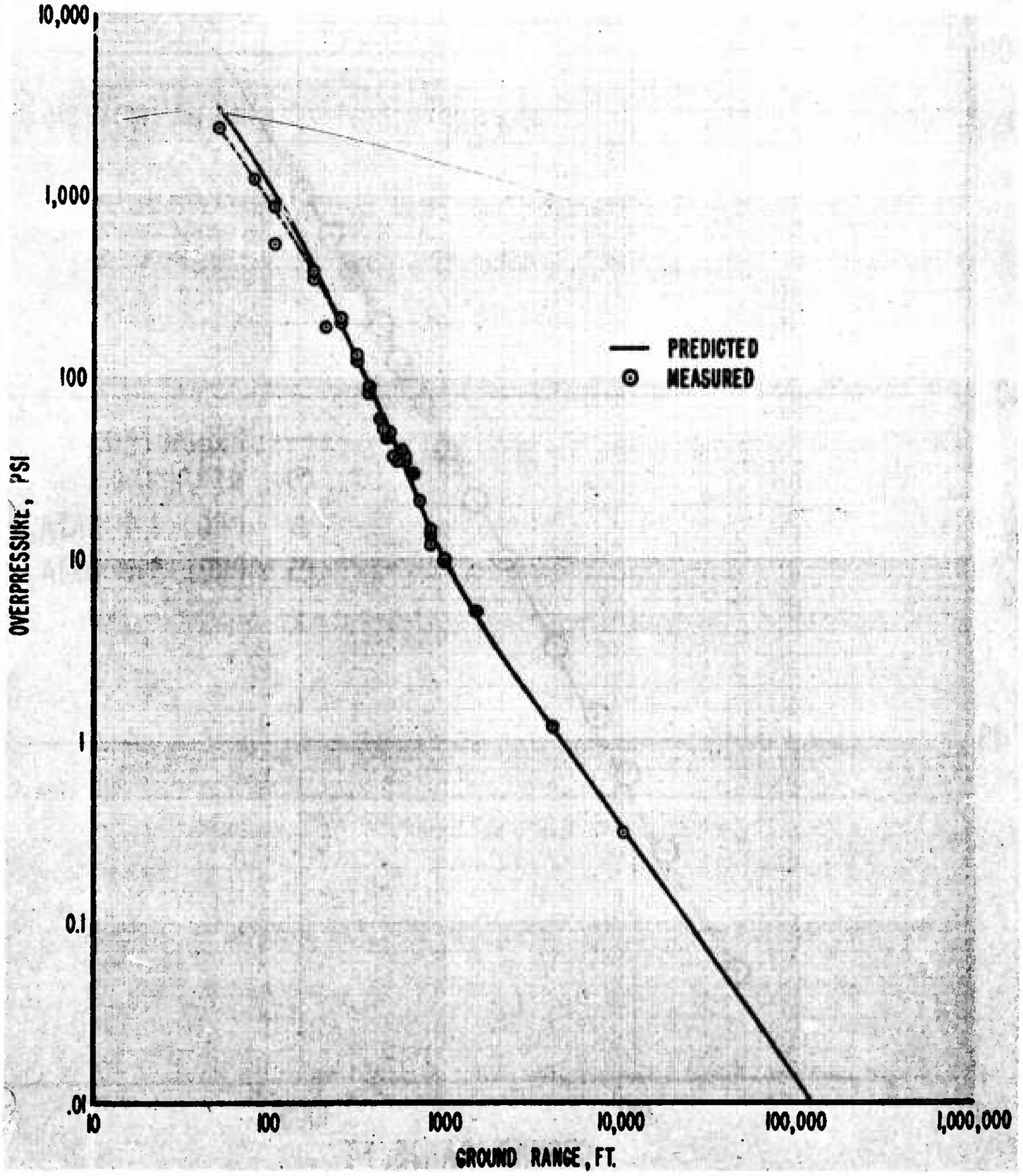


Figure 3.3 Predicted and Measured Overpressure versus Ground Range

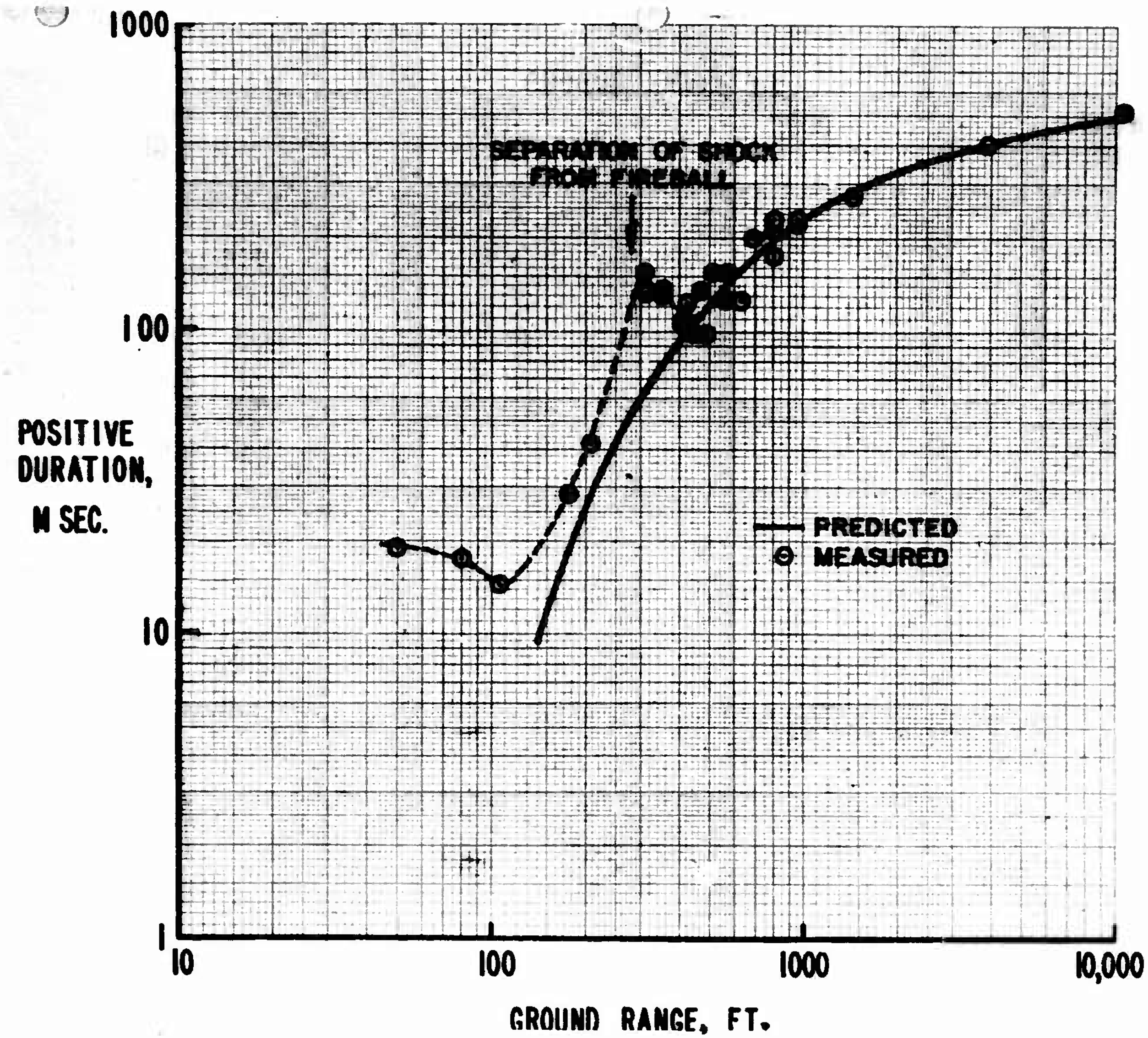


Figure 3.4 Predicted and Measured Positive Duration versus Ground Range

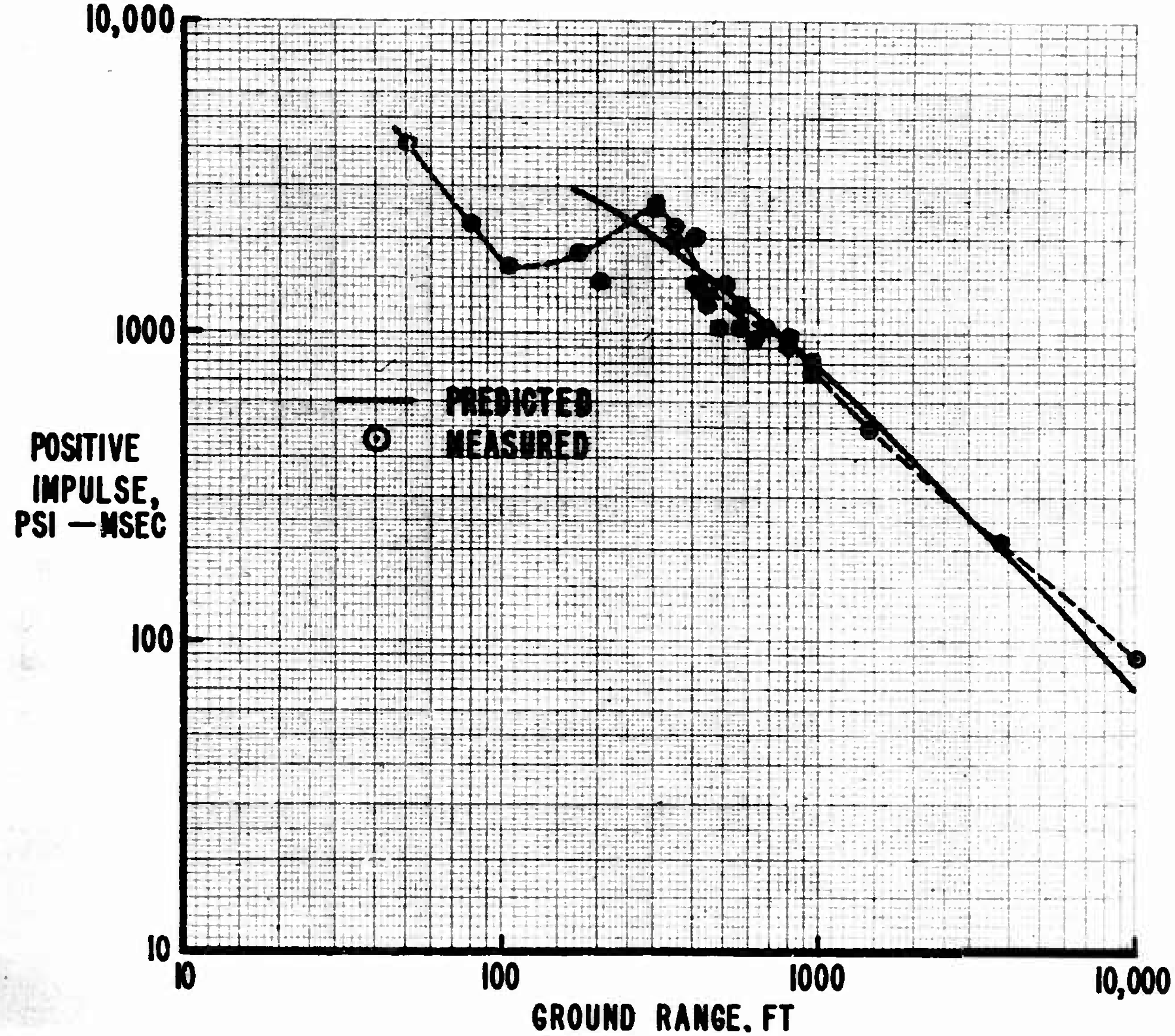


Figure 3.5 Predicted and Measured Positive Impulse versus Ground Range

The maximum dynamic pressure, noted as measured, was obtained by calculation from a static overpressure measurement made flush with the surface of the ground and a corrected total head measurement made at a three-foot elevation. The total head correction is a function of the Mach number of the flow behind the shock front and was obtained in the same manner as described in Reference 7. Presented in Figure 3.6 is the measured data plotted versus distance and compared to the predicted dynamic pressure curve. Very good agreement is noted between the measured and predicted curves.

The appendix contains linear graphs of the pressure versus time records obtained from each gage station. In the last section of the appendix, the dynamic pressure parameters of corrected dynamic pressure and Mach number versus time are given. In a number of cases, the side-on values at a point in the pressure decay exceeded the pressure value of the total head measurement at the corresponding time. Where this occurred, the time history was terminated at that point. This is seen at stations 12 and 20; the apparent cause is attributed to instrumentation performance.

The very low pressure Station, No. 27, established quickly 1 hour prior to the detonation on the basis of predicted focusing, gave three records which are shown in Figure A.10. Gage 59 had a leak in the gage case so the record from that gage should be discounted. The other gages produced records which were dissimilar in wave shape although the gages were at the same radial distances, but separated by 2000 feet. The instrumentation gives no indication of inaccuracy.

4. DISCUSSION

The wave shapes recorded by both types of recording systems were non-classical in nature. At the close-in-station, Station 1 (50 feet from the center of the charge) a peak pressure of 2327 psi was recorded. Within the first millisecond the pressure at this station dropped to 300 psi; from this minimum, the pressure increased slightly and then decayed slowly to atmospheric pressure. The records obtained from

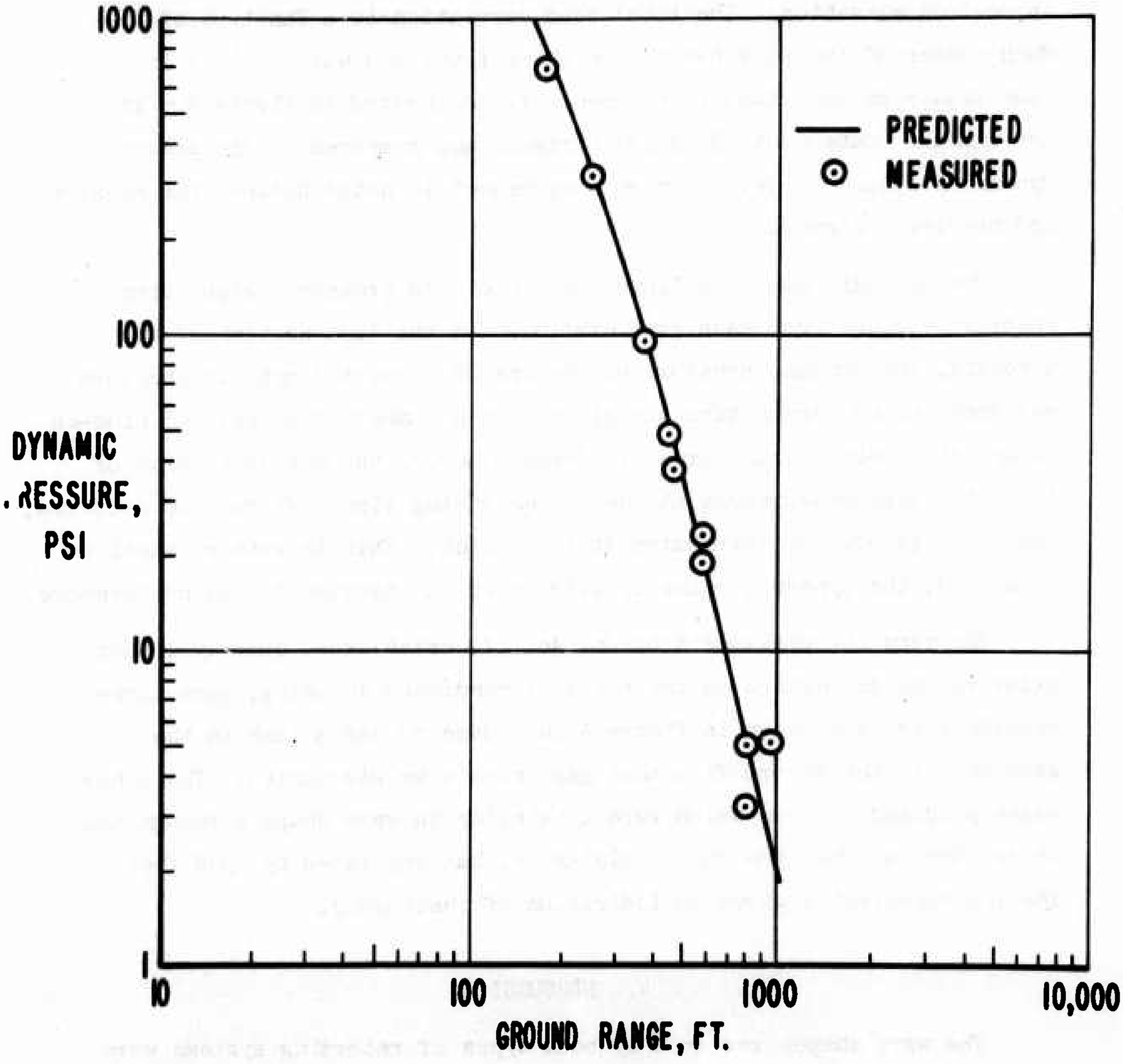


Figure 3.6 Predicted and Measured Dynamic Pressure versus Ground Range

instruments along the blast line from Stations 12 through 20 show a marked departure from the usual smooth exponentially decaying pressure records one would expect to see. A look at the SES recorded film of the detonation revealed the occurrence of jetting action. A photograph of one frame of the film is seen in Figure 4.1. It is believed that this jetting action was responsible for the anomalies recorded by the sensor systems. Variations in the amount of dust carried by the shock wave as observed by SES photography and the jetting action just discussed leads one to restrict the use of the measured data to experiments located in the vicinity of the main blast line.

Evidences of a disturbance in the shock propagation seen in the wave shapes recorded by the pressure sensors at the greater distances (500-1000') are the only indication Project 1.1 could see of the occurrence of an anomaly. Other participating projects, namely SES and Project 1.6 located in various sectors on the layout show conclusively by film and gage records that five major protuberances occurred. As stated in Reference 8, two dust jets shot out from the fireball to the west of the charge, a similar jet moved to the southwest between the sectors occupied by the British and the Canadians, and two protuberances of the main shock were observed in the United States sector. SES gages detected the arrival of more than one shock with marked transverse components in certain cases. Project 1.6 data showed the non-radial displacement of their full scale military equipment and simple objects. The occurrence of the protuberances on Operation Snowball is not a unique phenomenon. Photographs obtained during the Sailor Hat series of high explosives tests show two distinct radially oriented "precursors".

Various explanations for the "precursors" have been advanced and are discussed in Reference 8; the most plausible explanation appears to be the debris-precursor concept explained by J. Moulton. Briefly, Moulton attributes the phenomena to high speed chunks of debris originating at or near the surface in the immediate vicinity of the crater and traveling a very low trajectory. As a result of energy imparted to them by the

Figure 4.1 Early Time Photograph of Detonation

rapidly moving and relatively dense explosion product gases, these particles are given a supersonic speed that exceeds the speed of the main shock. A more detailed discussion is to be found in the report of Panel N-2.[8]

A comparison was made between the U.S. blast line gage records and the records obtained by the United Kingdom where the individual lines were approximately 170 degrees apart. This comparison was limited to four instrument positions where the distances from ground zero were nearly equal. The results of this comparison are presented in Figure 4.2. All United Kingdom gages were mounted on instrument stands 3 or 4 feet above the ground, whereas all U.S. gages were mounted flush with the ground surface. The call-outs on the illustration indicate EL for electronic and SR for self-recording gages. The shapes of the shock waves expected at various gage stations were predicted using a method established by H. L. Brode[2] for predicting free-air overpressure as a function of time for TNT explosions. A reflection factor of 1.63 was used since the 500-ton event was a surface burst. A comparison of the predicted wave shapes was made with those measured, Figure 4.3. Records from five gage stations were selected for this comparison; pressure levels at the stations covered the range from 300 psi to 5 psi. Excellent agreement exists at the three more distant stations, 570, 801, and 1450 feet; however, as one advances into the higher pressure region, large differences between actual and predicted wave shapes begin to develop. As a further check, a comparison was made of the predicted wave shapes and those measured by the United Kingdom (Figure 4.4). The validity of the prediction technique is again confirmed by the good agreement especially at the pressure levels of less than 100 psi.

For many years the consistency of the initial shock pressure as a function of distance has been examined by the use of the plotted maximum pressure-distance curves. In order to study the consistency of the entire blast-wave pattern and predict the shape of the pressure-time wave for distances other than those measured, a family of overpressure distance curves for various times after shock arrival was plotted.

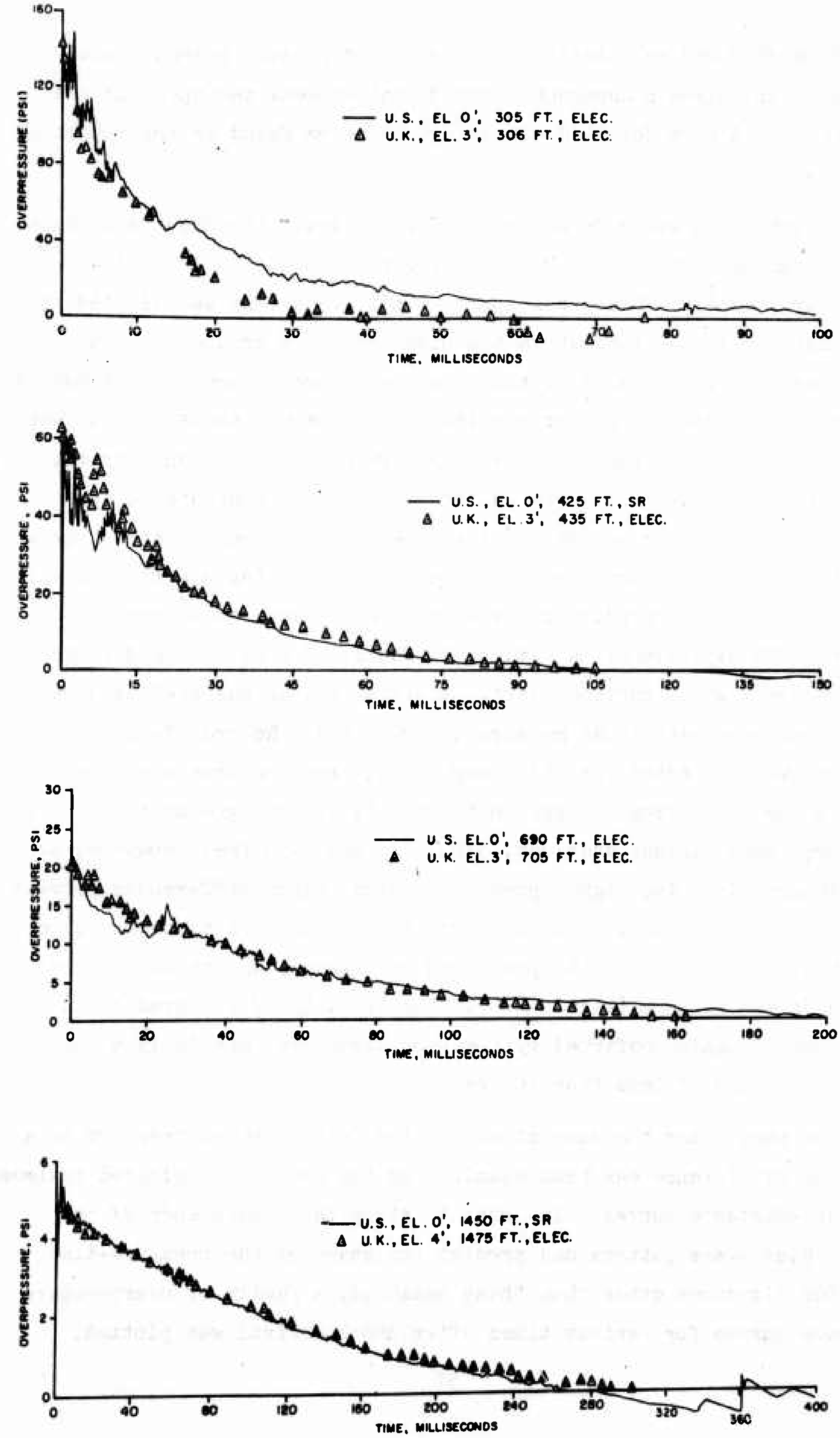


Figure 4.2 Record Comparisons of U.S. and U.K. Gage Results

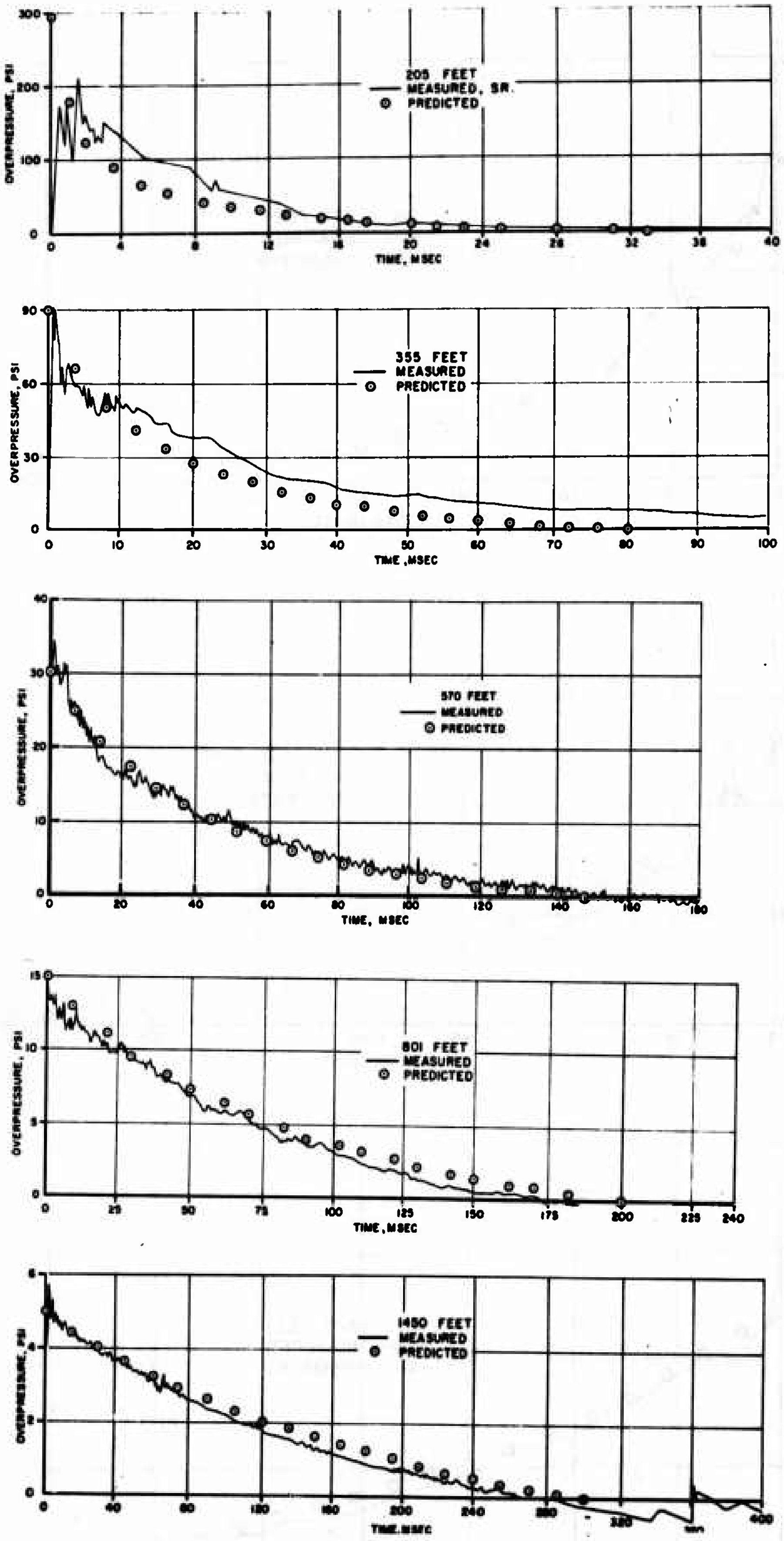


Figure 4.3 Predicted and Measured Pressure Time Histories for Selected Stations

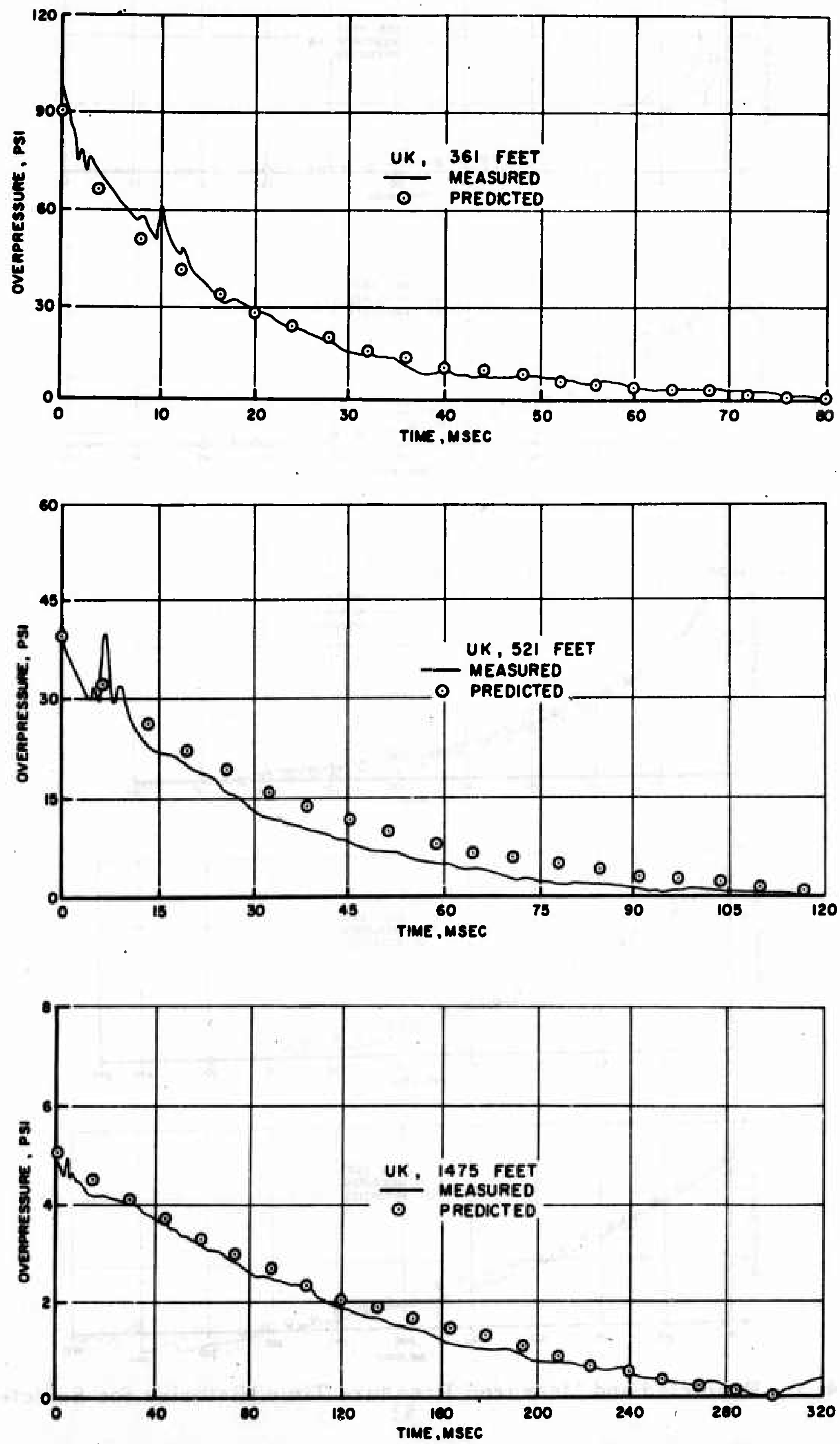


Figure 4.4 Predicted and Measured Pressure Time Histories for Selected U.K. Stations

Figure 4.5 shows the pressure measured at 1 msec after passage of the shock wave presented by the curve labled t_1, the pressure at 2 msec is labled t_2, at 4 msec t_4, etc. At the bottom of the figure a curve shows the time when the pressure has returned to atmospheric pressure. By using these curves one can plot points for estimating pressure-time curves to be expected from a 500-ton hemispherical surface detonation for any distance from 50 feet to 1400 feet. The points read from these curves for 690 feet are plotted at the top of Figure 4.5. An error of five percent is to be anticipated.

The factors for scaling the 500-ton charge to 1 lb at sea level conditionsare presented as follows:

$$\text{Pressure } S_p = \left[\frac{Po}{Pa}\right] = 1.08$$

$$\text{Distance } S_d = \left[\frac{Pa}{Po}\right]^{1/3} \left[\frac{1}{W}\right]^{1/3} = 0.00974$$

$$\text{Time } S_t = \left[\frac{Ta + 273}{288}\right]^{1/2} \left[\frac{Pa}{Po}\right]^{1/3} \left[\frac{1}{W}\right]^{1/3} = 0.0100449$$

$$\text{Impulse } S_I = \left[\frac{Ta + 273}{288}\right]^{1/2} \left[\frac{Po}{Pa}\right]^{2/3} \left[\frac{1}{W}\right]^{1/3} = 0.010854$$

Figure 4.6 shows the scaled 500-ton overpressure data compared with the scaled free air overpressure curve; a reflection factor of 1.63 was used. The curve was determined from theoretical calculations and empirical data. Reasonable agreement of the 500-ton data with the free-air data is seen.

Figure 4.7 is the predicted ray trajectory for the event as determined by the computer program based on Reference 9. The predicted pressure for the 138,500-foot station was 0.006 psi. The measured values of 0.05 to 0.07 indicate an amplification factor of 10. The predicted trajectories would indicate that the station was located on the eastward edge of the focal point.

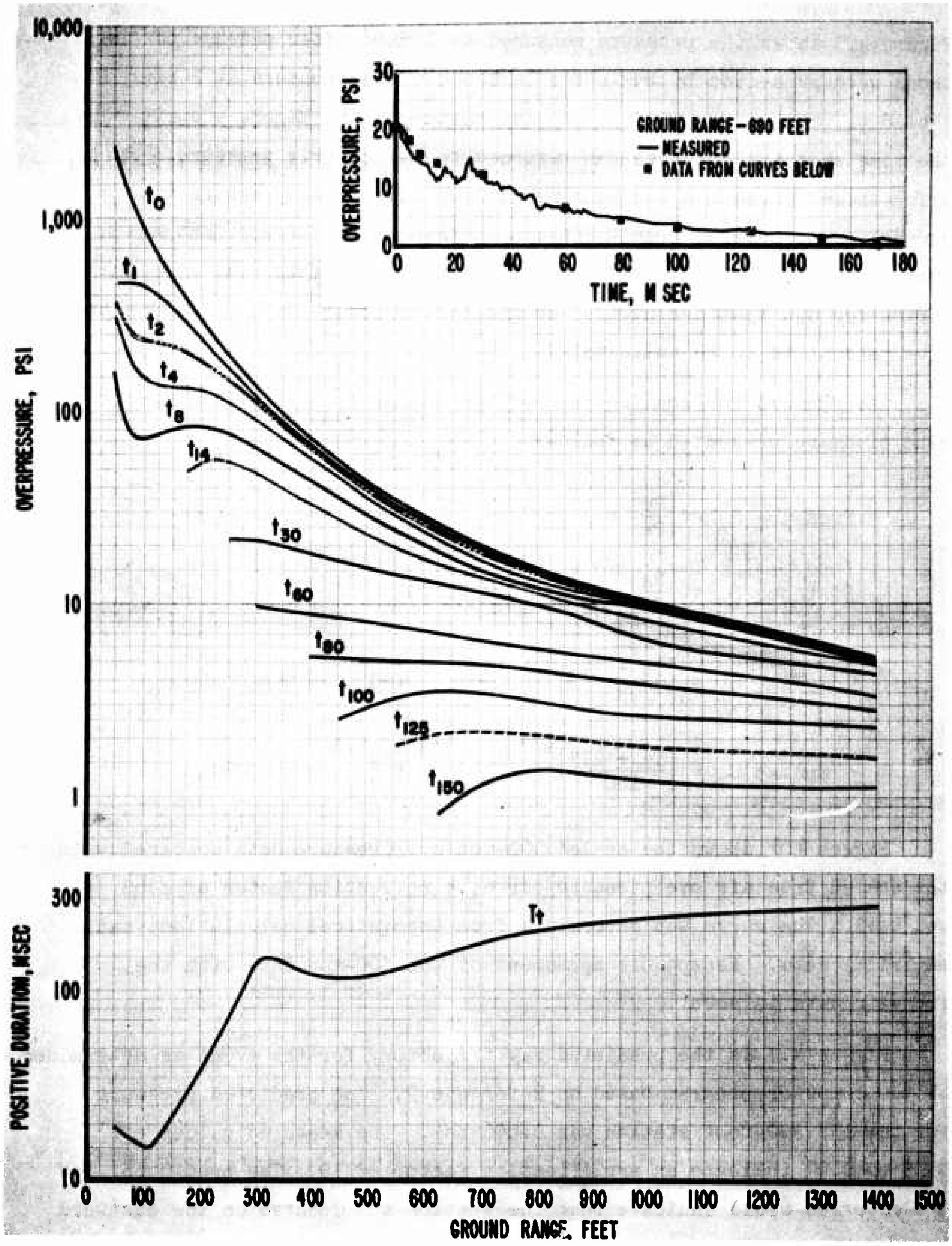


Figure 4.5 A Family of Overpressure Distance Curves for Various Times After Shock Arrival

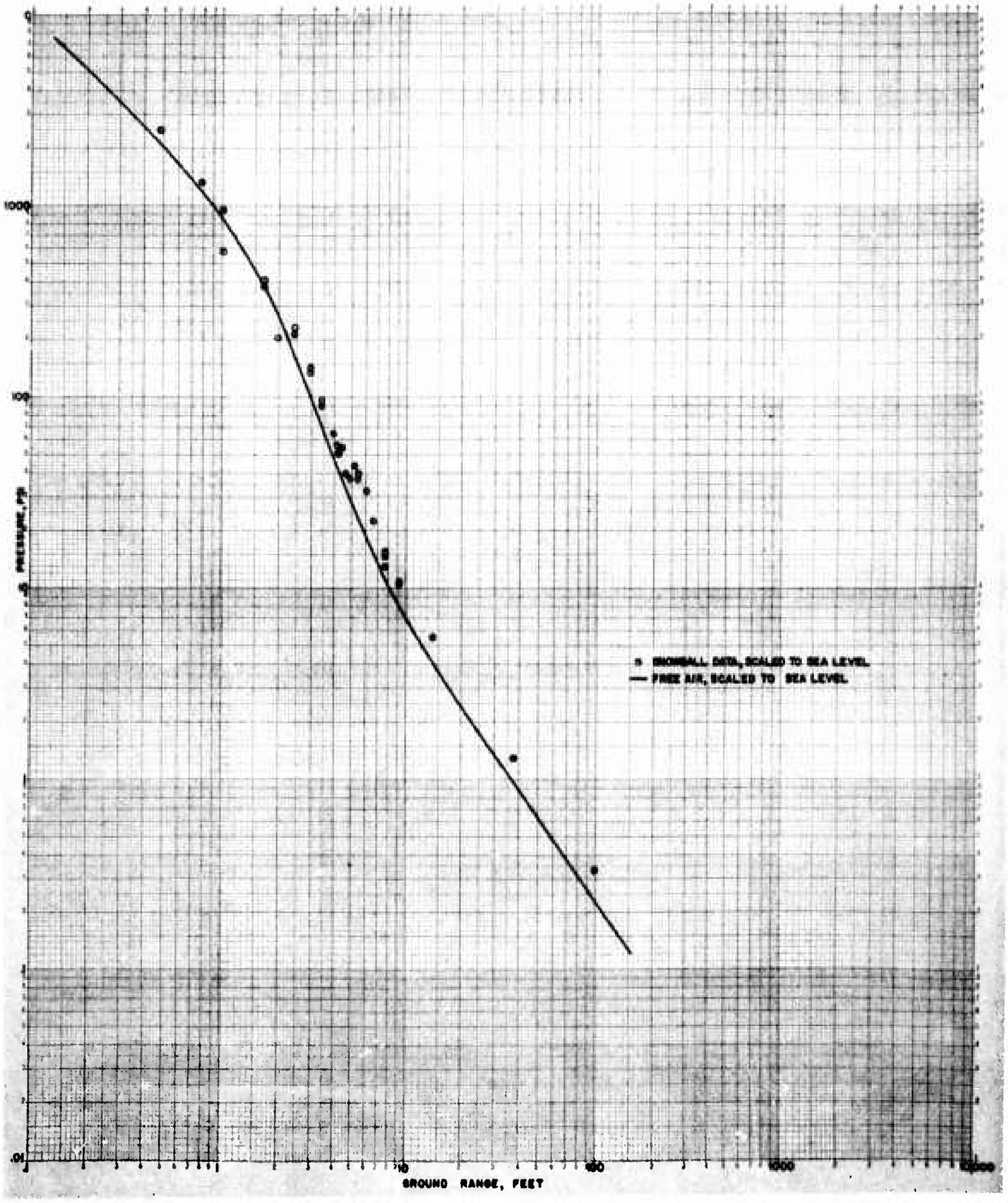


Figure 4.6 Snowball Scaled Data Compared to Free Air Curve for 1-lb at Sea Level

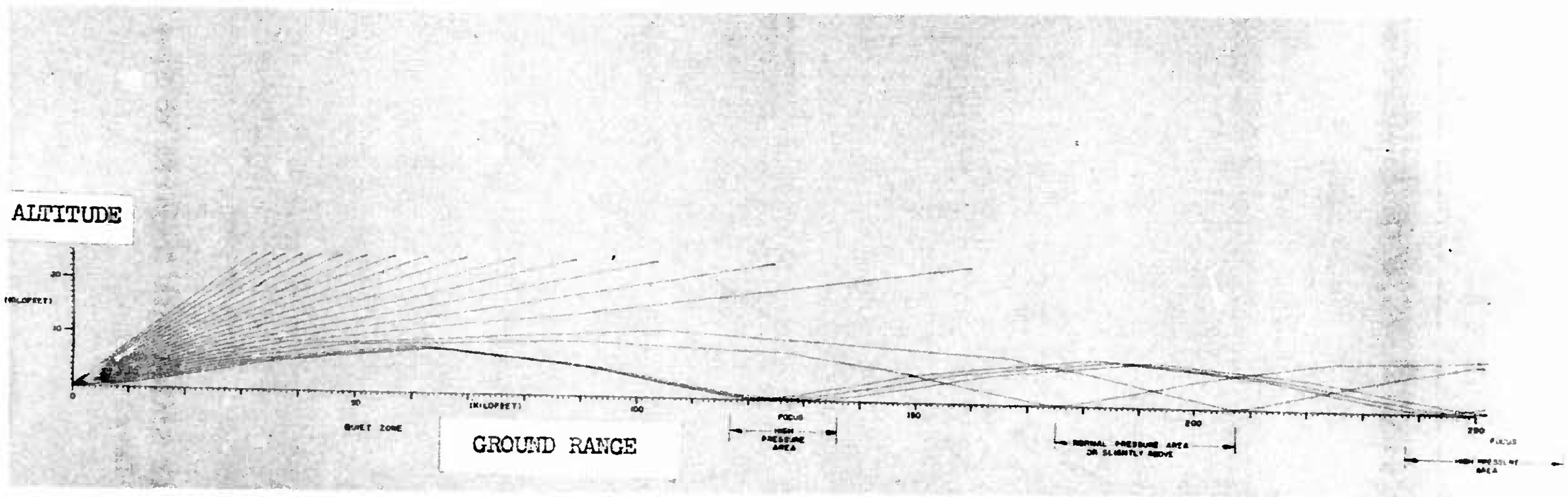


Figure 4.7 Computed Sound Ray Trajectories

5. CONCLUSIONS

The overall free-field measurements of overpressure versus time along the established blast line were successful. Anomalies occurred in the shock propagation and these anomalies were seen in the wave shape of the records. The predicted parameter versus distance curves developed from the empirical data from the 5, 20, and 100 ton events were confirmed in the moderate to low pressure regions. In the moderate to high pressure areas, the results of this experiment produced an extension or modification of the curves. The arrival time curve was extended from 120 feet to the close-in region of 50 feet. A small modification of the overpressure curve was made by the realization of lower pressures (approximately 20 percent) than predicted at 500 psi and above. The positive duration and positive impulse data led to a change in the shape of the curve at the region of shock breakaway from the fireball to the close-in-positions. Longer durations were measured at 33 feet from the edge of the charge than at stations farther out (90 feet from the charge). This resulted in a rapid drop in the initial portion of the curve; the maximum occurs in the region of shock breakaway.

The wave shape prediction technique established for pressures of 100 psi and less was confirmed by the comparison curves. Peak dynamic pressure measurements agreed well with those predicted. The good agreement shown between the scaled Snowball data and the free air curve add to the confidence level already established for the scaling technique.

For future tests of this nature, measurements should be obtained in the moderate-to-high pressure region to further confirm the overpressure parameters in this area. Dynamic pressure impulse data continues to be a sought after measurement. Pressure-time measurements made at large distances from where focusing occurs are also desired.

ACKNOWLEDGEMENTS

Appreciation is expressed to the Suffield Experimental Station Staff who provided major assistance and help during the field phase of this experiment.

The advance site preparation carried out by R. L. Peterson greatly facilitated the instrumentation phase of the work and is hereby acknowledged.

The excellent advice and guidance of J. J. Meszaros and C. N. Kingery throughout the conduct of this effort is greatly appreciated. The assistance given by A. Thompson in the low pressure data analysis is also acknowledged.

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APPENDIX

RECORDS OF PRESSURE VERSUS TIME

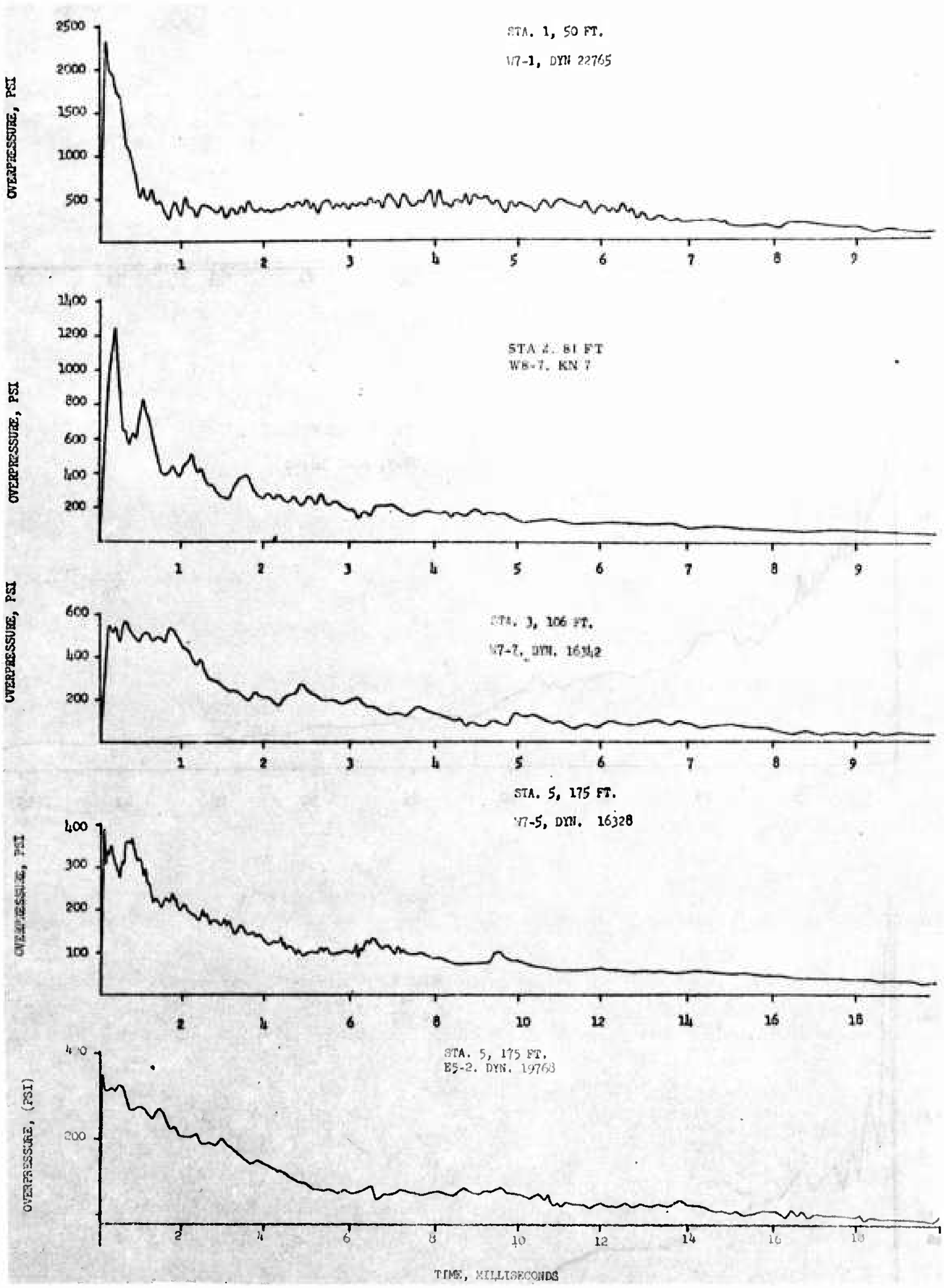

Figure A.1 Pressure-Time Records for Stations 1 to 5

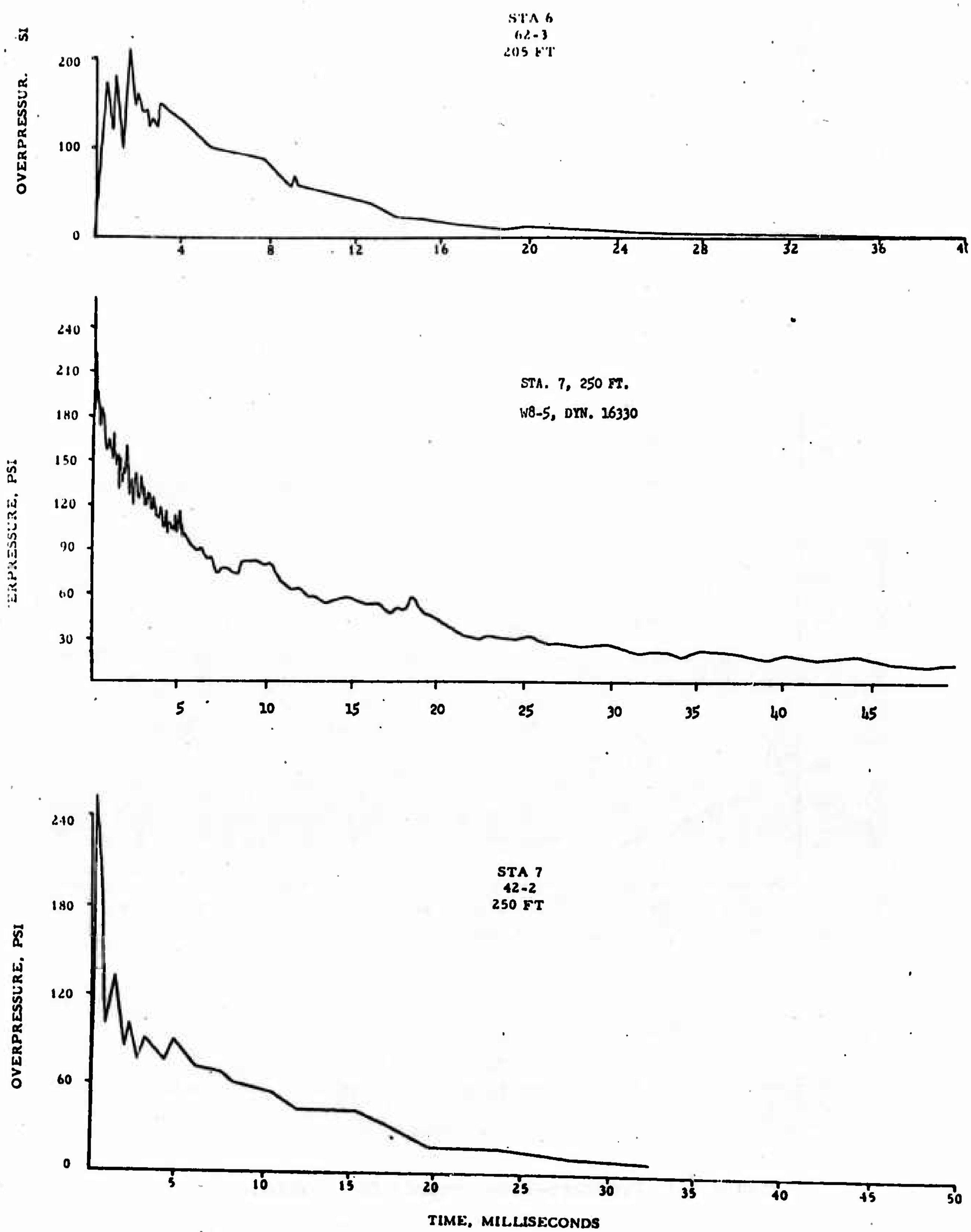

Figure A.2 Pressure-Time Records for Stations 6 and 7

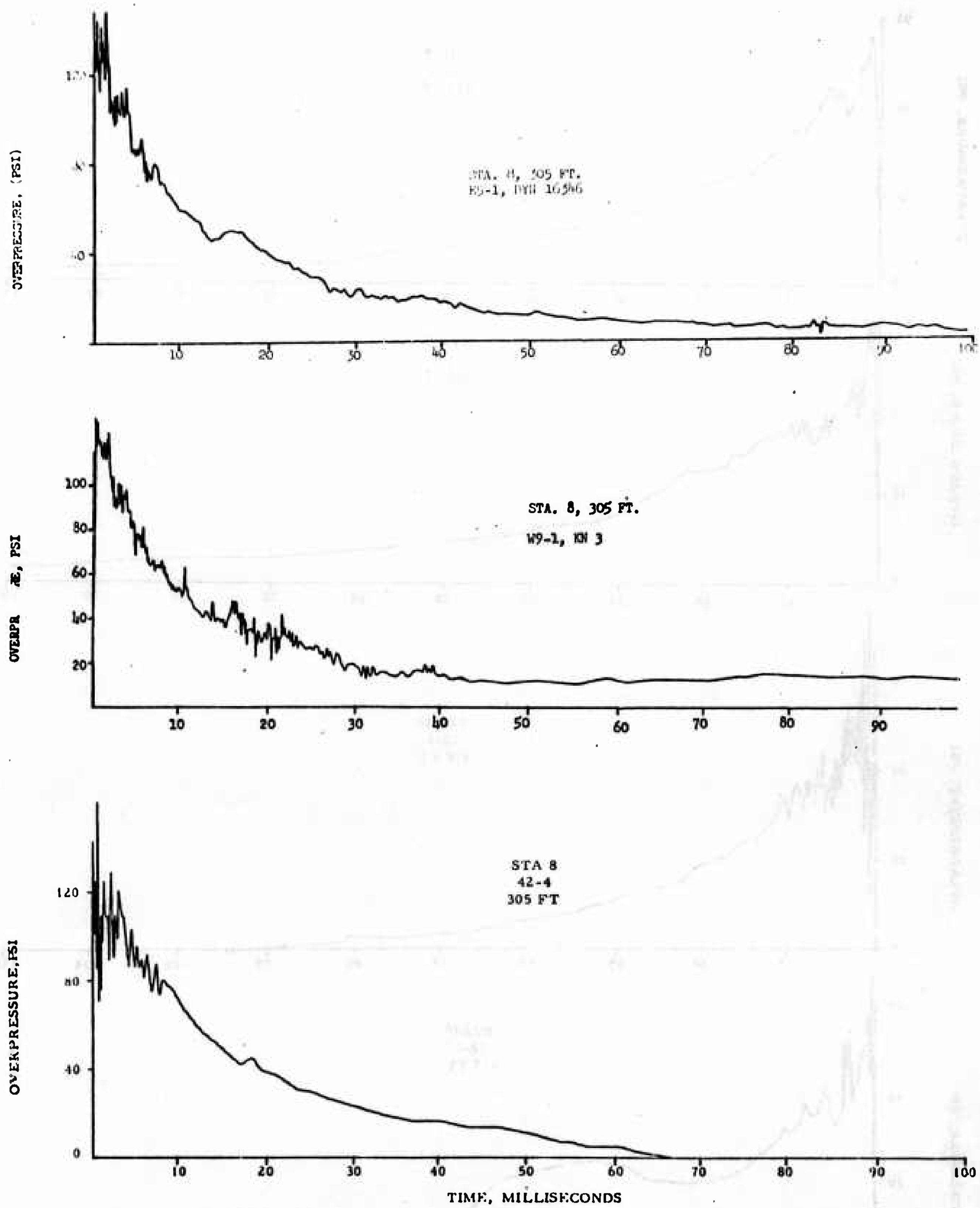

Figure A.3 Pressure-Time Records for Station 8

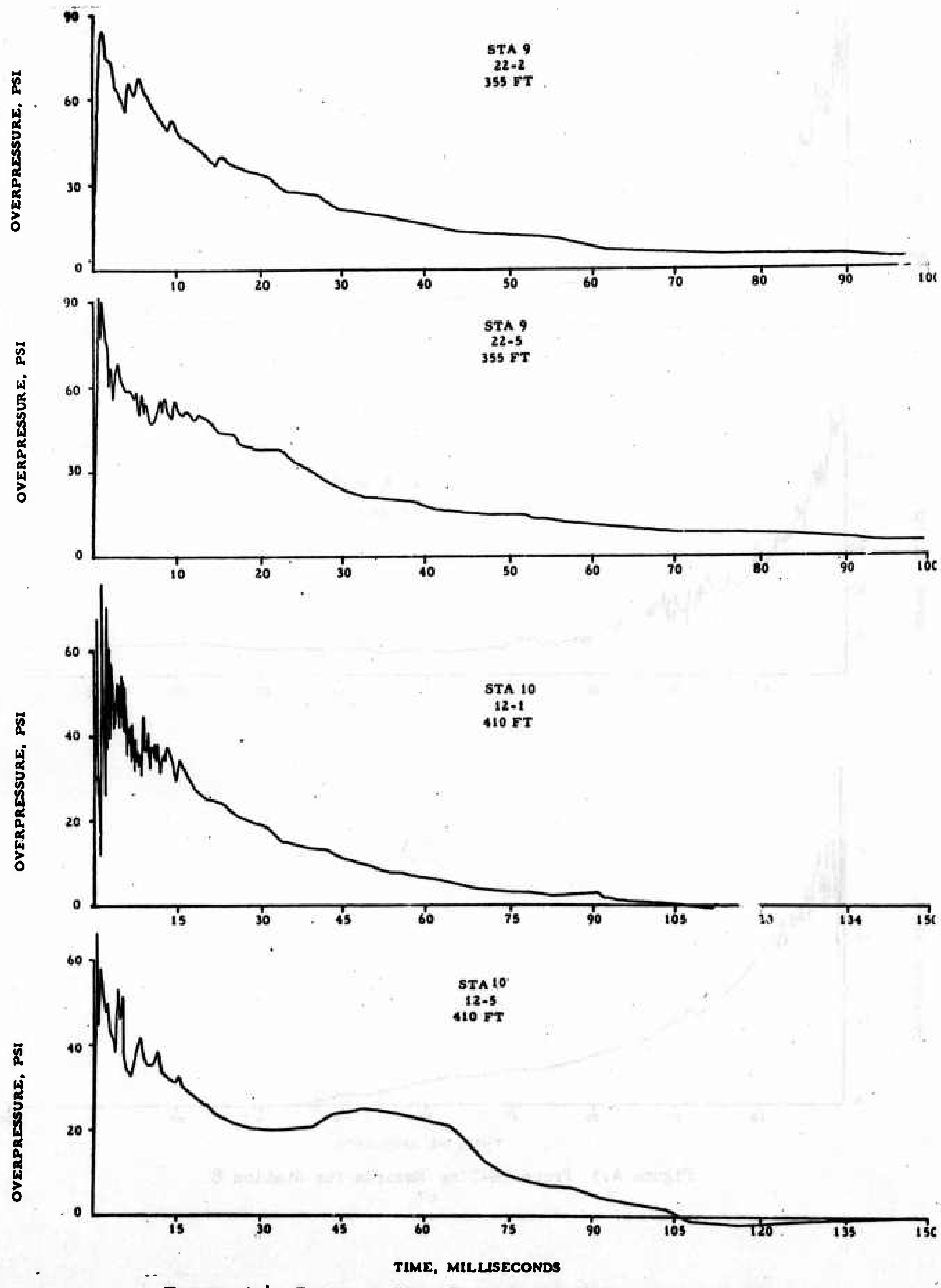

Figure A.4 Pressure-Time Records for Stations 9 and 10

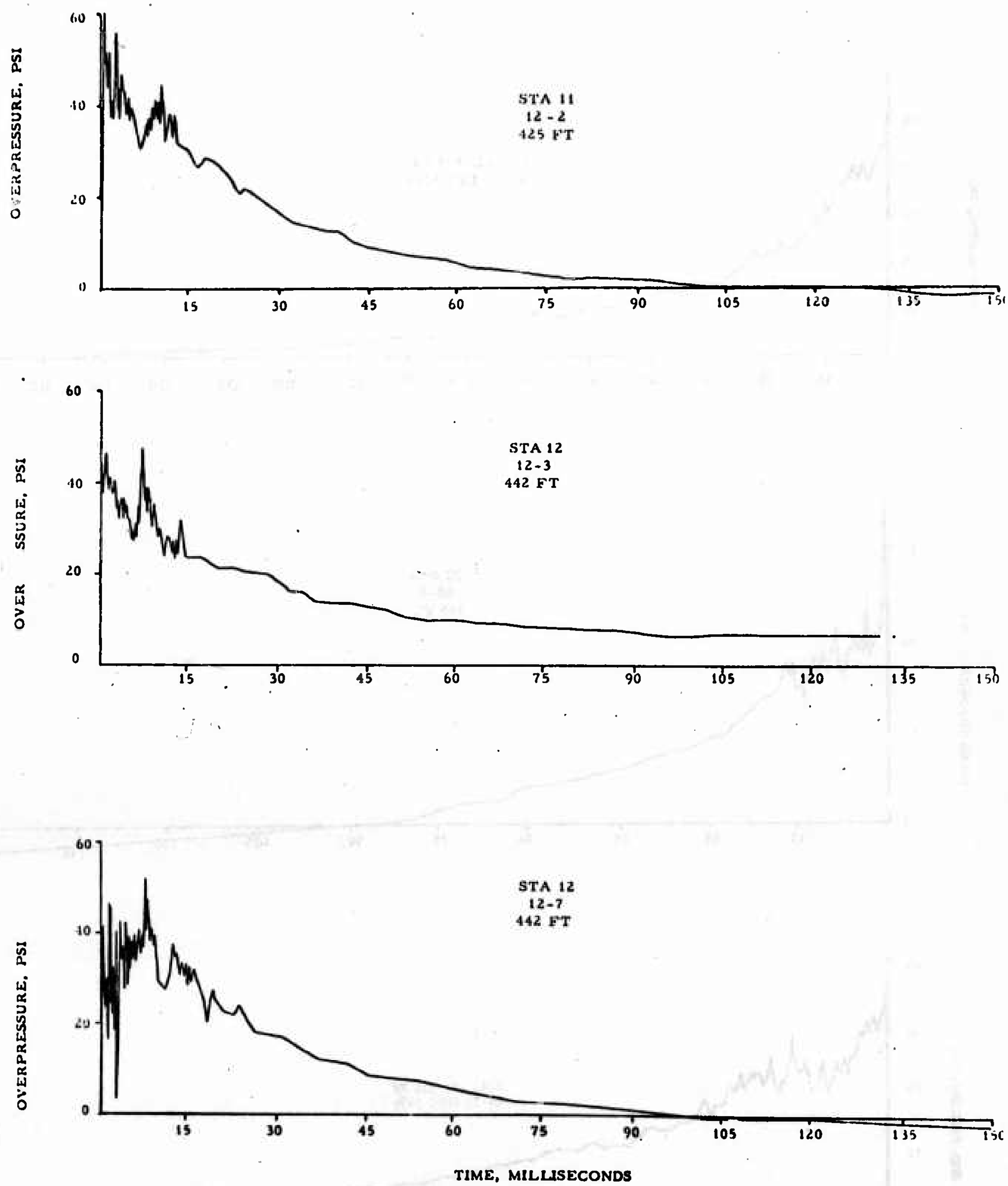

Figure A.5 Pressure-Time Records for Stations 11 and 12

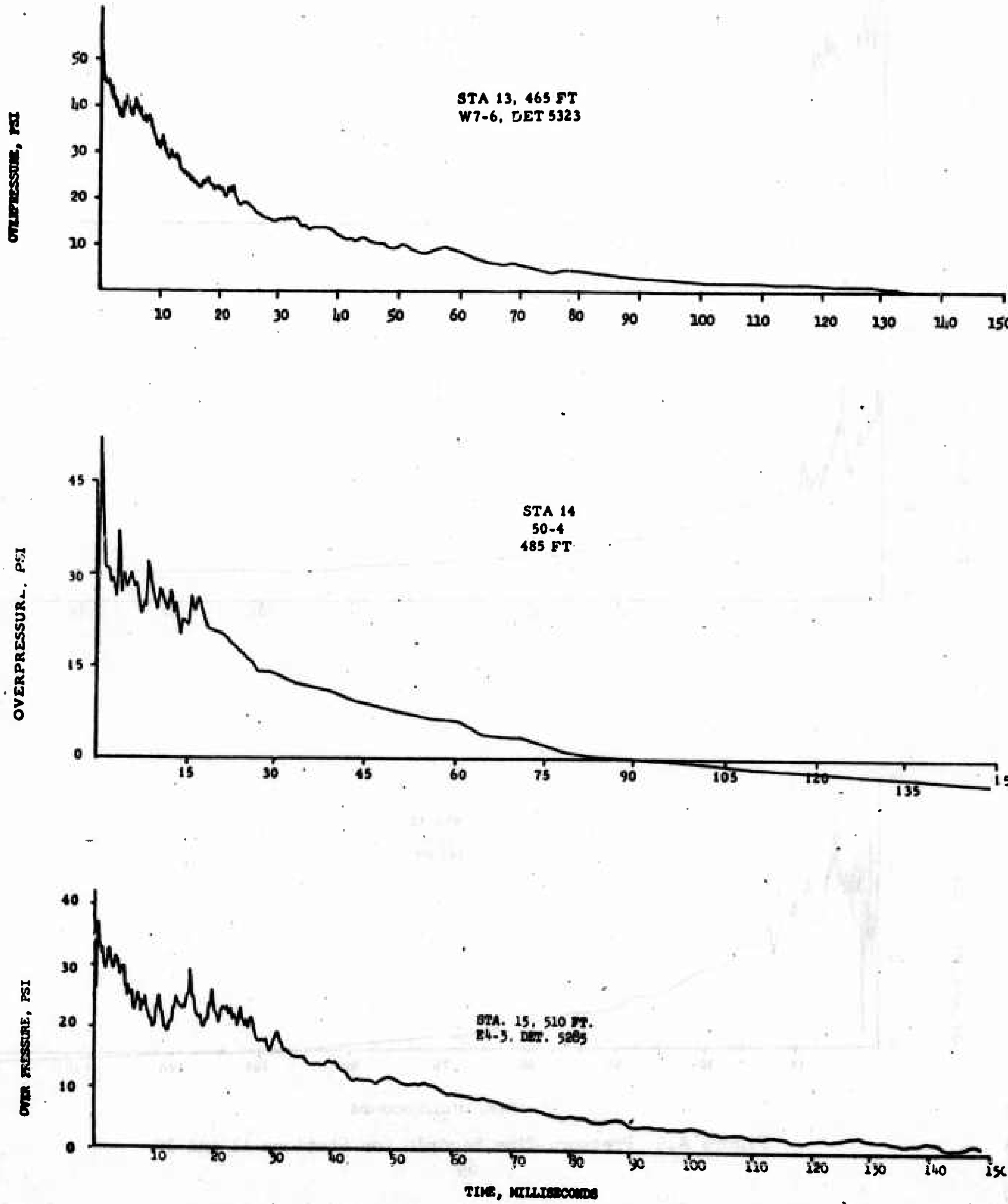

Figure A.6 Pressure-Time Records for Stations 13 to 15

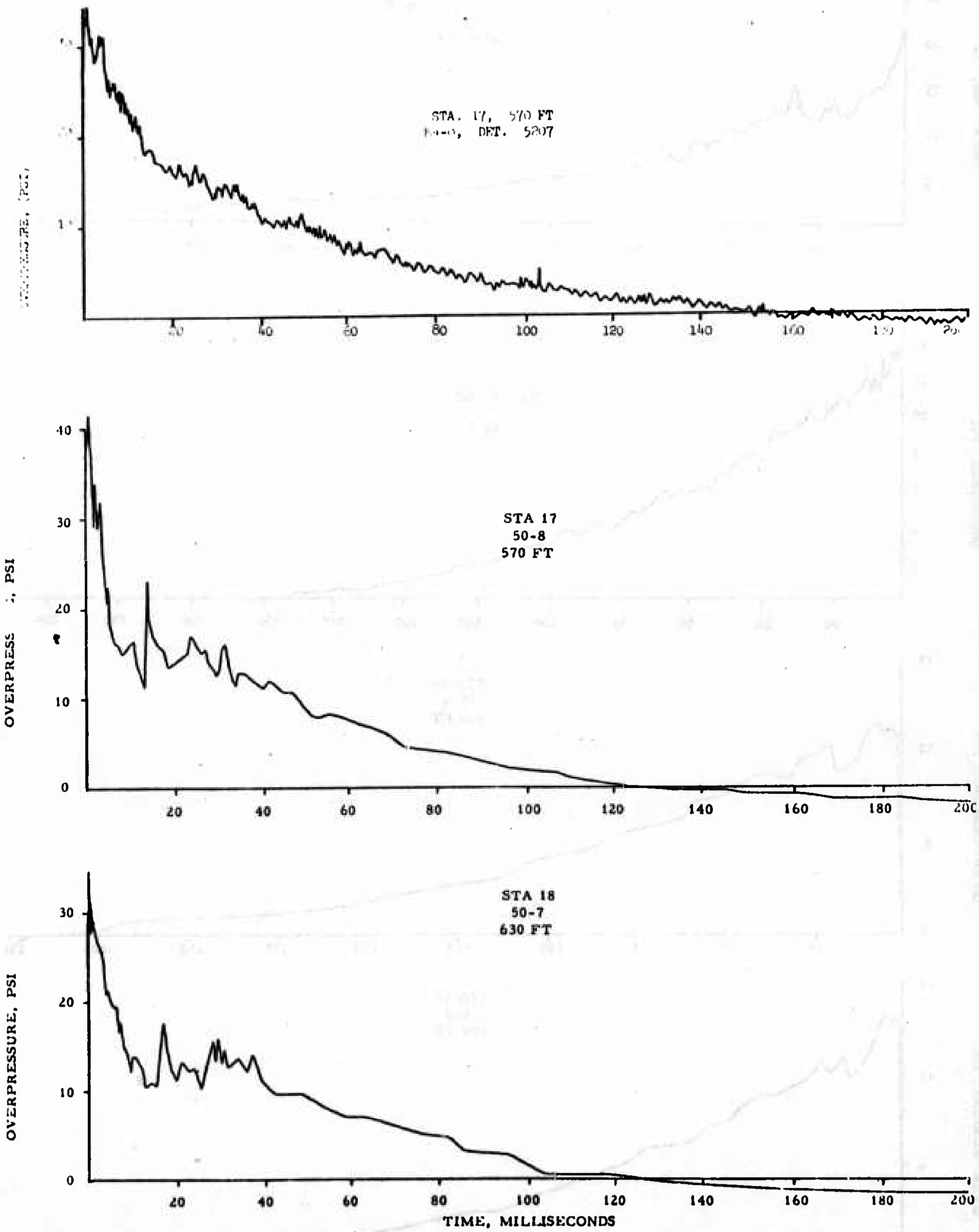

Figure A.7 Pressure-Time Records for Stations 17 and 18

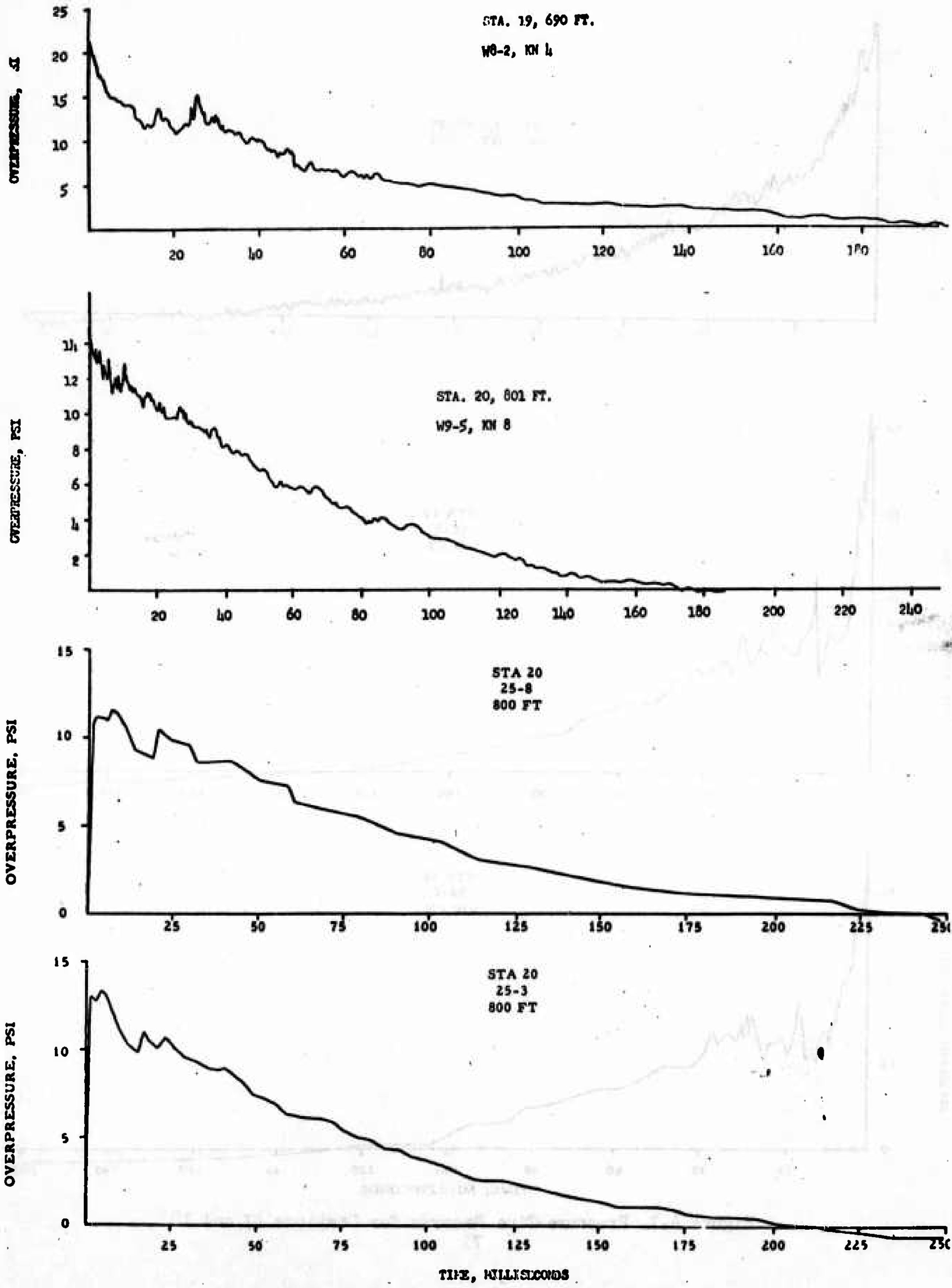

Figure A.8 Pressure-Time Records for Stations 19 and 20

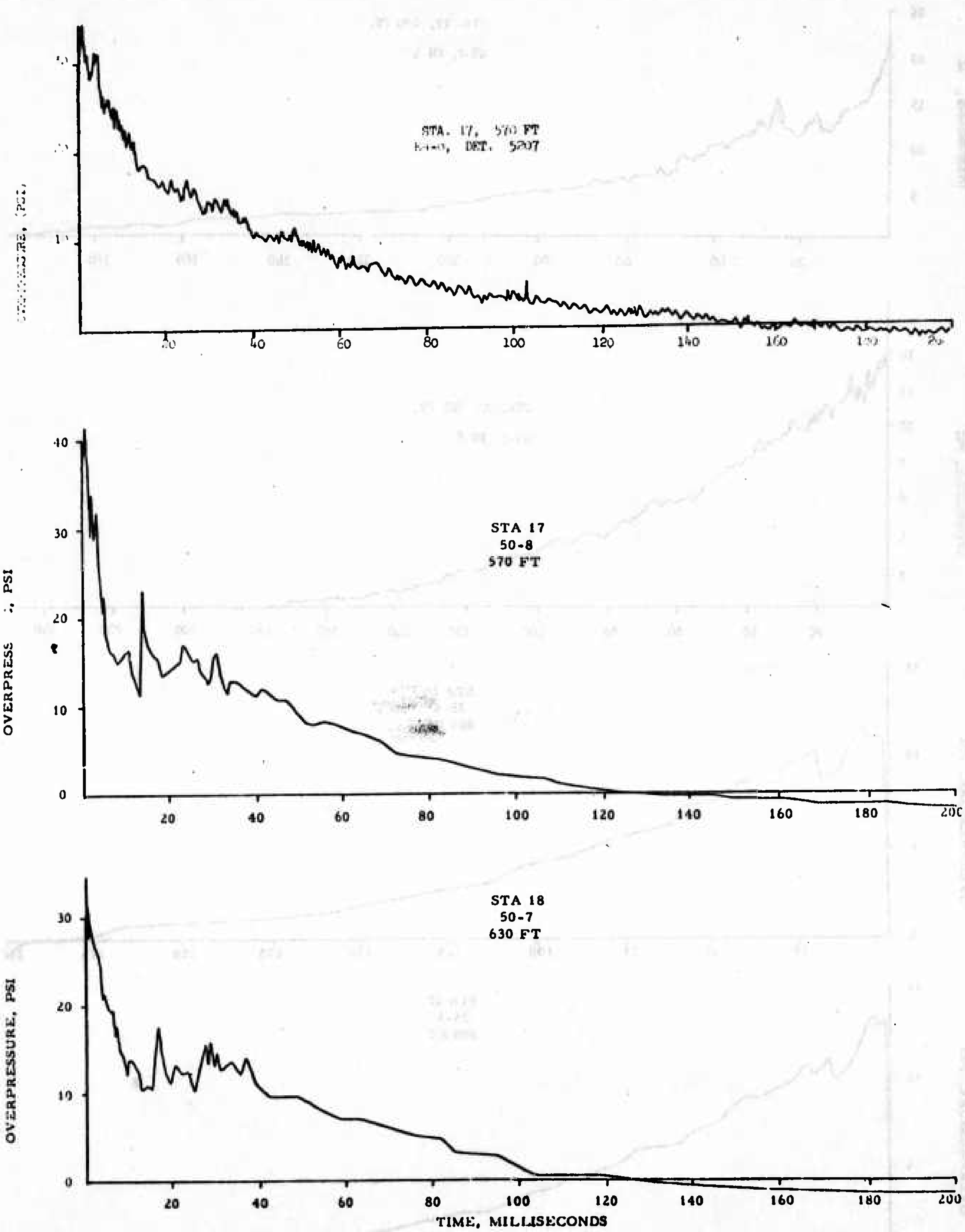

Figure A.7 Pressure-Time Records for Stations 17 and 18

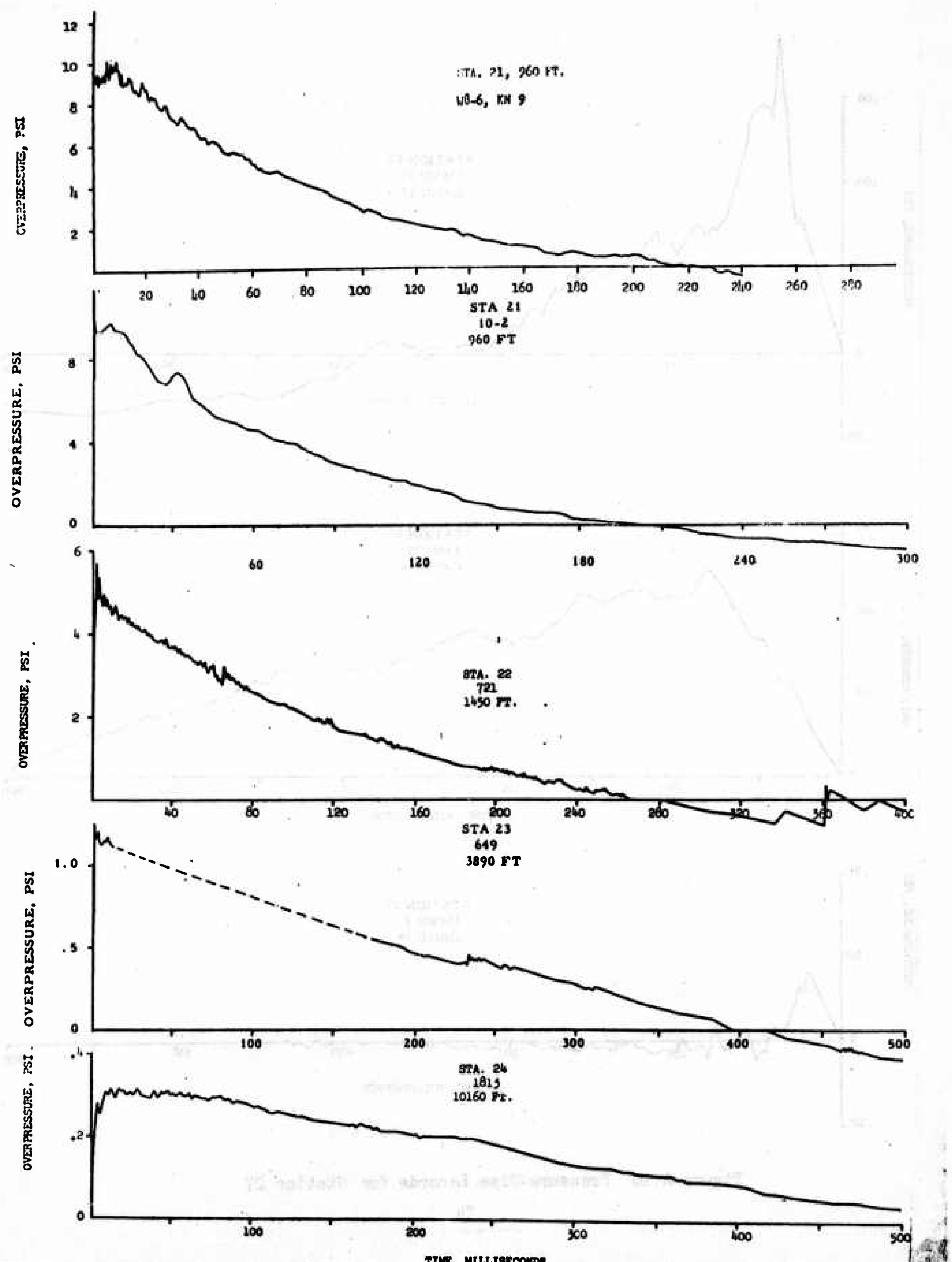

Figure A.9 Pressure-Time Records for Stations 21 to 24

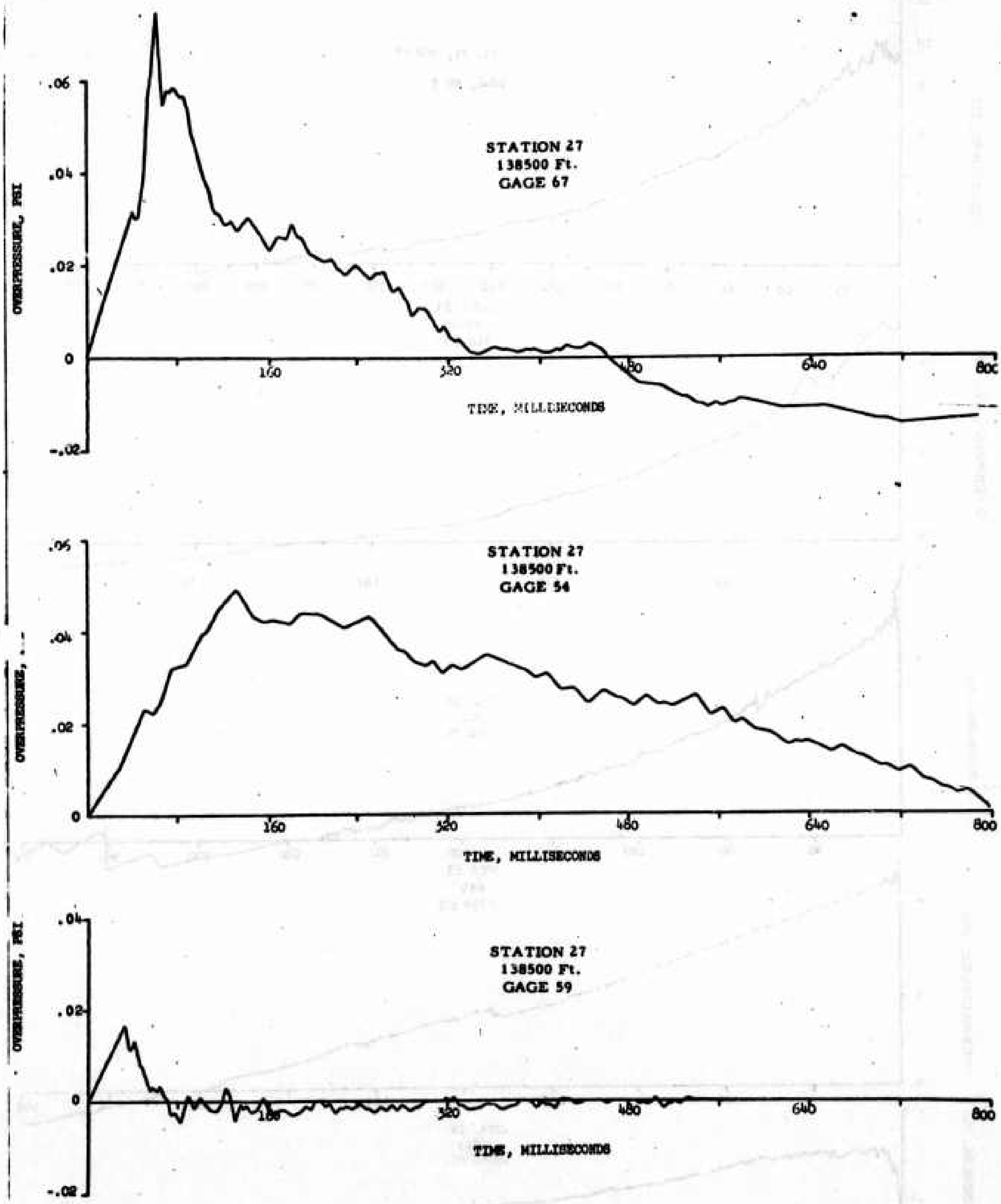

Figure A.10 Pressure-Time Records for Station 27

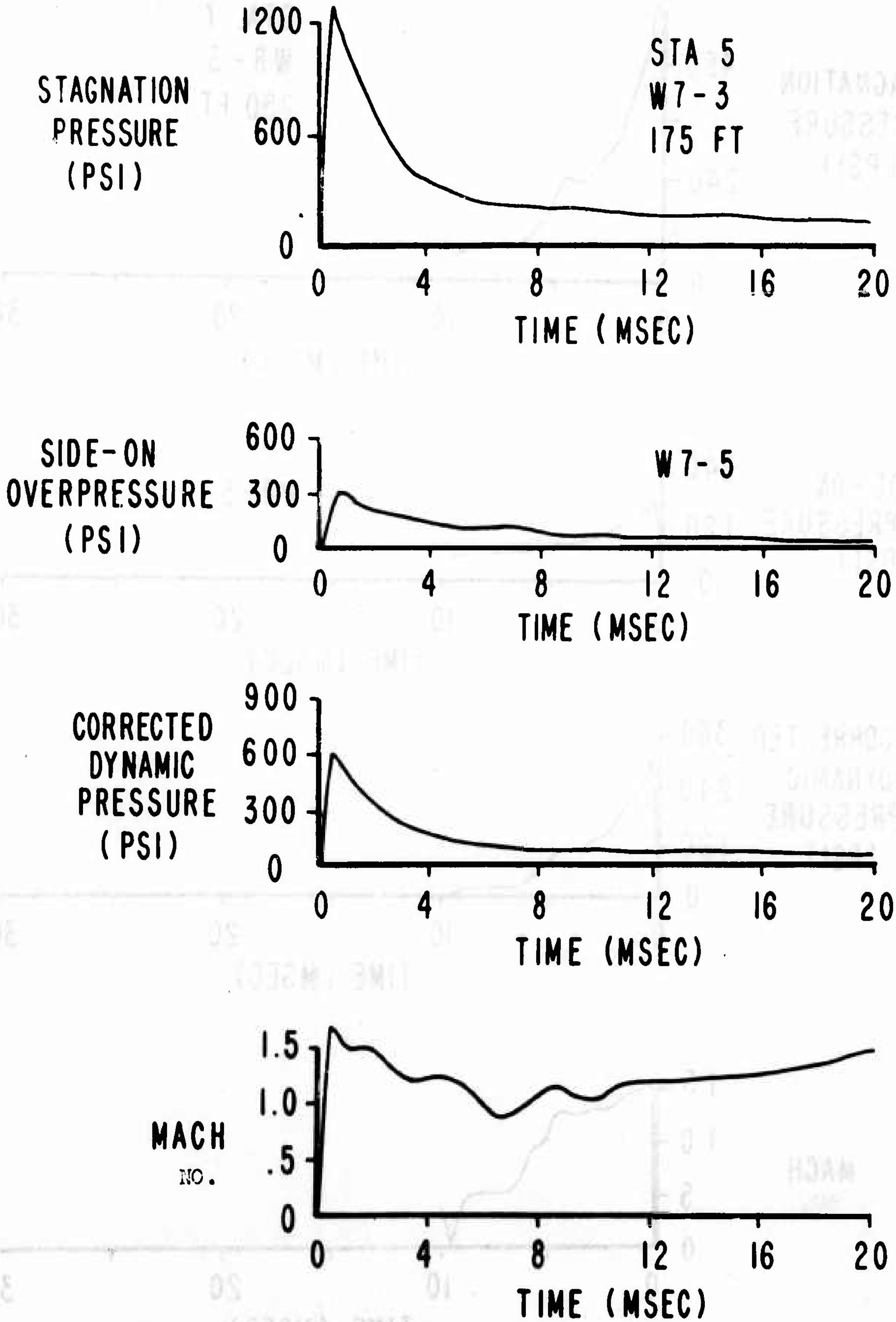

Figure A.11 Dynamic Pressure Measurements from Electronic Gages Station 5

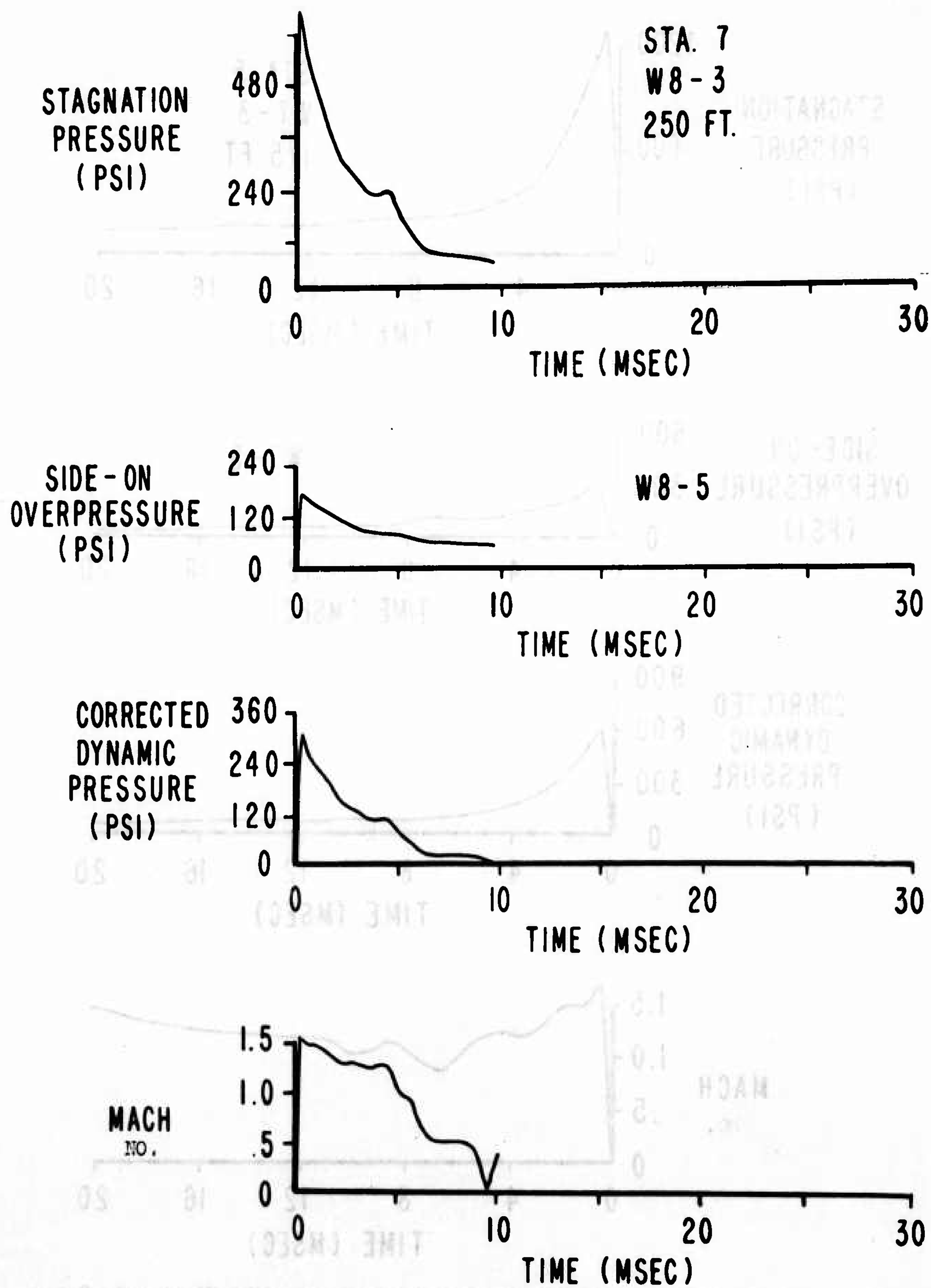

Figure A.12 Dynamic Pressure Measurements from Electronic Gages Station 7

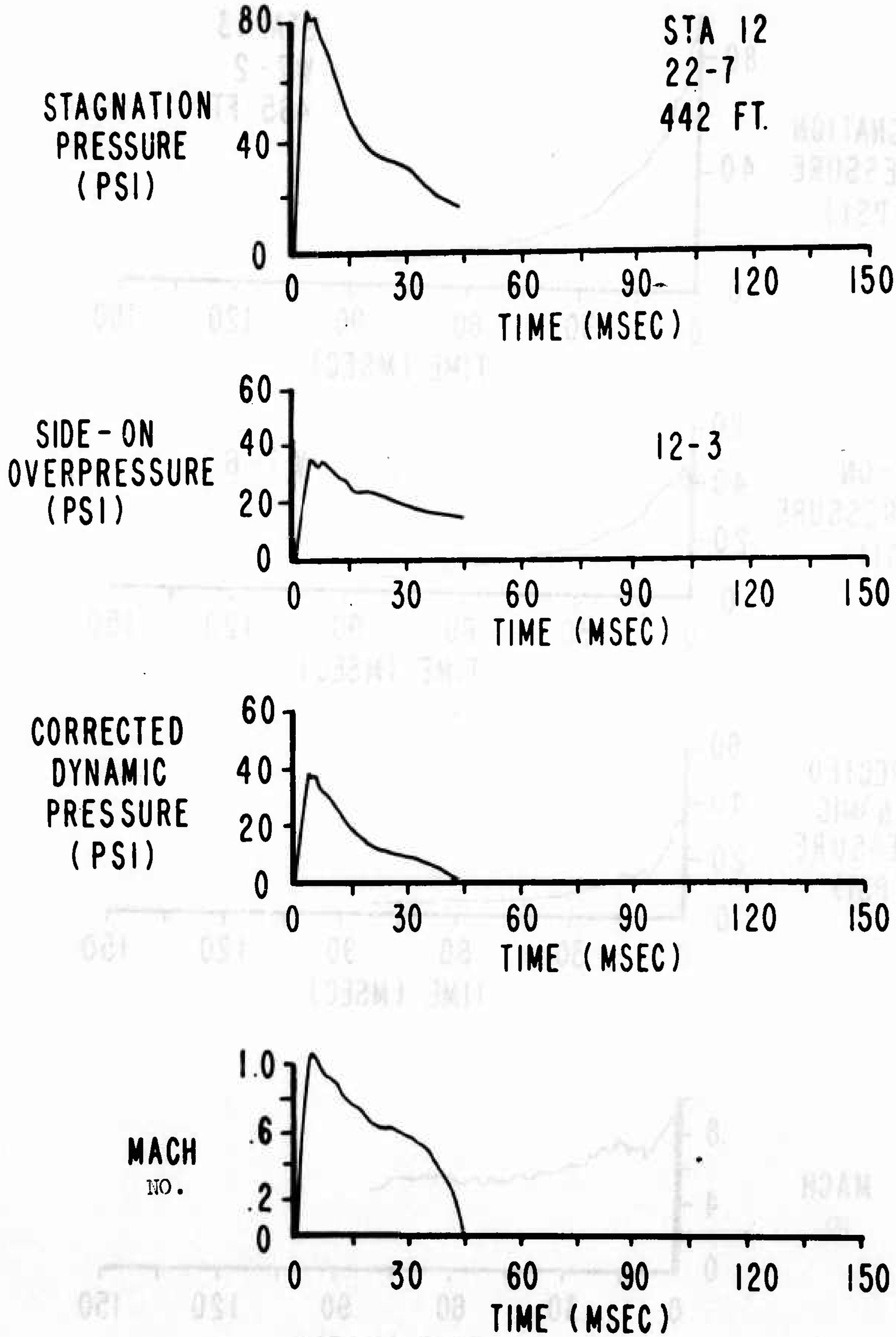

Figure A.13 Dynamic Pressure Measurements from Self-Recording Gages Station 12

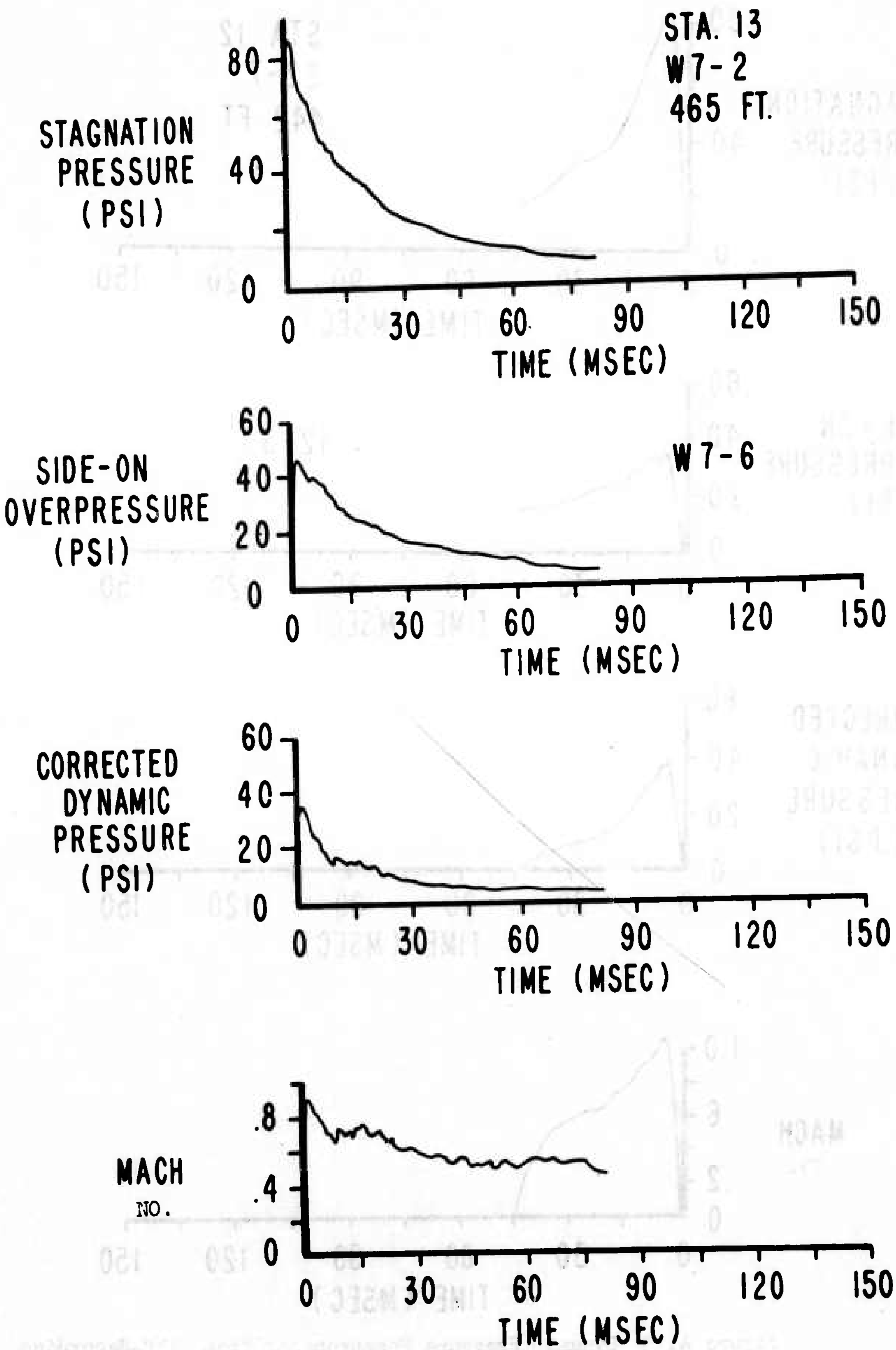

Figure A.14 Dynamic Pressure Measurements from Electronic Gages Station 13

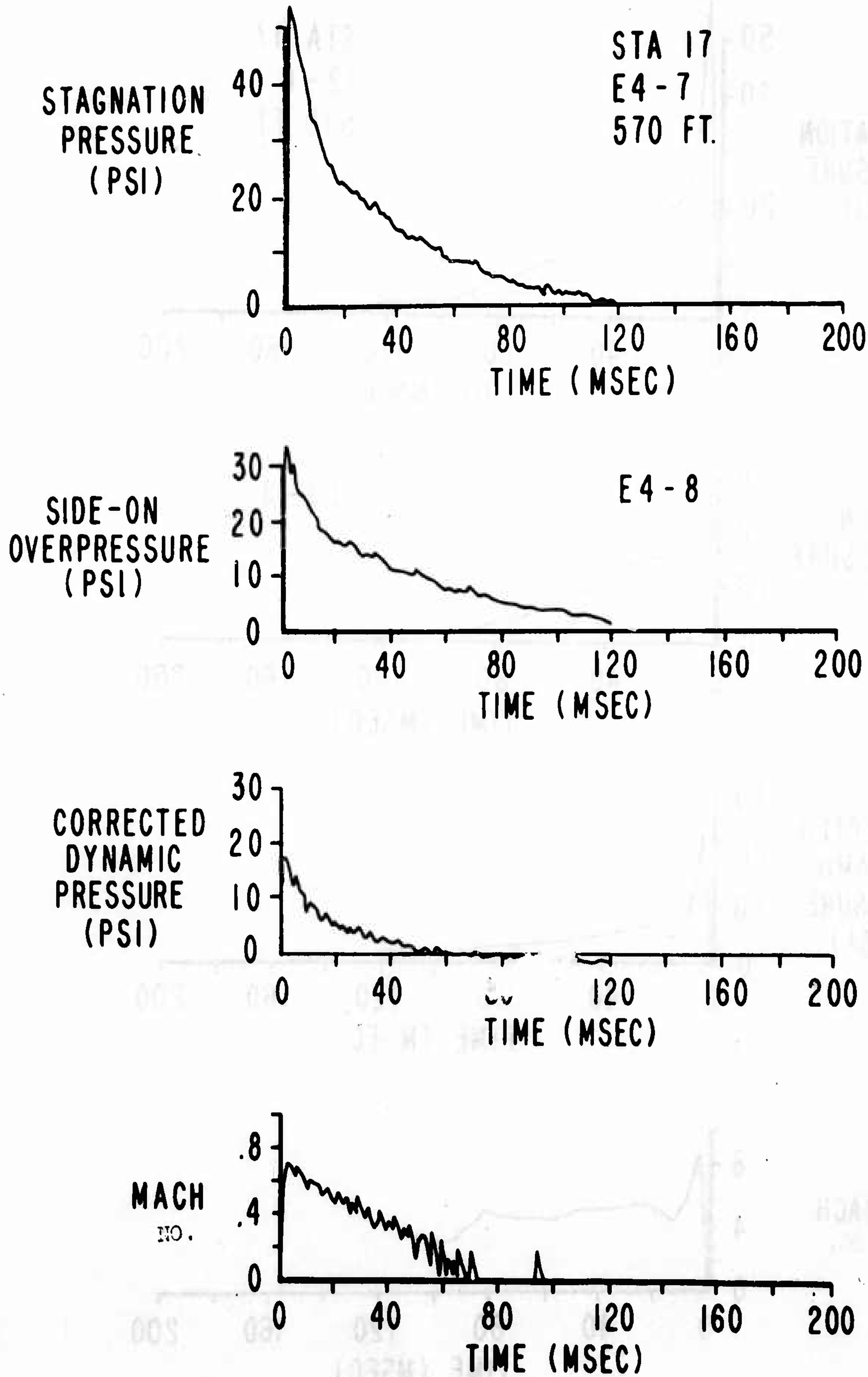

Figure A.15 Dynamic Pressure Measurements from Electronic Gages Station 17

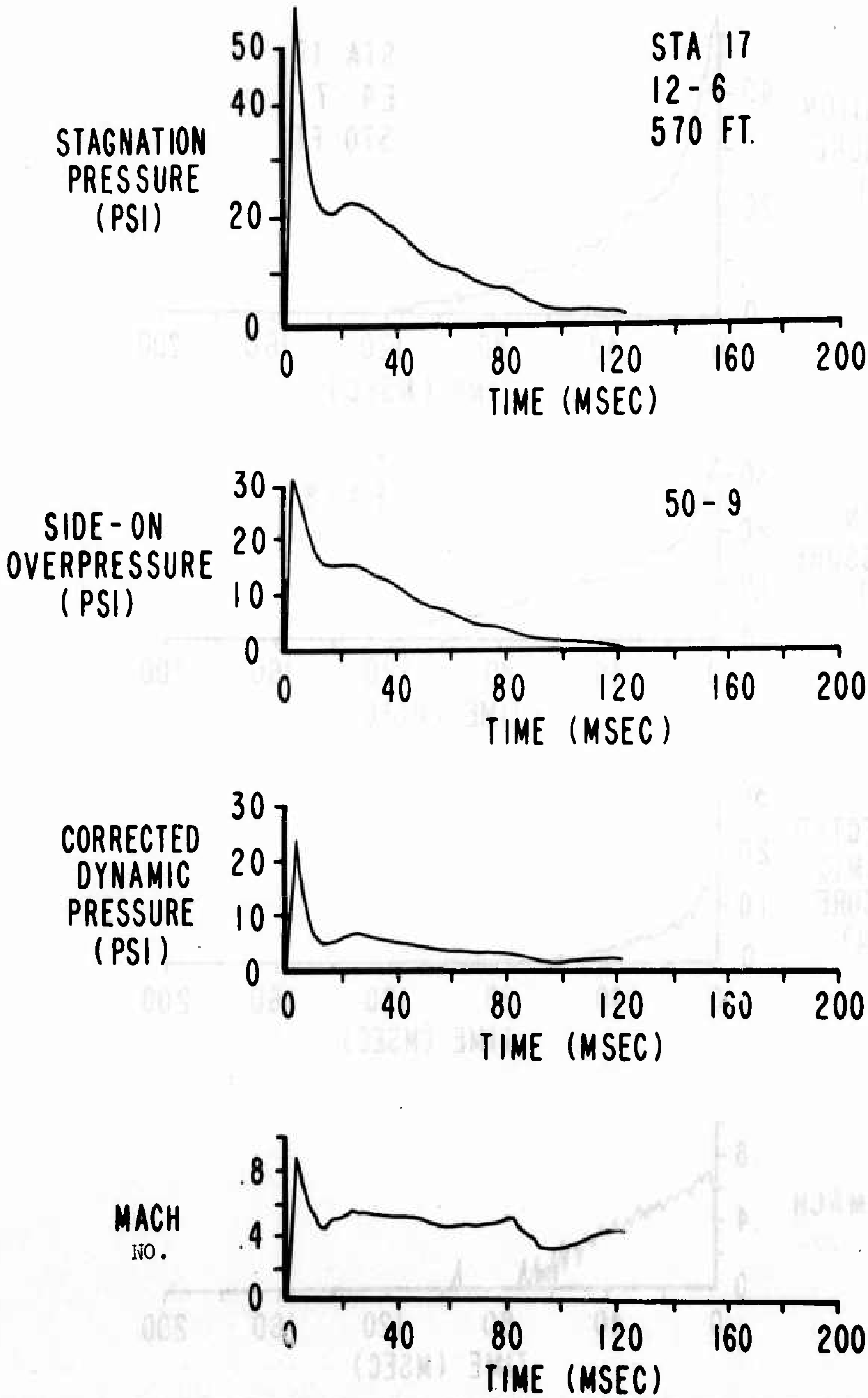

Figure A.16 Dynamic Pressure Measurements from Self-Recording Gages Station 17

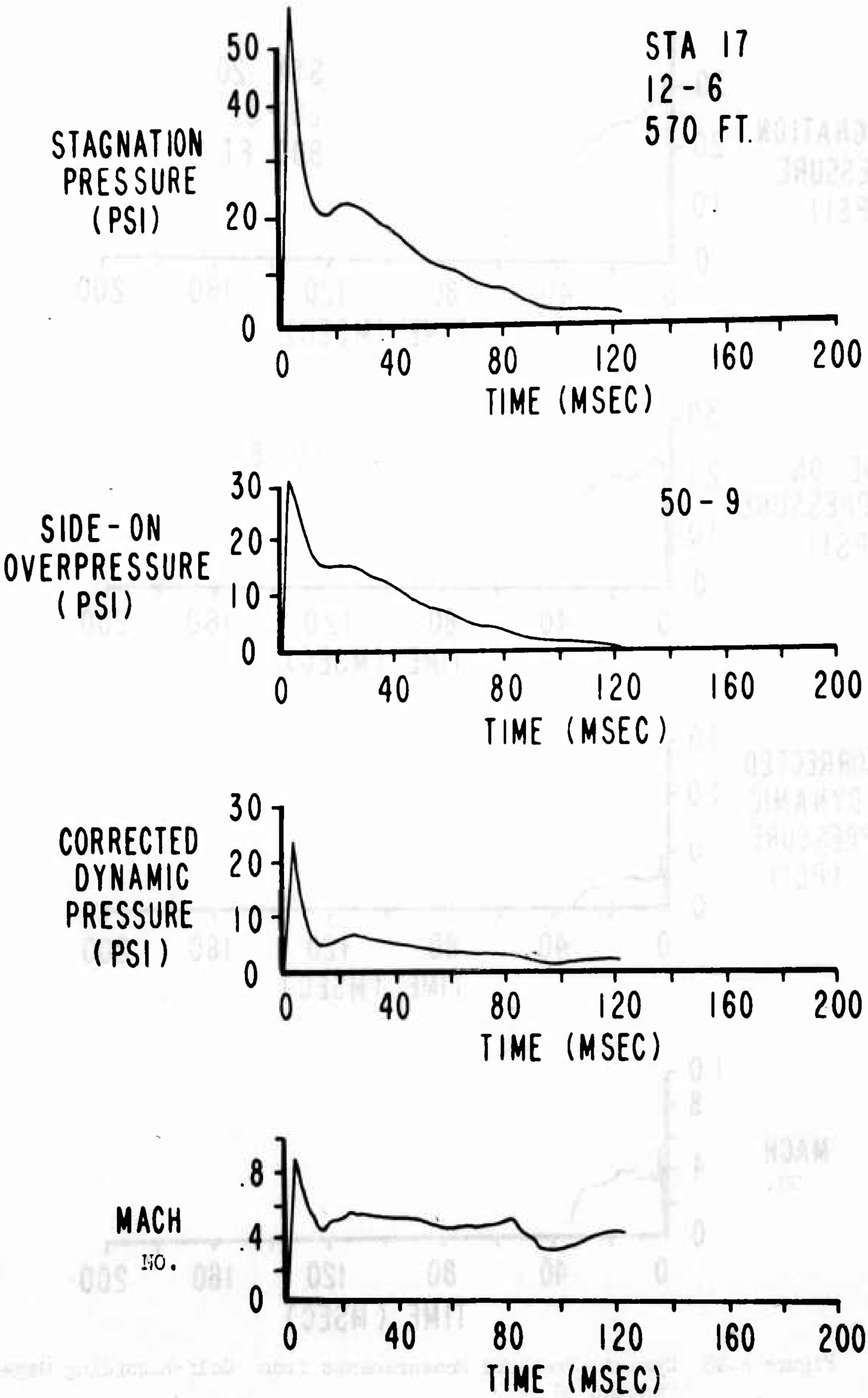

Figure A.17 Dynamic Pressure Measurements from Electronic Gages Station 20

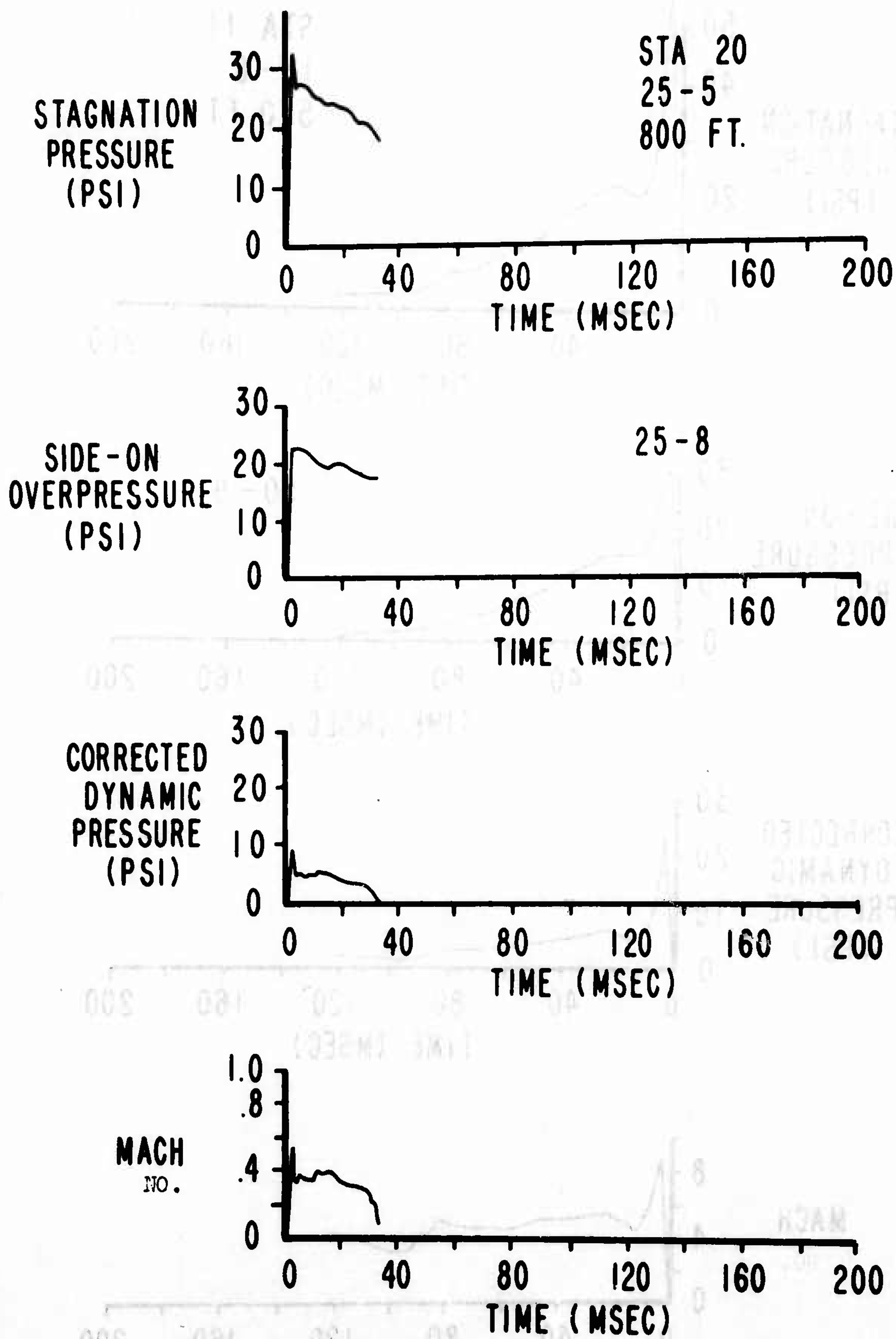

Figure A.18 Dynamic Pressure Measurements from Self-Recording Gages Station 20

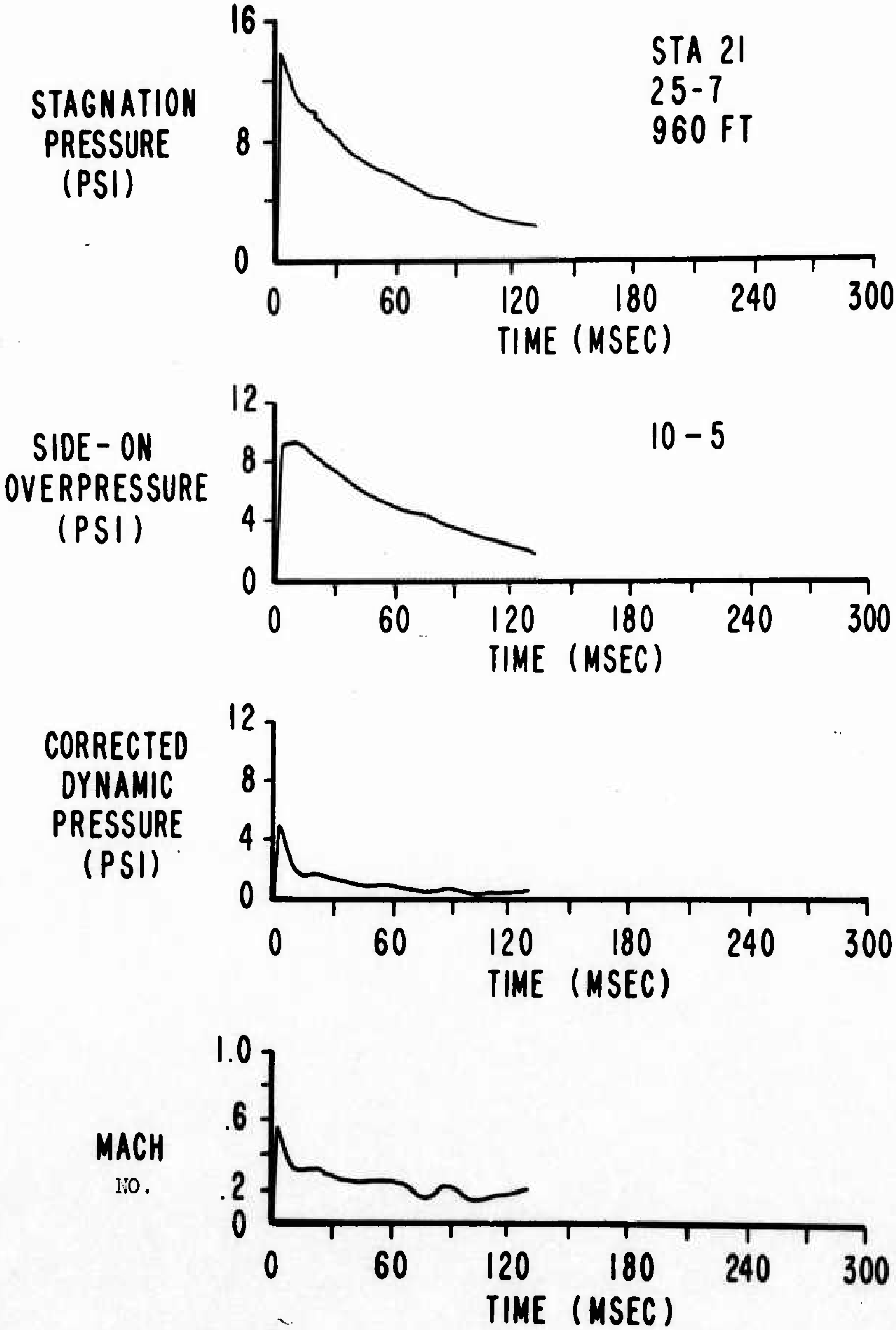

Figure A.19 Dynamic Pressure Measurements from Self-Recording Gages Station 21

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13. ABSTRACT

This report presents free field blast data obtained by instruments positioned at selected distances from the center of a 500-ton hemispherical surface charge of TNT. Measured values of shock arrival time, overpressure, duration of positive phase of the shock wave, impulse, and dynamic pressure are plotted as functions of distance and are compared with predicted values. Pressure-time histories obtained at pressure levels of 300, 90, 30 and 15 psi are compared with predicted wave shapes. Measured data in the low and moderate pressure regions compare favorably with predicted values.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Detonation						
High Explosive Charge						
Instrumentation						
Transducers						
Overpressure						
Positive Duration						
Dynamic Pressure						

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