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ADTC GUIDE TO BLAST PRESSURE TESTING

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# ADTC GUIDE TO BLAST PRESSURE TESTING

OCTOBER 1974

Prepared by the
Fuel Air Explosives Instrumentation Study Group

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ARMAMENT DEVELOPMENT AND TEST CENTER
AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE
EGLIN AIR FORCE BASE, FLORIDA

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## PREFACE

The ADTC Task Team responsible for the study and for report preparation was formed under the authority of Range Support Directive JON 9993V421. The preliminary study and report preparation took place from 1 October 1973 to August 1974.

Personnel responsible for the study, report preparation, and coordination were:

| | | |
|---|---|---|
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| C.J. Hattaway | C.J. Hattaway | TSGPS |
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The contents of this publication, including any conclusions, represent the views of the authors only and should not be considered as having official Department of the Air Force approval, either expressed or implied.

This guide represents a comprehensive summary of findings of the FAE Instrumentation Study Group as applies to the most common types of blast pressure tests conducted at ADTC. As with most reports which attempt to put into writing the state-of-the-art practices for instrumentation systems, this report also suffers from being somewhat out of date before it is actually published; however, the practices, procedures, and equipment described herein represent the most current information available to the authors at the time of writing. It is anticipated that this document must be updated frequently to keep pace with advances in technology, technique, and instrumentation. Plans are to revise and update this document approximately 1 January 1976. Comments, both technical and editorial, are solicited and should be forwarded to the following address:

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Attn: Mr. S. Shelley
Eglin AFB, FL 32542

CONTENTS

CONTENTS (Concluded)

## SECTION I

## INTRODUCTION

### BACKGROUND

The requirement exists at ADTC to measure the airblast parameters of numerous types of DOD munitions including fuel-air explosives (FAE), bare charges (such as pentolite, TNT, H-6, etc.), bombs, and warheads. Because of the technical difficulties and expense involved in collecting good data in sufficient quantity under dynamic conditions, most of the air-blast measurements are made from static tests; however, it is sometimes desired to conduct tests (such as on sled track) under dynamic conditions to determine if there is a significant difference between the static and dynamic test results.

Measurement of airblast pressure parameters places rather stringent requirements on facilities and instrumentation. Extreme difficulty has been encountered at ADTC in consistently collecting quantitative airblast overpressure data and it has been virtually impossible to collect indisputable data. Basically, problems fall into one of three categories - equipment malfunctions (recorders, transducers, etc.), inadequate procedures (data handling, calibrating, arena design and setup, etc.), and environmental conditions (weather, heat transients, peak pressures in excess of 1,000 psi).

Because of the problems identified above, an ADTC Task Team was established to define the specific pressure measurement problems and to implement solutions to those problems identified. A survey was conducted by this Team to determine the instrumentation and methodology utilized by other agencies to collect pressure data. This survey was made using available literature and by contacting other agencies. Preparation of this document was based on information gathered during the survey and on information gathered empirically at Eglin AFB.

### SCOPE

This document provides a procedure for measuring airblast pressure for free airblast tests, FAE tests, and Joint Munitions Effectiveness Manual (JMEM) warhead tests. That information which should be provided by the test requester (normally Air Force Armament Laboratory) is identified.

Also, specific instrumentation including transducer type, mounting arrangements, cables, signal conditioning, and recorders are discussed and recommended for each type of test. Calibration techniques and intervals (both laboratory and field) are identified. Guidelines to be used by the test designer in arriving at an appropriate arena configuration are provided. Procedures to be followed by personnel involved in the actual conduct of a test are provided. These include procedures for building up the arena, accomplishing field calibration, operating the instrumentation system, and documenting test results. In addition, data handling and data reduction procedures have been established which identify (1) the information required from site personnel to process magnetic tapes (both analog and digital), (2) the technique(s) utilized to process the data, (3) the format of the reduced data, and (4) the disposition of processed data.

## OBJECTIVE/PURPOSE

The objective of this document is to delineate procedures for collecting airblast pressure data, e.g., to provide a procedure that identifies the best available instrumentation (transducers, mounts, signal conditioning equipment, recorders, etc.) and methodology (techniques for test design, test conduct, data reduction, etc.) to be utilized at ADTC to collect airblast pressure data for conventional munitions and explosives.

## ORGANIZATION

This guide is organized in six sections (plus the introduction). Each section is directed at a specific area of responsibility concerning the test. The Test Requirements Section (Section II) provides guidelines for the test requester. The Instrumentation Section (Section III) describes available instrumentation. Calibration equipment is described in Section IV. Section V details several common test designs for the test designer to follow in developing a test plan. The Test Conduct Section (Section VI) describes actual range setup procedures for personnel participating in test preparation and conduct. Section VII provides information regarding data handling and reduction.

## SECTION II

## TEST REQUIREMENTS

### GENERAL

The initiation of any test program is derived from a need to gather specific experimental data. The initiator of any such program has the responsibility of providing sufficient technical data about the test item and clearly establishing the experimental data to be measured. When a separate organization designs and executes the test program, the test "requester" is responsible for transmitting this information to the design organization. The following paragraphs outline techniques and procedures the test requester may use as a guide for this interface. In particular, it is intended as a guide for planning and requesting tests requiring pressure data or closely related information. The information requirements specified below are in accordance with ADTCM 80-1 and AFATL Reg 136-1.

### TEST ITEM TECHNICAL DATA

The following data on the test item will be required by the testing organization:

1. General word and pictorial description (dimensioned sketch) of the item.

2. Types, weights, and densities of explosives.

3. Fuze type and operational details.

4. Height of burst and weapon orientation.

5. TNT equivalent charge weight of item.

6. Weather constraints; i.e., a list of meteorological limits imposed on the test.

7. Fuel weight (FAE items only).

8. Cloud detonator or second event specifications, i.e., number, weight, explosive type, time delay, and locations (FAE items only).

The above data are related to the planning of item detonation. The following sections are all related to determining what data will be derived from the test, and in what manner they will be collected.

PRESSURE DATA TERMINOLOGY

"Pressure Data" is a general term applied to many properties and characteristics of blast waves. The intent of this section is to review and familiarize the test requester with the different blast properties that may be derived directly, or indirectly from measured data. The decision as to which properties are to be measured, and where they shall be measured, is entirely the responsibility of the data user, or test requester. The following list contains the more common properties, and should be closely reviewed by the requester; a thorough understanding of these terms is necessary for proper identification of any data collected:

1. Incident (side-on) pressure-time history
2. Reflected (face-on) pressure-time history
3. Impulse (side-on or face-on)
4. Dynamic pressure
5. Shock wave velocity
6. Time of arrival of shock.

The above properties may be determined at any location relative to ground zero; however, particular regions where blast characteristics vary radically are often given general nomenclature to assist in hardware selection, and to classify particular blast phenomena. These regions are listed below and should be applied in identifying gage locations.

1. Far field measurements
2. Near field measurements
3. Free air measurements
4. Mach stem measurements

5. Inside FAE cloud

6. Outside FAE cloud.

## DEFINING GAGE LOCATIONS AND PROPERTIES TO BE MEASURED

The selection of hardware to measure pressure data is often dependent on the property to be measured, its magnitude, and the general location of the gage as defined above. If the test requester is not familiar with blast pressure testing he may consult Section V to determine if any of the "standard" airblast test designs described are applicable to his test situation. Several of the more routine, standard tests are detailed to provide guidance to test designers and requesters unfamiliar with ADTC resources. The following items must be furnished the test designer:

1. A schematic showing the number and location of all desired data collection points (if known; if not known, consult with test design (TGWC) or other appropriate agency).

2. The property to be measured and its general classification as defined above.

3. Predicted pressure ranges at each gage location.

4. The desired accuracy of the data to be collected.

5. System frequency response (this item may be optionally specified by the requester, and would obviously require knowledge of the existing hardware limits).

## PHOTOGRAPHIC DATA

Photography is often necessary to interpret or analyze blast data, particularly when fuel-air explosions, or targets are involved. High-speed photography is useful in identifying the direction of shock wave travel and target response to blast. When utilizing this type of support the requester must furnish the design organization the following information (see Section V for standard configuration):

1. Desired frame rate of all cameras.

2. Field of view and line of sight for cameras.

3. Type of film (black/white or color).

4. Requirements for special views such as overhead or aerial photography.

5. Requirements for still shots and documentary films.

6. Film size required (16 or 25 mm).

7. Danger area for placement of cameras.

## DATA REDUCTION REQUIREMENTS

The raw test data are usually recorded in analog form on magnetic tape and must be reduced to a usable form. The process of reducing these data affords many options which the test requester or test designer must define. As a minimum, the requester must furnish the test agency a format to be used for final data output and a general statement of how the data will be used. Optional requests or control may be specified by the requester and include such items as:

1. Digitizing sample rate.

2. Filtering and data smoothing.

3. Special plots (semilog or log-log).

4. Meteorological corrections.

5. Mathematical analysis of data.

## MISCELLANEOUS AND SPECIAL DATA

Many shock phenomenon and blast evaluation precedures require the knowledge of meteorological conditions and terrain conditions at the time of testing. For this reason, the following data may be requested when testing blast oriented weapons:

1. Barometric pressure

2. Temperature

3. Humidity

4. Wind direction and velocity

5. General observation (inversions, cloud conditions, etc.)

6. Surface or ground condition and makeup (moisture content, soil composition, reflection coefficient, etc.).

## TARGETING

Historically, the evaluation of blast damage to targets has been empirical or semi-empirical; however, it would be valuable to collect such empirical data in terms of variables useful for objective analysis. Establishing the relationship between observed damage and target blast loading is desirable. Designing pressure instrumentation for acquisition of loading is quite complex due to the irregularity of target surfaces, protection of cabling, and other factors; therefore, if a thorough analysis of the aerodynamics of the target/shock wave interaction is not possible, target data should be taken using transducers mounted near (but not on) the target in known mounting fixtures (aerodynamic probe or surface mounts).

## SECTION III

## INSTRUMENTATION

### GENERAL

Instrumentation systems designed to measure blast pressure consist of transducers, cabling, signal conditioning amplifiers and data recording devices. The following paragraphs describe the instrumentation available at ADTC and discuss advantages, disadvantages and problem areas. Also, specific instrumentation including transducer type, mounting arrangements, cables, signal conditioning, and recorders are identified and recommended for different types of tests.

### TRANSDUCER SELECTION

The single most important part of the pressure instrumentation system is the transducer, which converts the phenomenon to be measured into an electrical signal. Pressure transducers are of many different types such as piezoelectric, resistive strain gage, variable inductance, variable capacitance, and variable resistance. The leading candidates for use in measuring blast pressure are piezoelectric and piezoresistive strain gage types because of their superior high frequency response.

Piezoelectric transducer designs are based on the principle that asymmetrical crystalline materials produce an electrical potential upon the application of strain or stress. The most widely employed piezoelectric crystals are quartz, tourmaline, Rochelle salt, lead metaniobate, and barium titanite. The pressure is applied to the crystal through a thin diaphragm. The crystal elements in piezoelectric transducers perform a dual function: they act as a precision spring to oppose the applied pressure or force and supply an electrical signal proportional to their deflection.

Piezoresistive strain gage transducers utilize a monolithic, integrated circuit Wheatstone bridge formed directly on a silicon diaphragm by solid state diffusion techniques. Integral silicon diaphragms incorporating a four-active-arm Wheatstone bridge provide an output proportional to pressure and the bridge excitation voltage. The stress sensors are arranged so that under load, two elements are in tension and two in compression producing a relatively high output.

The transducers currently in use at ADTC for blast pressure measurements are piezoelectric types, while other agencies such as Sandia Laboratories, Air Force Weapons Laboratory and Ballistic Research Laboratory, use piezoresistive strain types as well. Since most ADTC experience has been with piezoelectric types, the discussion of piezoresistive strain gage pressure transducers will be limited to general comments only. Piezoresistive strain gage types are under test and evaluation for ADTC requirements. Following are discussions regarding some of the transducers currently utilized by DOD agencies to collect blast pressure data. Table 1 lists the primary characteristics of these transducers.

PCB PIEZOTRONICS SERIES 102 (FIGURE 1).

<u>Description.</u> The Series 102 piezoelectric transducer consists of a quartz crystal mounted in a 3/8 - 24 housing with built-in high to low impedance electronics. The transducer is designed to be flush-mounted on a flat surface.

<u>Applications.</u> Applications are as follows:

1. Pressure-time measurements (face-on or side-on).
2. Time of arrival (TOA).
3. Shock wave velocity (when used in pairs).

<u>Advantages.</u> Advantages are as follows:

1. Moderately high output (1 or 10 mv/psi).
2. High natural frequency (500 kHz).
3. Simple mounting.
4. Good shock and vibration specifications (0.002 psi/G).
5. Low output impedance (100 ohms).
6. High range ( 0 to 5,000 psi).
7. Ground isolated.

Table 1. Operational characteristics of several transducer types

| Transducer | Ground isolation | Vibration sensitivity | Range (psi) | Maximum overpressure (psi) | Sensitivity | Resonant frequency | Time constant | Rise time (μsec) |
|---|---|---|---|---|---|---|---|---|
| Kistler Model 202A1 | $10^7$ ohms | 0.002 psi/G | 5,000 | 7,000 | 1.0 ±0.05 mv/psi | 400 kHz | 1,000 sec at 68° F | 1.0 |
| Kistler Model 202A2 | $10^7$ ohms | 0.002 psi/G | 500 | 2,000 | 10.0 ±0.05 mv/psi | 400 kHz | 200 sec at 68° F | 1.0 |
| PCB Model 102M24 | $10^7$ ohms | 0.002 psi/G | 5,000 | 7,000 | 1.0 ±0.05 mv/psi | 500 kHz | 1,000 sec at 68° F | 1.0 |
| PCB Model 102M25 | $10^7$ ohms | 0.002 psi/G | 500 | 2,000 | 10.0 ±0.5 mv/psi | 500 kHz | 200 sec at 68° F | 1.0 |
| Susquehanna Model ST-2 | None | Undefined but excellent | 500 | 500 | 24.0 ±5.0 pcmb/psi | 250 kHz | NA | 1.0 |
| Susquehanna Model ST-4 | None | Undefined but excellent | 10,000 | 15,000 | 0.1 pcmb/psi | 1.5 MHz | NA | 0.1 |
| Susquehanna Model ST-7 | None | Undefined but excellent | 500 | 700 | 20.0 ±4.0 pcmb/psi | 250 kHz | NA | 1.0 |
| Kulite Model HKS-375-1000 | Yes | 0.0001% FS/G | 1,000 | 1,500 | 0.125 mv/psi | 500 kHz | dc | 10.0 |
| Kulite Model XTS-1-190-1000 | Yes | 0.0001% FS/G | 1,000 | 2,000 | 0.125 mv/psi | 500 kHz | dc | 10.0 |

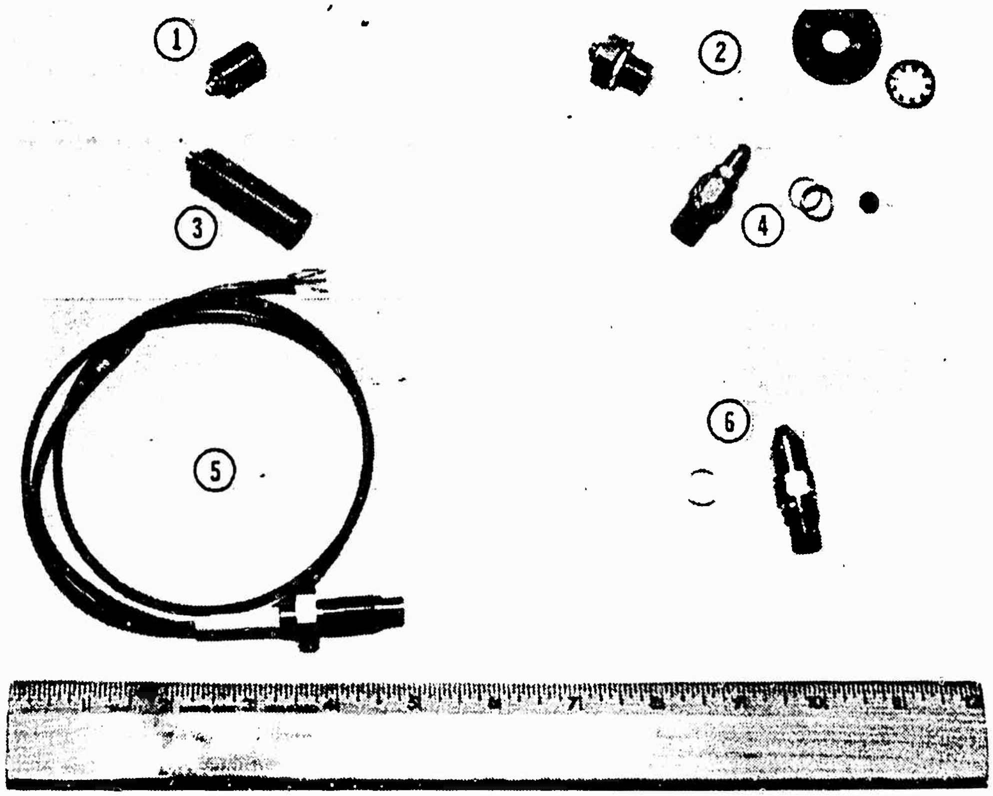



Figure 1. Pressure transducers showing: (1) Susquehanna Model ST-2, (2) Atlantic Research Model LD-25, (3) Susquehanna Model ST-4, (4) Kistler Model 202A1/662M2, (5) Kulite Model HKS-375-1000, and (6) PCB Model 102M24

Disadvantages. Disadvantages are as follows:

1. Subject to baseline shift due to temperature and other unknown factors.

2. Small cable connectors which loosen easily.

3. Subject to "pre-shoot" and ringing when used to measure shock waves with fast shock front velocities.

4. Moderately high cost ($350 each).[1]

5. Require dynamic calibration (no dc response).

[1] Cost figures are approximate values based on latest procurement bids.

KISTLER SERIES 202 (FIGURE 1).

Description. The Kistler Series 202 is almost identical to the PCB transducers. The sensor is quartz with an output of 1 or 10 mv/psi. Size and mounting are the same as those of the PCB and can be used interchangeably in the same mounts.

Applications. Applications are as follows:

1. Pressure-time measurements (face-on and side-on).

2. TOA

3. Shock wave velocity (when used in pairs).

Advantages. Advantages are as follows:

1. Moderately high output (1 or 10 mv/psi).

2. High natural frequency (400 kHz).

3. Simple mounting.

4. Good shock and vibration specifications (0.002 psi/G).

5. Low output impedance (100 ohms).

6. High range (0 to 5000 psi).

7. Ground isolated.

Disadvantages. Disadvantages are as follows:

1. Subject to baseline shift due to temperature and other unknown factors.

2. Small cable connectors which loosen easily.

3. Subject to pre-shoot and ringing when used to measure shock waves with fast shock front velocities (more than PCB).

4. Moderately high cost ($350 each).[2]

5. Require dynamic calibration (no dc response).

---

[2] ibid

SUSQUEHANNA INSTRUMENTS ST-2 (FIGURE 1).

Description. The ST-2 transducer consists of a lead metaniobate sensor mounted in a 1/2- by 9/16-inch stainless steel housing. The natural frequency of the transducer is 250 kHz with a charge sensitivity of approximately 20 pcmb/psi. This flush-mounted transducer is an excellent transducer to measure side-on pressure from moderately fast shock fronts.

Applications. Applications are as follows:

1. Pressure-time measurements (side-on).

2. TOA

3. Shock wave velocity (when used in pairs).

Advantages. Advantages are as follows:

1. Low cost ($200).[3]

2. High output (20 pcmb/psi).

3. Insensitive to mechanical vibrations.

4. High natural frequency (250 kHz). (Not as high as PCB or Kistler.)

5. Simple mounting.

Disadvantages. Disadvantages are as follows:

1. Subject to baseline shift due to over-range pressure and high velocity shock front.

2. Subject to baseline shift due to temperature (can be minimized by use of one layer of black plastic tape).

3. High output impedance (should be converted to low impedance at transducer by use of impedance converter).

---

[3] ibid

4. Subject to pre-shoot and ringing when used to measure shock waves with very fast shock front velocities.

5. Small cable connectors which loosen easily.

6. Grounded.

7. Require dynamic calibration (no dc response).

8. Limited range (0 to 500 psi).

SUSQUEHANNA INSTRUMENTS ST-4 (FIGURE 1).

Description. The ST-4 is an aperiodic pressure transducer designed so that high speed reflected shocks can be accurately measured in 1 microsecond or better. Natural resonance of the crystal element is dissipated in an acoustic waveguide within the transducer. The sensor is tourmaline with a natural frequency of 1.5 megaHertz and a charge sensitivity of approximately 0.1 pcmb/psi. The ST-4 is an excellent transducer for measuring fast rise time pressure pulses. Due to pyroelectric effects the ST-4 should be used only to measure peak pressure in FAE tests.

Application. This transducer is used for pressure-time measurements (peak only if in FAE cloud).

Advantages. Advantages are as follows:

1. Very high natural frequency (1.5 MHz).

2. Insensitive to mechanical vibrations.

3. Simple mounting.

4. Versatile usage (face-on or side-on).

5. Wide range (10 to 10,000 psi).

---

[3] ibid

Disadvantages. Disadvantages are as follows:

1. Susceptable to pyroelectric effects (baseline shift).

2. High cost ($400).[4]

3. High output impedance (should be converted to low impedance at transducer).

4. Small cable connectors which loosen easily.

5. Grounded.

6. Require dynamic calibration (no dc response).

SUSQUEHANNA INSTRUMENTS ST-7 (FIGURE 2).

Description. The ST-7 is a free-field side-on pressure probe consisting of a lead metaniobate sensor. The natural frequency of the transducer is 250 kHz with a charge sensitivity of approximately 20 pcmb/psi. This probe is virtually free from mechanical noises usually produced by shock, flying missiles, or resonance of the transducer element. This transducer is excellent for measurement in the free-field (outside the detonation area).

Applications. Applications are as follows:

1. Pressure-time measurements outside detonation area (side-on).

2. TOA

3. Shock wave velocity (when used in pairs).

Advantages. Advantages are as follows:

1. Relatively low cost ($280).[5]

2. High output (20 pcmb/psi).

3. High natural frequency (250 kHz).

---

[4, 5] ibid

4. Has own aerodynamic mount.

5. Good aerodynamic characteristics.

Disadvantages. Disadvantages are as follows:

1. High output impedance (should be converted to low impedance at transducer by use of impedance converter).

2. Limited use (free air, side-on only).

3. Subject to baseline shift due to temperature (can be minimized by use of one layer of black plastic tape).

4. Subject to mechanical damage in high pressure regions.

5. Limited range (0 to 500 psi).

6. Grounded.

7. Small cable connections loosen easily.

8. Require dynamic calibration (no dc response).

ATLANTIC RESEARCH MODEL LD-25 (FIGURE 1).

Description. The LD-25 transducer consists of a lead ziroconate litanate sensor mounted in a 3/8 - 32 stainless steel housing. This transducer is designed for flush mounting.

Application. This transducer is used for time of arrival measurements only (at ADTC).

Advantages. Advantages are as follows:

1. Low cost ($25).[6]

2. High output (35 pcmb/psi).

3. Simple mounting.

4. High range (0 to 3000 psi).

---

[6] ibid

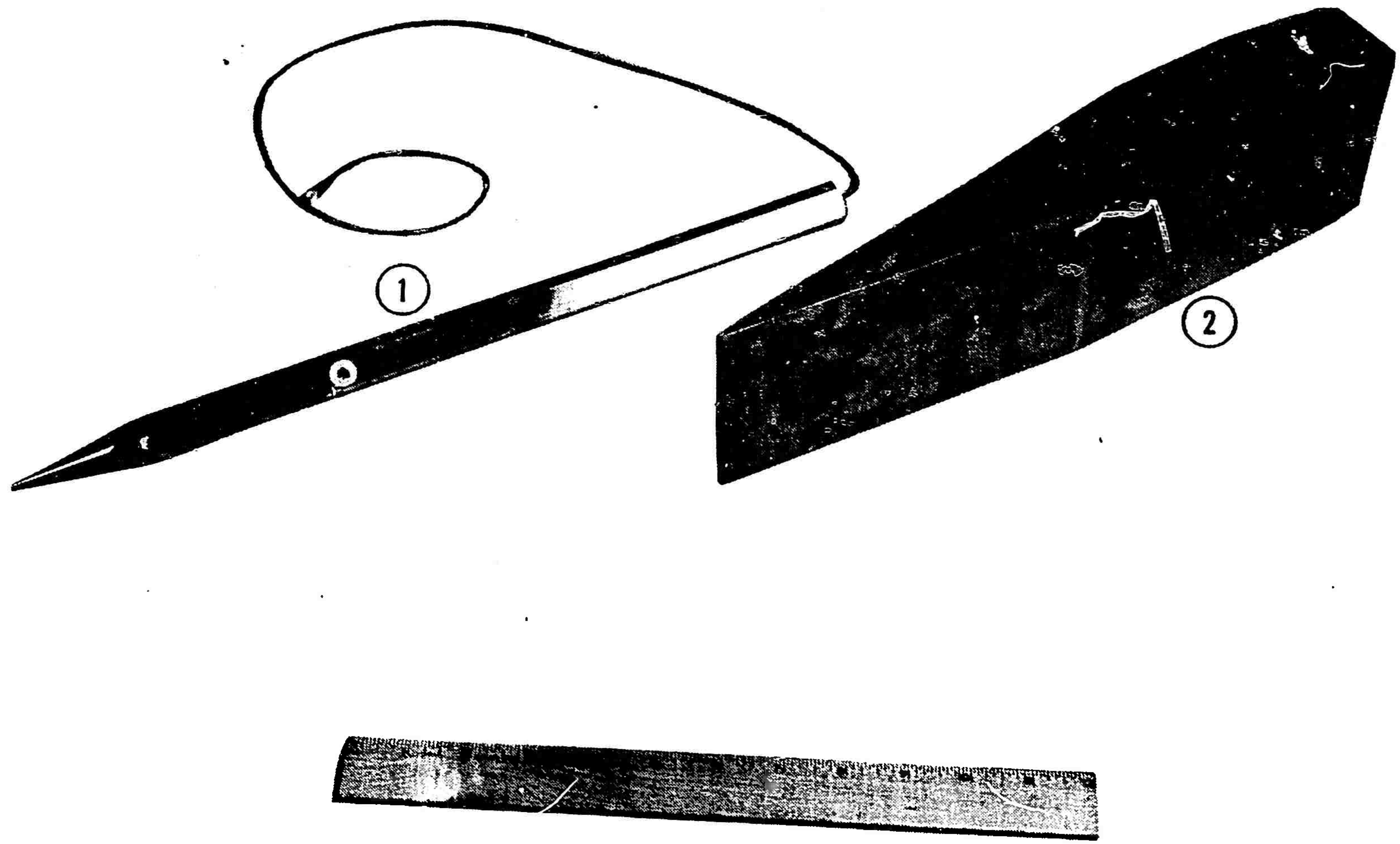


Figure 2. Transducer mounts showing:
(1) Susquehanna ST-7 and (2) "axhead"

Disadvantages. Disadvantages are as follows:

1. Subject to baseline shift due to pyroelectric effects.

2. High output impedance.

3. Grounded.

4. Require dynamic calibration.

PIEZORESISTIVE STRAIN GAGE TYPE, KULITE MODELS XTS-1-190 AND HKS-375 (FIGURE 1).

Description. The piezoresistive strain gage transducer consists of four active strain gages as an integral part of a silicon diaphragm. This diaphragm is mounted in a stainless steel housing comparable in size to that of the piezoelectric transducer. The output impedance is 350 ±50 ohms and requires 5 to 10 volts ac or dc excitation.

Applications. Applications of these transducers are undefined for ADTC.

Advantages. The following comments and observations are based primarily on manufacturer specifications:

1. Static response (can be calibrated with a static calibrator).

2. Natural frequency equal to most piezoelectric types (500 kHz).

3. Vibrations and shock specifications are good (0.0001% FS/g).

4. Small and simple to mount.

5. Can be calibrated remotely (electrical calibration).

Disadvantages. Disadvantages are as follows:

1. Frequency response limited (0 to 30 kHz).

2. Subject to baseline shift due to temperature.

3. Require more complex signal conditioning.

4. Relatively high cost ($450).[7]

## TRANSDUCER MOUNTING

ABOVE GROUND SURFACE. If transducers are mounted above the surface, then the support should be rigid so it will not move when the blast wave traverses the measuring point. The transducer mount should be aerodynamically designed to minimize distortion of the blast wave as it passes the transducer. Two types of mounts are available at ADTC for making side-on pressure measurements above ground surface. One is a wedge-shaped mount manufactured by Brown Engineering Company which can be utilized to hold PCB and Kistler gages; the other mount available is that supplied by Susquehanna Instrument Company with the ST-7 transducer and is of a pencil shape (Figure 2). Both type mounts have the transducer flush-mounted in the side; the point of the wedge or pencil faces the munition. Both type mounts have been used at ADTC with equal success. Large errors may occur in the data regardless of the type mount if the point of the wedge or pencil is not normal to the oncoming shock wave. The Susquehanna pencil type mount is manufactured with an ST-2 type transducer "built-in" and has a maximum over-pressure range of 500 psi. Stands for accommodating the transducer/mount can be locally constructed on the Test Area C-80 Complex; several stands are available for positioning the transducer/mount above ground surface (Figure 3). In addition to providing a means for measuring incident (side-on) pressure, these techniques may also be utilized for making TOA measurements.

FLUSH WITH GROUND SURFACE. If transducers are mounted flush with the ground surface, the mount should be large enough to provide a clear flat area at least 6 inches around the transducer and heavy enough to minimize movement during the passage of the shock wave. Approximately 50, 1-foot-square, 2-inch-thick steel plates are available at ADTC to be utilized as mounts for the Kistler, PCB, and Susquehanna transducers required for flush ground mounting (Figure 4). Each mount weighs approximately 80 pounds. These mounts contain nylon inserts which provide mechanical and electrical isolation for the transducer.

[7] ibid

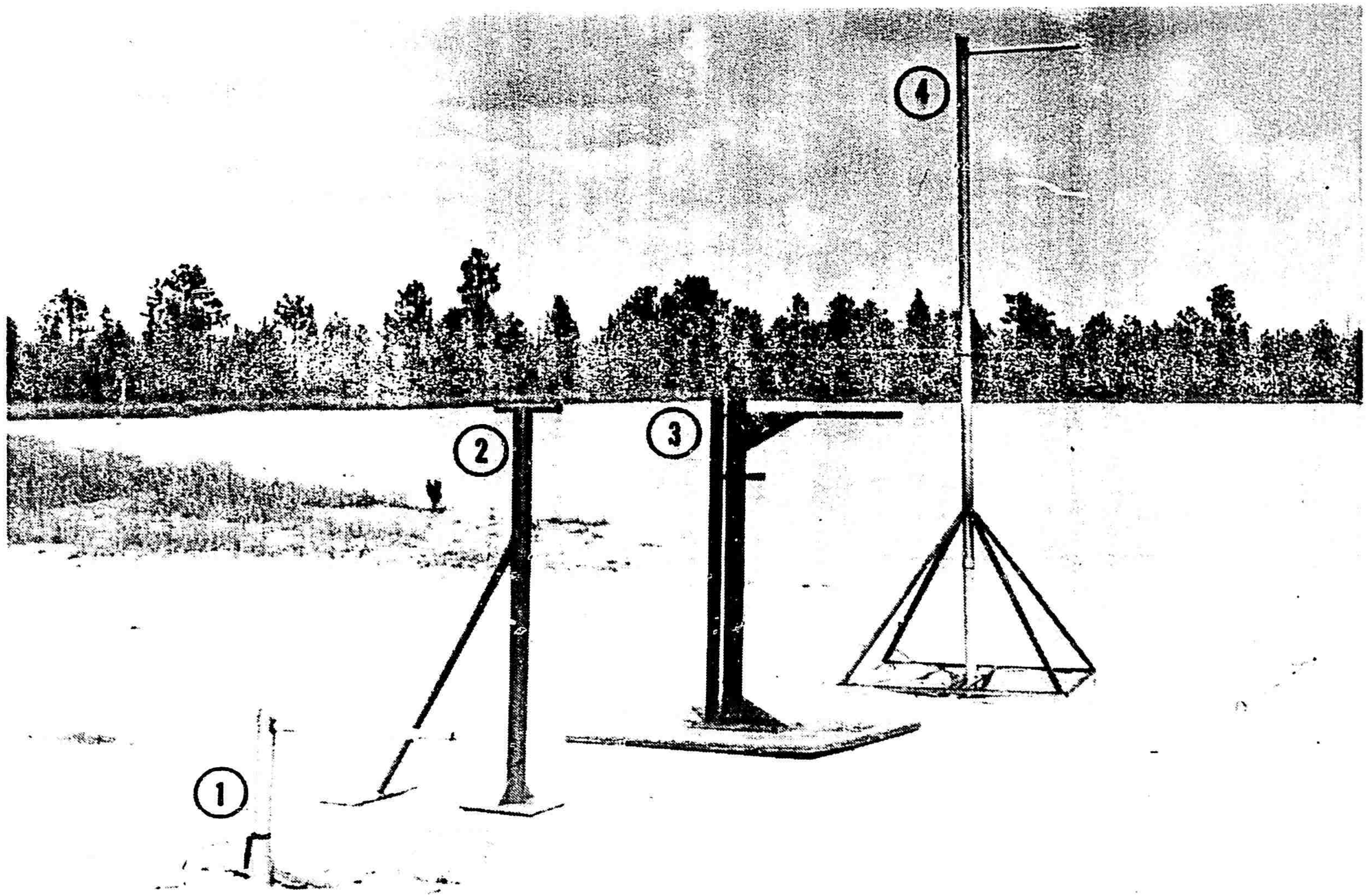



Figure 3. Transducer stands showing: (1) 2-foot stand, (2) T-stand, (3) F-stand, and (4) 12-foot stand

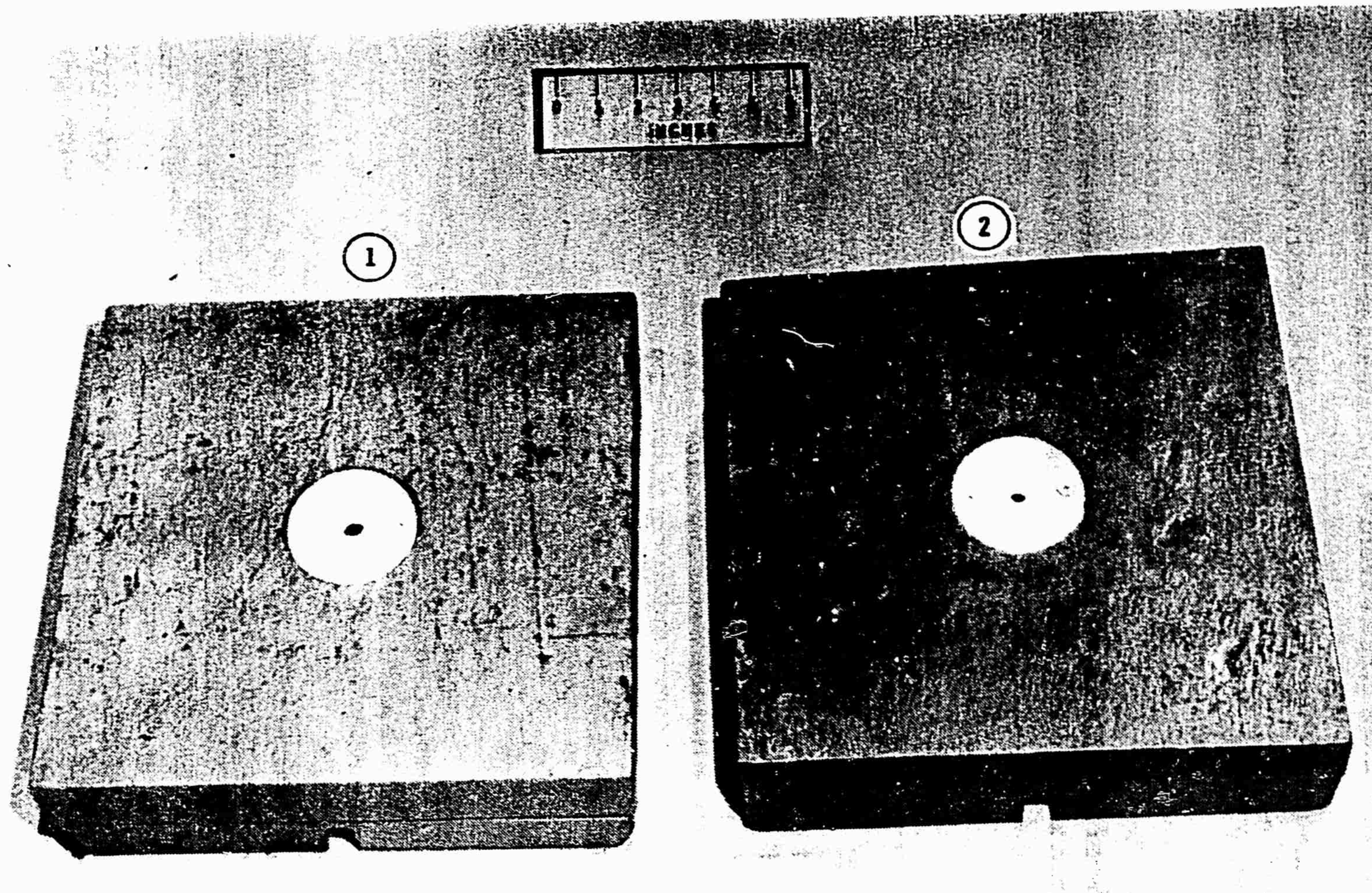



Figure 4. Transducer mounts showing: (1) flush mount for ST-2 or ST-4 transducer, and (2) flush mount for Kistler transducers

## CABLING

The high impedance circuit from a charge signal transducer is subject to noise, as well as to attenuation due to capacitive loading. For this reason, the transducer cable should be kept as short as possible. Insulation resistance must be kept as high as possible both by rigorous attention to cleanliness and connector sealing and by use of low noise cable. The use of an impedance converter at the transducer permits use of a long cable without increasing system noise level. A good coaxial cable such as RG-62 can be used in areas totally protected from shock wave effects; however, special low noise cable is required between the impedance converter and the transducer and also in the immediate vicinity of the transducer where shock disturbance is expected (reference Section VI).

## INSTRUMENTATION SYSTEMS

Currently, ADTC has four instrumentation systems that can be used to collect blast pressure data. One system is portable; the other three are located at Test Areas C-80A, C-80C, and C-64A respectively. The portable system is used to augment the fixed pressure measuring systems and to provide capability for pressure data collection at test areas which have no permanent pressure measuring instrumentation such as Test Areas C-74 and C-64. Following is a description of the various components of the instrumentation equipment (Figures 5 and 6).

### RECORDERS.

Magnetic Tape. Each of the four systems utilizes a magnetic tape recorder to store pressure data. Magnetic tape is ideal for recording transient data such as blast pressure because data can be stored on tape indefinitely. A recorder with frequency modulation (FM) electronics is preferred because the frequency response extends to dc. Voice annotation capability is desirable so mission countdown can be recorded and can provide easy location of the data. Also, a "shuttle" capability is desirable because it automatically runs the tape back and forth through the data allowing the data to be observed repeatedly or digitized channel by channel with very little loss of time. The recorder used with the portable system is a Bell and Howell Model CPR-4010 with 13 channels of 40-kHz IRIG wideband Group 1 FM electronics (record and reproduce). The other three systems use Bell and Howell Model VR-3700B recorders with 13 channels of 80-kHz IRIG wideband Group 1 FM electronics (record and reproduce). Twelve of the channels are for recording pressure data and one is for recording time.

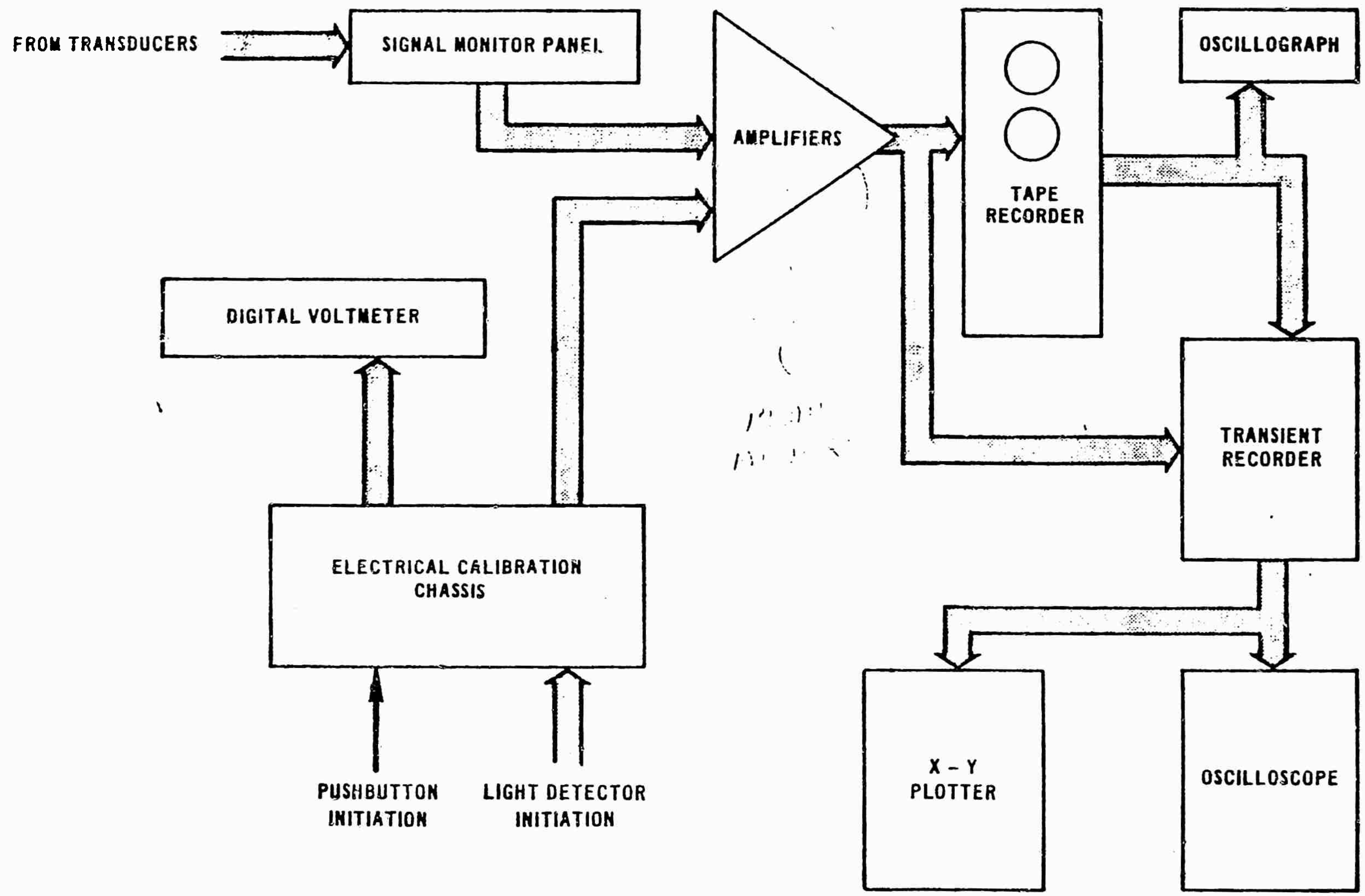



Figure 5. Functional diagram of pressure system

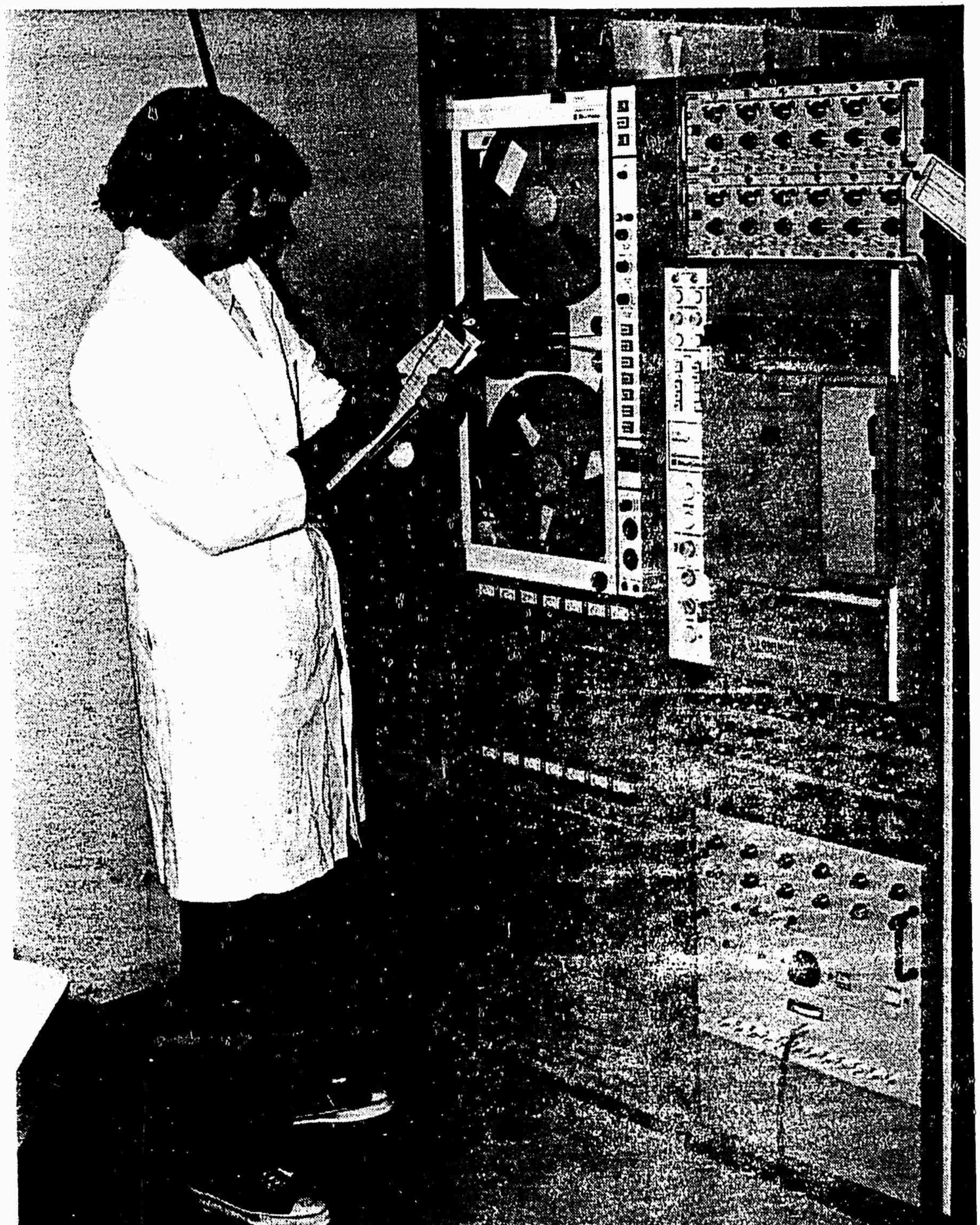


Figure 6. Pressure instrumentation system.

Oscillographs. The fixed instrumentation systems (Test Areas C-80A, C-80C, and C-64A) are equipped with 12-channel recording oscillographs for post-mission quick-look review of pressure data collected on analog magnetic tape. Frequency response of the oscillographs is only 5 kHz, but this is adequate utilizing the time base expansion capability (slow down of recorder) of the magnetic tape recorders. Although 12 signals can be recorded simultaneously on the oscillograph, usually not more than eight are recorded at one time to obtain wider amplitude display.

Oscilloscopes. Oscilloscopes are used with each system and are the only instruments with sufficient frequency response to record the highest frequencies associated with fast rise time pressure pulses. Because of problems with triggering, limited dynamic range, and the number of channels available, oscilloscopes are not normally used as primary data collection means; however, there are cases where the oscilloscope is the only instrument which will serve the purpose.

Transient Recorders. Transient recorders manufactured by Biomation are available with each system. As the name implies, these recorders are used to capture short duration events and to reproduce them when desired. A typical application is to capture the short pressure pulse and reproduce it back to an oscilloscope. A transient recorder effectively makes a storage oscilloscope out of any normal oscilloscope. Using the analog output from the transient recorders, plots of pressure data (in engineering units) may be obtained on X-Y recorders. These recorders are used on-site when determining system sensitivity during Phase II calibration.

X-Y Recorders. One X-Y plotter is available with each of the four instrumentation systems. These recorders are used in conjunction with the transient recorders to accomplish Phase II calibration and also to provide quick-look on-site plots of the pressure data in engineering units.

SIGNAL CONDITIONING.

Amplifiers. Kistler Model 504D amplifier serves as the power source and signal conditioning amplifier for piezoelectric transducers. This amplifier serves as a power source by providing +28 VDC, 8 ±1 milliampere power for the transducer. The unit also serves as an amplifier in that it provides front panel controls for normalizing a wide range of input signals to a 1-volt, full-scale output. Each unit also contains a calibration feature wherein the data channel integrity can be assured by the insertion of a known input voltage to the calibration input connector.

Electrical Calibration Signal. A calibration chassis provides and gates a precision voltage to the calibration input of each amplifier. This precision voltage is gated to the amplifier and onto magnetic tape just prior to collecting pressure data. Gating may be initiated by pushbutton control, remotely by sequencer, or from a light detector or breakwire.

Monitoring of Calibration Signal. A digital voltmeter is used for adjusting and measuring the voltages in the calibration chassis that are to be gated to the calibration input of the amplifiers.

Signal Monitor Panel. A signal monitor panel is utilized for checking the static condition of the cable, connectors, and transducer of each data channel. A reading of the power supply voltage indicates the cable is broken or open, a reading of zero indicates the cable is shorted, and a reading of 11 ±3 volts indicates proper operation of the cable, connections, and transducer.

## FREQUENCY RESPONSE

It is usually desirable to know the frequency response of the system being used to collect blast pressure data. Obviously, frequency response depends on several factors including the transducer response, amount of cable the transducer must drive, signal conditioning equipment response, and recorder response. For practically all cases at ADTC, the frequency response will be limited by the cable length and the signal amplitude. Maximum frequency response of the four ADTC pressure instrumentation systems (including transducer) can be determined from the following relationship:[8]

$$f\ max\ (\text{kHz}) = \frac{0.32\ [\text{Available transducer current (mA)} - 1\ \text{(mA)}]}{\text{Cable capacitance } (\mu F) \times \text{signal amplitude (Vpp)}}$$

The available transducer current for the four ADTC systems is 8 milliamperes. An example is as follows:

Test location - Test Area C-80C
Cable length - 2,000 feet (type RG-62)
Transducer sensitivity - 10 mv/psi
Peak pressure - 500 psi

[8] Piezotron ® Couplers, Kistler Instrument Company, brochure, date code 223-6/173R

Cable capacitance = 2,000 ft X 13 pF/ft
= 26,000 pF = 0.026μF

Vpp = 500 psi X 0.01 V/psi = 5V

$$f\ max = \frac{0.32\ (8-1)}{(0.026)\ (5)} = 17.2\ kHz$$

In addition to being limited by the above relationship, the maximum frequency response of the portable system is 40 kHz (tape recorder) and 80 kHz at C-80A, C-80C, and C-64A.

The frequency response may vary from channel to channel on the same instrumentation system because of transducer type and maximum pressure. If a transducer with 1 mv/psi sensitivity were utilized in the above example, an f (max) of 172 kHz would result. The system frequency response would then be limited by the recorder (either 40 kHz or 80 kHz).

## RECOMMENDATIONS

INSTRUMENTATION SYSTEM. Selection of one of the four instrumentation systems should be based on availability of the system as well as test site requirements. Twelve channels of pressure instrumentation are available on a permanent basis at Test Areas C-80A, C-80C, and C-64A. The portable system has 12 available channels and can be scheduled to augment the capabilities at the fixed locations and provide pressure measuring capabilities at remote locations.

TRANSDUCERS/MOUNTS. Table 2 provides a handy reference guide for transducer/mount selection.

For free-air side-on pressure measurements, either the Susquehanna ST-7 pencil type probe or the Brown Engineering wedge-shaped mounts with Kistler or PCB transducers may be used. The ST-7 probe is more streamlined (has less surface area) than the Brown wedge-shaped probe; therefore, the placement of the point directly facing the oncoming wave front is not as critical (this statement should not be interpreted as meaning it is not important to point the ST-7 directly toward the wave front). As mentioned earlier, the ST-7 uses an ST-2 type transducer and has a maximum range of 500 psi. The Brown wedge-shaped probe may be adapted with either the PCB or Kistler transducer with higher ranging capability. Both the ST-7 pencil type probe or the Brown wedge type probe may be used inside or outside the Mach stem area. The ST-7 probe should always be used in conjunction with an impedance converter. PCB and Kistler transducers have the impedance converter built in.

For pressure measurements flush with ground surface and inside a FAE cloud, either the PCB or Kistler ground isolated transducers mounted in the 1-foot-square, 2-inch-thick steel plates may be used. Either transducer used should have an RTV coating for heat protection. The steel plate is recommended because it is large enough to provide a cleared area around the transducer and heavy enough to minimize movement during passage of the shock wave. Susquehanna transducers are not recommended in this environment because they seem to be more susceptable to heat transients and do not have sufficient range in some cases.

For pressure measurements flush with the ground surface and outside a FAE cloud, the Susquehanna ST-2 transducer mounted in a 1-foot-square, 2-inch-thick plate may be used. Although the Kistler and PCB transducers in the same type mount can be used for this application, the ST-2 is recommended because of its near immunity to vibration and/or ringing. The ST-2 should be used in conjunction with an impedance converter and range capacitor. In addition, the ST-2 should be covered with one layer of electricial tape to delay thermal pulses.

For face-on pressure measurements inside or outside the FAE cloud or other free-air tests, the PCB transducer is suggested. Although it sometimes experiences baseline shift, experience has shown that the PCB transducer appears to be the most reliable for this type of work. Unless the transducer is to be mounted in the existing steel plates, provision must be made for mounting the transducers in the desired target. Under no conditions should cables be left unprotected.

For measurements of fast rise times with emphasis on peak pressure (not impulse and duration), the Susquehanna ST-4 transducer with an impedance converter is recommended. This transducer has a 1.5-MHz natural frequency and is virtually immune to oscillation; however, it is highly sensitive to other forms of energy such as thermal radiation. Several of the 1-foot-square, 2-inch-thick steel plates are available for mounting the ST-4 gage.

Table 2. Transducer selection chart

| Measurement | PCB series-100 | Kistler 202 | Susquehanna ST-2 | Susquehanna ST-4 | Susquehanna ST-7 | Kulite XTS-190 | Kulite HKS-375 | Mount |
|---|---|---|---|---|---|---|---|---|
| Face-on inside FAE cloud | X | | | | | [a] | [a] | 2- by 12-inch steel plate |
| Face-on outside FAE cloud | X | X | | X | | [a] | [a] | 2- by 12-inch steel plate |
| Side-on inside FAE cloud | X | | | | | [a] | [a] | 2- by 12-inch steel plate |
| Side-on outside FAE cloud | X | X | X | | | [a] | [a] | 2- by 12-inch steel plate |
| Free air (side-on) | X | X | | | X | [a] | [a] | Aerodynamic probe |
| Mach stem (side-on) | | | | | X | [a] | [a] | Aerodynamic probe |
| TOA | X | X | X | X | X | X | X | As appropriate depending on region |
| Shock wave velocity | X | X | X | X | X | X | X | Used in pairs |

[a] Applicability in these situations not yet determined for ADTC use.

## SECTION IV

## CALIBRATION

### GENERAL

The most important item to be considered after the selection of the instrumentation system is its calibration. This calibration should include a minimum of two phases. Phase I is the calibration of the transducer under laboratory conditions and Phase II is the field calibration of the entire instrumentation system. Explosive charge calibration is sometimes required to establish baseline reference data. Phase I and Phase II calibration is traceable to the National Bureau of Standards through the output monitoring equipment.

### PHASE I CALIBRATION

#### EQUIPMENT.

Pneumatic Pulse Calibration (Figure 7). The pneumatic pulse calibrator consist of a buffer tank which is filled with nitrogen from a high pressure source, a precision (0.1%) high pressure (0 to 300 psi) gage, a fast acting electric air valve, and a transducer mount. The transducer to be calibrated is mounted and the buffer tank is filled with nitrogen to the desired pressure. The valve is operated producing a pressure pulse with a rise time of about 5 milliseconds.

Ball Drop Calibrator. The ball drop calibrator consists of an oil-filled transducer mount, piston, and a drop tube. A small ball is dropped down the drop tube onto the piston producing a pressure pulse up to 20, 000 psi with rise times between 1 and 4 milliseconds. The output of the test transducer is compared with the output of a standard transducer; accuracy of the ball drop calibrator is approximately ±1%.

Dead Weight Tester. The dead weight tester consists of a set of precision weights and a hydraulic pump, which is used to produce a known static pressure for calibration. A dynamic pressure pulse can be generated by suddenly releasing the weights. The dead weight tester has a range of 0 to 5000 psi.

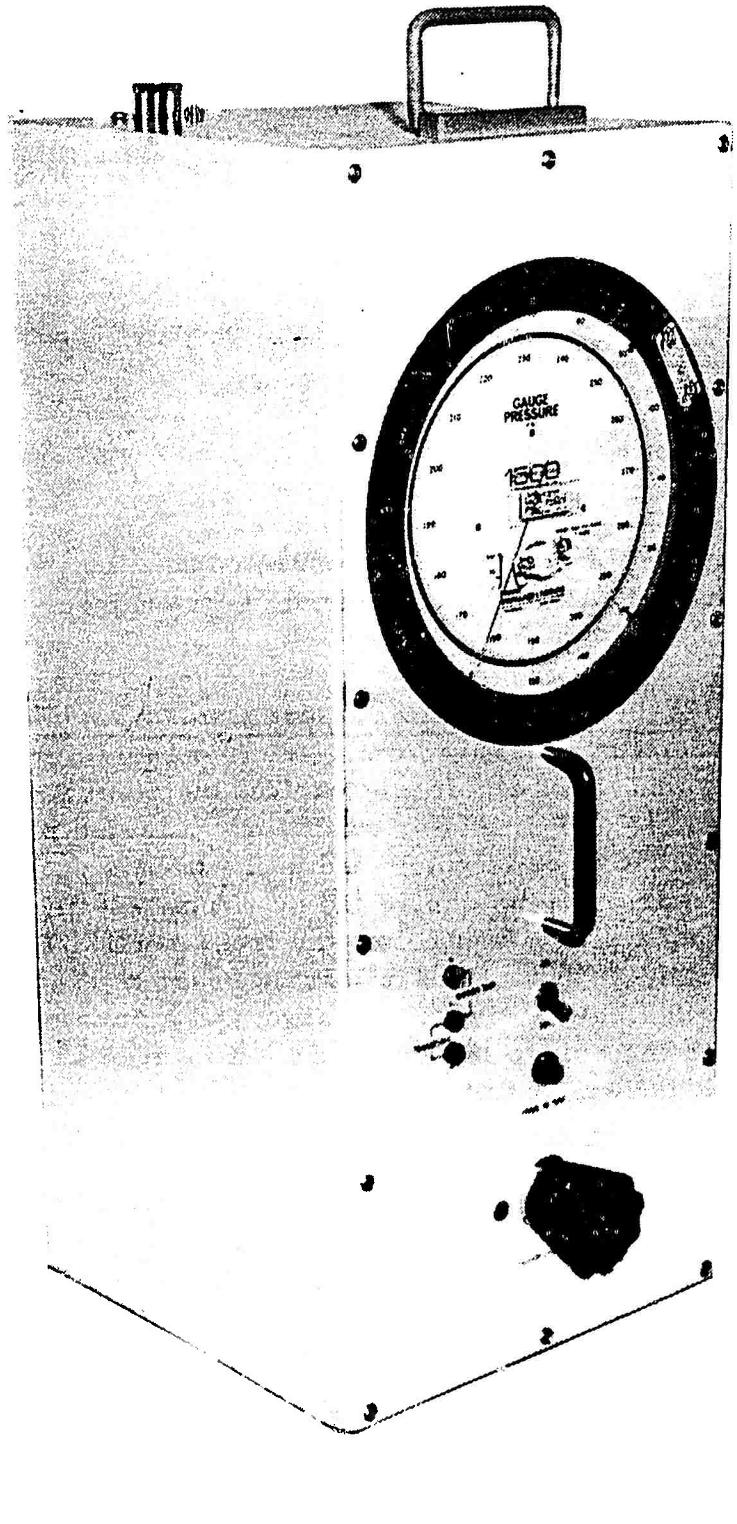


Figure 7. Pneumatic pulse calibrator used during transducer calibration

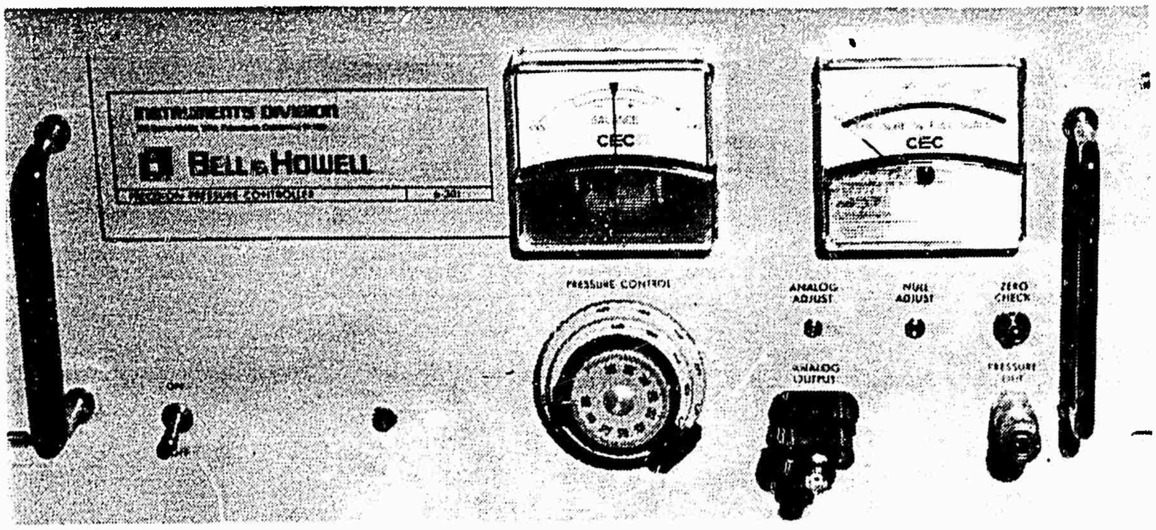


Figure 8. Precision pressure controller used during Phase I calibration to determine transducer sensitivity

Type 6-301-001 Precision Pressure Controller (Figure 8). The 6-301-001 precision pressure controller is manufactured by Bell and Howell, Inc., and is an electromechanical instrument designed to automatically regulate and precisely maintain a selected pneumatic pressure. After a pressure source is connected to the precision pressure controller, an output pressure may be controlled by simply dialing in the desired pressure, using a single control on the front panel. The output will be maintained within 0.05% of the full-scale pressure range of the controller. The unit provides both a visual indication and an analog output voltage proportional to the controlled pressure. It is used as a secondary standard for convenient calibration of pressure transducers.

High Pressure Hand Pump (Figure 9). The OH-101 hand pump is manufactured by Pressure Products Industries and is capable of developing an operating pressure of 150,000 psi. It is equipped with a 0 to 100,000 psi Astragage pressure gage, a 0 to 100,000 psi Astraducer strain gage pressure transducer, and a quick-release valve. This equipment is used to provide static high-pressure calibration with an accuracy of 0.25%.

Two-Inch Shock Tube (Figure 10). The 2-inch shock tube consists of a 12-inch-long driver section and a 6-foot-long test section. Bottled helium or nitrogen is used as driver gas. This causes preselected diaphragms between the driver and test sections to break and create the shock waves. The test transducers can be mounted either on the side of the tube for side-on pressure or on the end of the tube for face-on measurements. The shock tube is used primarily to excite resonance frequencies of the transducer and to record the output of the transducer when subjected to fast rise time pulses.

Model 292 Sinusoidal Pressure Generator. The Model 292 pressure calibrator is manufactured by Kistler Instruments, Inc. and consists of a piston and mass assembly which is filled with a light oil. The calibrator is vibrated on a standard vibration table to produce a sinusoidal pressure of 24 psi/G at 300 Hz. At frequencies above 300 Hz the spring rate of the oil-filled cavity becomes significant. Sensitivity rolls off with increasing frequency to about 2 psi/G at 1,000 Hz. The system is intended for calibrating pressure transducers that have time constants too short for static calibration and for investigating dynamic response of statically calibrated instruments.

Flash Temperature Generator. The flash temperature generator consists of a dc motor, temperature shield, small propane torch, and a transducer mount. The transducer is mounted near the temperature source with the temperature shield between. The temperature shield contains a hole and, as the shield is rotated, the transducer is subject to a high temperature pulse as the hole lines up with the torch and the transducer. The duration and intensity can be adjusted by various combinations of torch temperature and motor rpm.

Type SM-105 Shock Test Machine, AVCO. The SM-105 shock test machine is composed of six major assemblies: (1) a base, (2) pneumatic cylinder, (3) brake, (4) carriage, (5) control panel, and (6) plate assembly. This shock machine does not depend upon gravity to obtain the desired terminal velocity; the changeover from one shock pulse level to another can be rapidly accomplished by a simple adjustment of an air pressure regulator rather than by changing the drop height as is necessary with a free-fall machine. This machine can produce shock pulses up to 10,000 Gs.

ADI - Electrodyne, Inc. Vibration System. The ADI - Electrodyne vibration system consists of a shaker head assembly, power amplifier, and a manually controlled oscillator. The vibration has a useful range of 0 to 70 Gs at frequencies from 1.5 to 10,000 Hz. The system is used to determine the vibration sensitivity of pressure transducers.

Unholtz-Dickie Vibration System. The Unholtz-Dickie vibration system consists of a shaker head assembly, power amplifier, and a control console. It has the capability of vibration levels up to 100 Gs with a frequency response of 2 to 500 kHz.

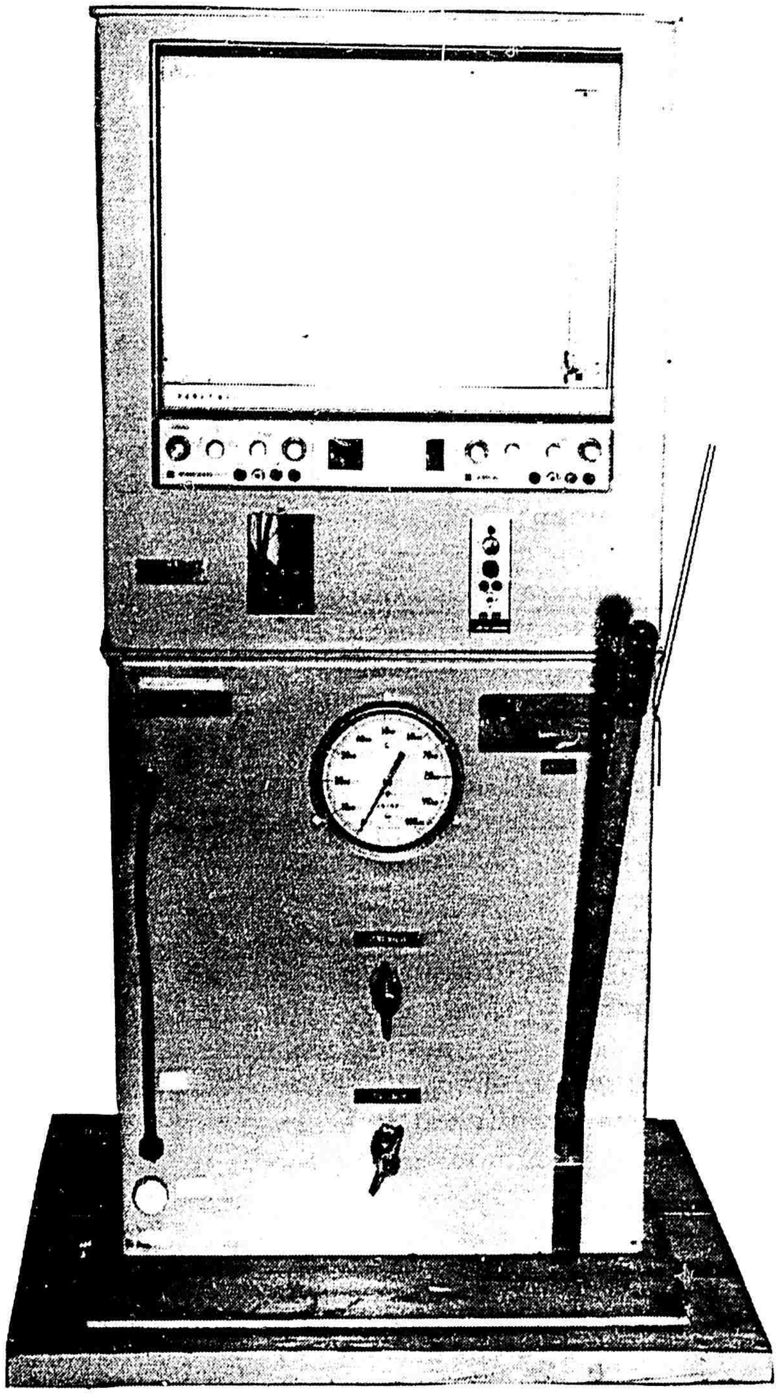


Figure 9. High-pressure hand pump used during Phase I calibration to provide static high pressures ( 0 to 100,000 psi)

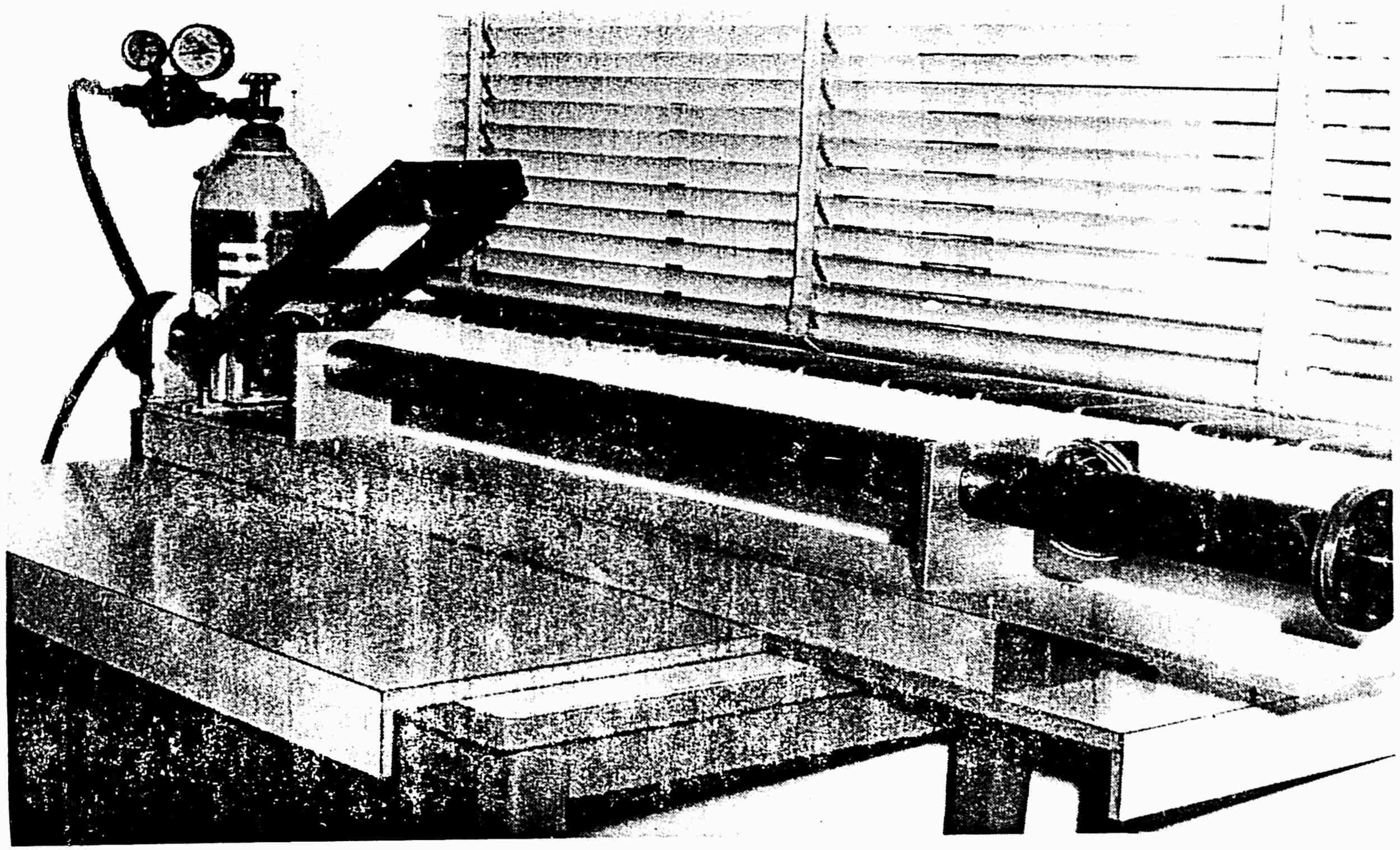


Figure 10. Two-inch shock tube used during Phase I calibration to determine transducer rise time and resonant frequency

Transducer Output Monitoring Equipment. The equipment used to monitor the transducer output during calibration consists of an oscilloscope, peak holding meter, digital voltmeter, transient recorder, and X-Y plotter

CALIBRATION/EVALUATION TECHNIQUES.

Sensitivity. The sensitivity of the transducer is determined by the use of either a pulse calibrator or ball drop calibrator. This sensitivity is compared to the factory calibration. Any transducer whose sensitivity differs as much as 5% from the factory calibration is rejected.

Hysteresis. The hysteresis of a transducer is determined by use of a dead weight tester to apply increasing and decreasing pressure. The output of the test transducer is plotted versus the output of a standard transducer. The hysteresis is then compared to the factory specifications.

Linearity. The linearity of the transducer is measured by applying variable pressure using a dead weight tester or pulse calibrator. The output linearity is compared to the factory specifications.

Frequency Response/Resonance Frequency. The frequency response and resonance frequency are determined by electrical excitations and shock tube analysis. The results are compared to the factory specifications.

Time Constant. The time constant of the transducer is measured using a pulse calibrator to produce a step pressure change and the decay of the peak output is observed on an oscilloscope.

Vibration/Shock Sensitivity. The vibration/shock sensitivity is determined by vibration and shock testing the transducer and recording the transducer output. The vibration and shock levels are monitored by an accelerometer mounted with the pressure transducer.

Flash Temperature Sensitivity. The sensitivity of the transducer to flash temperature is measured using a high temperature source and a fast moving temperature shield which allows the transducer to be subjected to a high-temperature short-duration pulse.

DOCUMENTATION/SCHEDULE. All the measured data are recorded and a history of the transducer usage is maintained, thus creating a "diary" on each transducer. Re-evaluation of transducers is accomplished after each test series or when the transducer has been subjected to extreme environments (heat, shock, or over pressure). Transducers are maintained in the Phase I laboratory facility until needed for a test project. In the event that more than 12 months have elapsed since the last calibration, the transducer is rechecked prior to use.

## PHASE II CALIBRATION

### EQUIPMENT.

Pneumatic Pulse Calibrator. A portable pneumatic pulse calibrator is utilized to apply pressure to each field-mounted transducer. Operational characteristics of this unit are the same as those of the unit used in Phase I calibration.

Output Monitoring Equipment. The equipment used to monitor the transducer output during calibration consists of a transient recorder, an oscilloscope, a peak holding meter, and an X-Y plotter.

TECHNIQUE. The transducer is installed in its field mount and connected by signal cable to the recording system. Where appropriate adaptors are not available between the pulse calibrator and the transducer mount, the transducer must be removed from the field mount. The predicted forcing function is then applied (pulse calibrator). Piezoelectric transducers do not have dc frequency response and require the use of a pulse calibrator to produce the predicted peak pressure function. Each transducer is subjected to the 100% forcing function (where possible) and the resultant output signal from the signal conditioning amplifiers (Kistler Model 504D amplifiers) is measured and observed. At this point, an electrical calibration level equal to the 100% forcing function is established. Calibration of the magnetic tape recorder is accomplished independently. The electrical calibration step is recorded on magnetic tape prior to each shot within seconds of the actual data acquisition. It may be recorded again at the time of item detonation. This technique serves as a check of the overall system gain change between field calibration time and event time. In addition, this electrical calibration signal is utilized during the data reduction process.

SCHEDULE. Scheduling is discussed in Section VI.

## EXPLOSIVE CHARGE CALIBRATION

TECHNIQUE. Explosive charge calibration may be performed to check for anomalies in the instrumentation system or field setup by using standardized conventional explosive charges such as pentolite spheres. This technique is extremely useful in establishing baseline reference data but is not usually practical for large FAE tests due to the size and scope of such an exercise. To produce representative blast pressures at all transducer locations, either a single very large charge or multiple smaller charges must be detonated in the test arena. Charges large enough to produce representative pressures at each transducer location are likely to cause damage to the arena surface and possibly to the transducers themselves.

SCHEDULE. Explosive charge calibration is recommended when the blast pressure data to be collected from a certain test item are to be compared with the pressure data collected from another test item. For examp[illegible]tolite spheres could be utilized to establish baseline data when comparing overpressures produced from TNT versus H-6. Also, it is obviously advisable to perform charge calibration when the test item pressure data are to be compared against the same or similar test item pressure data collected by another agency, particularly if the other agency performed charge calibration.

## SECTION V

## TEST DESIGN

### GENERAL

The purpose of this section is to describe recommended standardized test designs for several common explosive munitions tests (free airblast, surface airblast, and FAE tests). Contained in this section are descriptions of recommended test area configuration, data requirements, instrumentation, test hardware, and instrumentation calibration. These test designs were developed to take advantage of facilities, hardware, and instrumentation available, as of this writing, at ADTC. Also considered in the designs were compatibility with accepted standards and procedures used by other DOD and contractor agencies involved in similar testing.

Although each category of explosive blast test has certain unique features, each test design configuration should provide for the following:

1. Uniform surface conditions for repeatability
    a. Flat
    b. Level
    c. Hard-packed
    d. Cleaned.
2. Rigid transducer mounts
3. No obstructions to perturb the blast wave
4. Flexibility to meet varying test requirements
5. Clear field of view for photographic coverage
6. Provisions for photographic reference markers
7. Electrical power available for instrumentation.

FAE TESTS - STATIC/SLED

OBJECTIVE. To collect blast pressure data inside and outside the detonating FAE cloud.

PARAMETERS TO BE MEASURED (PRIMARY DATA). These parameters are as follows:

1. Time of shock arrival at each transducer (in milliseconds) referenced to the initiation time of the cloud detonators.

2. Pressure versus time history of blast shock wave (side-on or face on). From the pressure time histories, the following may be extracted:

a. Peak pressure (psi)

b. Maximum pressure in psi (see discussion on peak pressure)

c. Shock wave velocity (fps)

d. Positive phase duration (msec)

e. Positive phase impulse (psi/msec)

f. Dynamic pressure (psi).

3. Overhead and orthogonal side view (profile), high speed photographic coverage is indespensable in interpreting pressure data gathered inside the FAE cloud.

GENERAL INFORMATION REQUIREMENTS. The following are required for reporting, test design, and data interpretation:

1. Test item technical data (to be provided by the test requester):

a. A general and functional description of the test item, fuel, cloud detonators, subsystems and explosive components in accordance with AFATL Reg. 136-1 (Ref Section II).

b. Fuel weight (lb), actual and equivalent (TNT)

c. Types, weights, and fill densities of explosive

d. Desired time delay from canister burst to cloud detonator function

e. Height of burst (HOB) or standoff distance from arena surface (ft AGL)

f. Location of cloud detonators.

2. Meteorological data (taken at time and location of test if possible):

a. Barometric pressure (in. Hg)

b. Ambient temperature (°F)

c. Relative humidity (%)

d. Wind speed and direction (mph, degrees)

e. General observations (cloud ceiling, inversions, etc.).

3. Soil characteristics (optional data):

a. Blast reflection coefficient

b. Moisture content

c. Soil composition

d. Penetrometer readings.

4. Description of test arena including transducer locations/types, camera locations/types, reference markers, target locations (if used), and location and size of any above-ground obstructions large enough to perturb the blast wave or fuel dissemination (provided by test engineer and verified by the Range Control Officer after test).

5. Block diagram or schematic of pressure instrumentation systems(s) (Figure 5) (to be provided by the Range Control Officer). Equipment specifications (model, frequency response, etc.) must be included.

TEST ARENA DESIGN. The general guidelines outlined above apply. In addition, the following apply to static and sled tests:

1. Static Tests. To minimize interference with the fuel dissemination or the shock wave resulting from a FAE, tests should be conducted on a cleared, level, flat area with a hard-packed soil or concrete surface large enough to hold all required instrumentation. Figure 11 shows an arena design suggested for use on FAE static tests. The arena was designed for use with 80-pound-class items; however, it may be readily expanded for larger items or reduced for smaller items. A grid pattern of concentric circles spaced at regular intervals (10 or 20 feet) is helpful in analyzing overhead photographic records of cloud growth. White lime has proven to be a suitable grid marking material for use on clay surface areas.

2. Sled Tests. Sled tests of FAE items are conducted to evaluate the performance of various burster/fuel/detonator configurations under dynamic conditions at high speeds and low impact angles. The rocket sled track at ADTC Test Area C-74 is configured to support FAE tests of this nature. At the south end of the 2,000 foot dual rail track is an earth target mound with an inclined surface (Figure 12). Test items are accelerated down the track to operational velocities (typically 800 to 1,000 feet fps) and separated from the sled at the end of the track. Test items in free flight after release are functioned against the inclined target surface (airburst or impact). The impact surface of the mound is inclined 35° to the horizontal. Its dimensions on the face are approximately 100 foot wide by 80 feet long. A rectangular grid array as shown in Figure 13 provides a useful visual reference for reducing cloud growth data from overhead photography. Although the target surface is flat, relatively hard packed, and free of obstructions, reflections of the blast pressure wave off the sled track/diverter structures can be expected. These reflections must be considered in interpretation of pressure-time histories collected during sled track tests.

HARDWARE SELECTION. A pressure-time history should be obtained at selected locations inside the detonating FAE cloud, and outside the predicted cloud area. Pressure data taken within the detonating fuel air cloud are subject to several uncontrollable variables which make such data extremely difficult to interpret. The uncertainty of the direction of propagation of the detonation wave is probably the most serious parameter affecting the validity of the data. Pressure transducers positioned within the detonating aerosol give data which are difficult to interpret because of the complex nature of the detonation process and because the direction of propagation is unpredictable. Since all pressure transducers are directionally limited, the most widely accepted technique for measuring blast pressure inside the FAE cloud has been to place the transducer face flush with the test arena surface. High speed photographic coverage is usually necessary to interpret the pressures recorded. Other factors which have been found to degrade data quality are:

1. Thermal Effects (pyroelectric). Since the transducers are subjected to a large thermal pulse inside the detonating cloud, the surface of most transducers must be protected (insulated) by a suitable thermal barrier. Black electrical tape on Susquehanna transducers, RTV coatings on Kistler and PCB transducers, and a silicone barrier for Kulite strain strain gage transducers have produced satisfactory results under most test conditions.

2. Particle Impingement. Particle impingement on the transducer face is an ever-present source of unrecognizable data anomalies, especially inside the detonating FAE cloud where debris may be carried along with the detonation wave. Where practical, a stabilized, clean arena surface, (such as a level, concrete pad) is highly desirable.

3. Multiple Reflections. Reflections usually occur behind the detonation wave and may complicate data interpretation.

4. Mach Stem. If a fuel air explosive detonates while in contact with the ground a Mach stem may not form. If all or part of the mixture is not in contact with the ground at the time of detonation, a Mach stem will form and care must be exercised when interpreting the data.

Transducers. Several brands and models of piezoelectric pressure transducers are availabe at ADTC for blast pressure testing (Ref Section III and Table II). The following are recommended for the situation indicated:

1. Inside the predicted cloud area - 0 to 5,000 psi PCB Model 102M24

2. Outside the predicted cloud boundary (predicted pressure 1 to 500) 0 to 500 psi PCB Model 102M25 or 0 to 500 psi Susquehanna ST-2 or 0 to 500 psi Kistler Model 202A2 (flush-mounted at ground level).

3. Blast wave velocity data outside the cloud area - 0 to 500 psi PCB Model 102M25, or 0 to 500 psi Susquehanna ST-2, 0 to 500 psi Kistler Model 202A2, or 0 to 500 psi PCB Model 102M25 (flush mount, two

required; apart, in line, one behind the other along a radial line originating at ground zero). (Note: These setups also produce pressure-time histories. If pressure-time relationships are not important, any TOA transducer will suffice.)

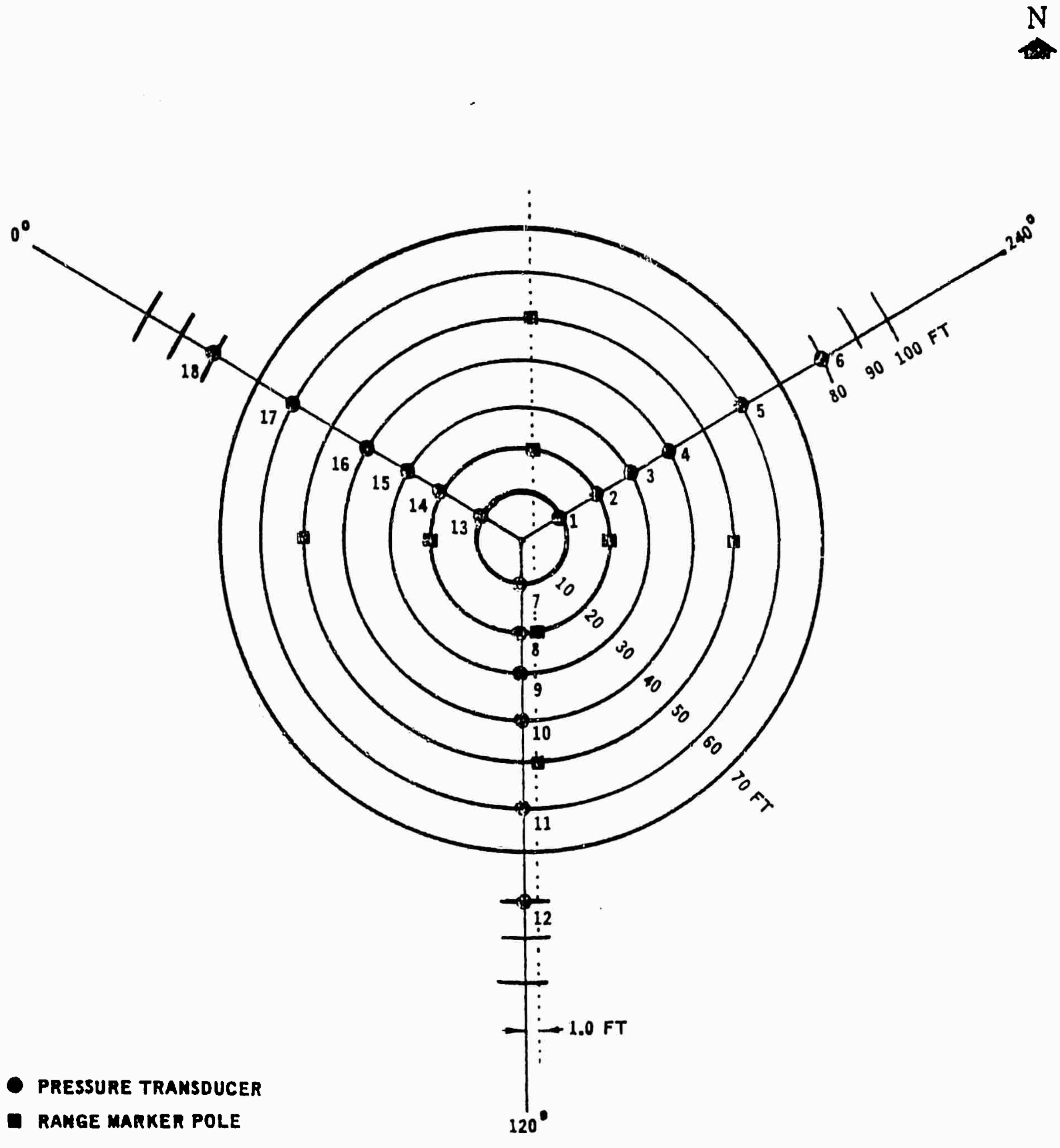



Figure 11. Typical FAE arena configuration

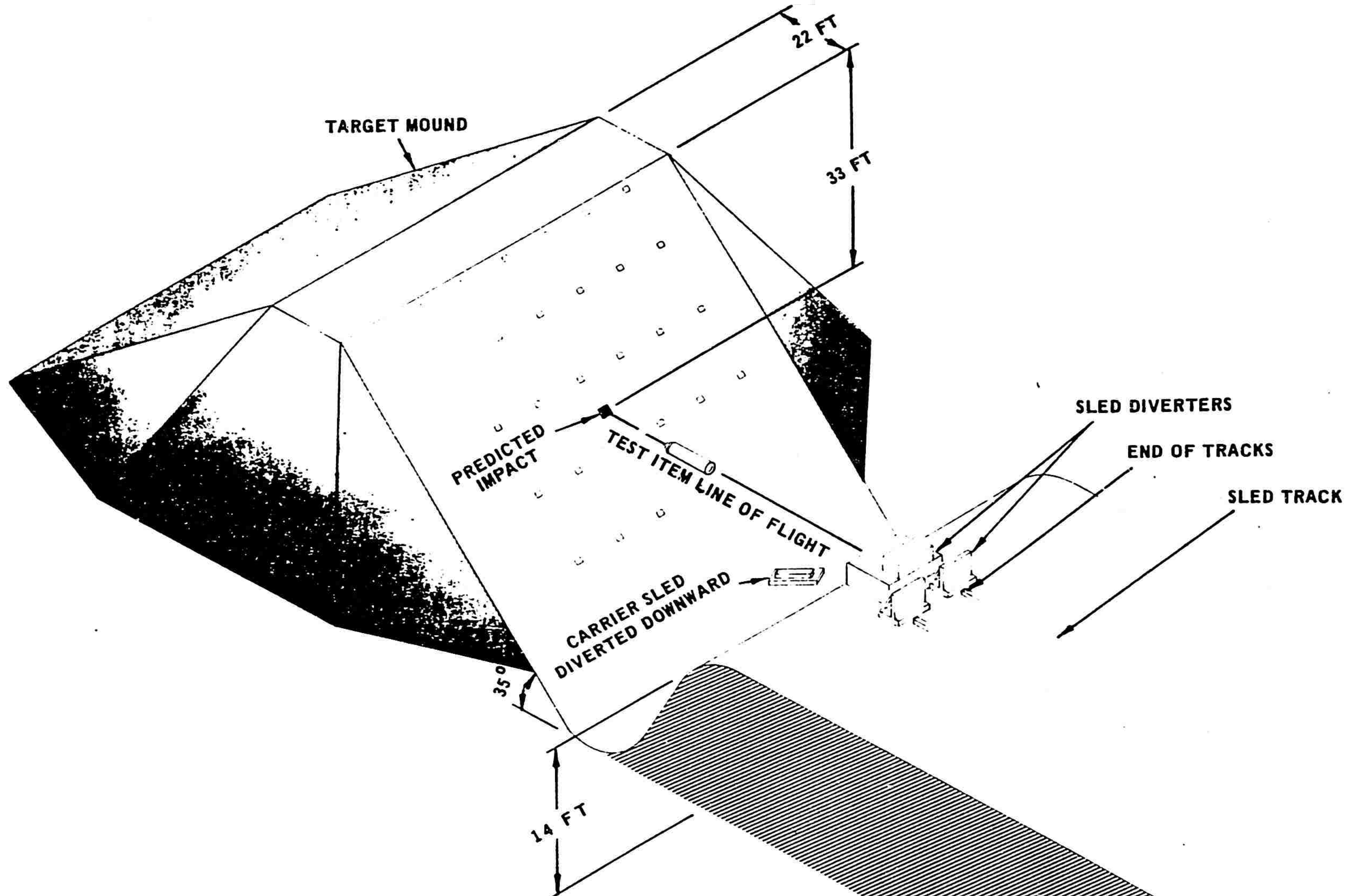



Figure 12. Sled test target instrumentation array

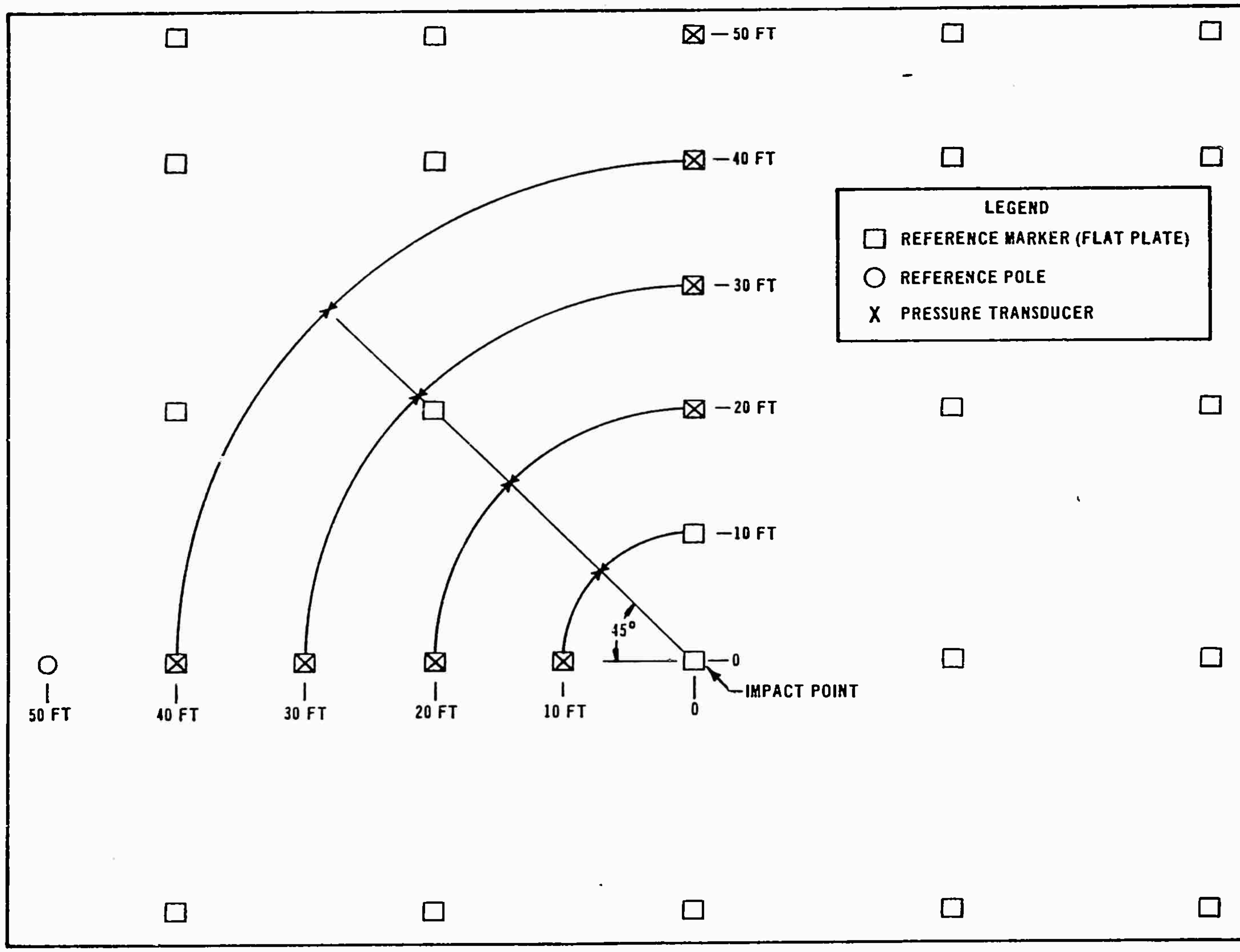



Figure 13. Rectangular reference grid and transducer array used for sled tests

Targets. Due to the complexity of instrumenting targets, each situation must be evaluated separately with guidance from the test requester; however, the techniques/guidelines described below have been shown capable of producing good quality data. When targets are located in areas where an air shock is well defined and its direction known, the loading may be estimated using the target description and the side-on pressure-time history of the shock wave. In this region, it is recommended two transducers be mounted flush with the ground beside the target. The transducers should be spaced 3 feet apart in line with the direction of shock travel. They should be approximately the same distance from ground zero as the exposed surface of the target, and far enough from the target to prevent reflection errors. This arrangement will provide redundant pressure-time histories, and shock wave velocity at the target. If targets are located inside a FAE cloud, it is recommended three or more flush gages be located around the target. Predicting the direction of travel of the detonation wave is difficult in this environment. Because of this and the unhomogeneity of cloud structures, redundant flush-mounted transducers provide a larger sample which may be averaged to provide representative pressure in the vicinity of the target. In the area of a FAE cloud-air interface, loadings on the targets are also complex. In the region between the cloud's edge, and some distance outside the cloud where gaseous byproducts are still expanding, a target does not see a pure air shock or a pure detonation wave. Here, the direction of shock and byproduct travel can be estimated assuming a cylindrical cloud shape. In this region, it would be desirable to measure side-on and face-on pressure-time histories. The side-on transducer should be flush-mounted beside the target. The face-on transducer would require a large plate of sufficient mass and rigidity to prevent acceleration errors induced. The transducer should be placed in the center of the plate flush with the plate surface. The plate must be large enough to allow the transducer to record the positive phase of the pressure-time history before a relief wave can travel from the edge of this plate to the transducer face. Orient the transducer face normal to the expected direction of shock arrival. Extreme care must be taken to protect cables in this kind of mount.

Mounts and Stands. Generally, the type of transducer mount will be determined by the type transducer and location required. The following are recommended based on hardware available at this time:

1. Inside the predicted cloud boundary - steel plate, flush-mounted at ground level (Figure 14).

2. Outside the predicted cloud boundary - steel plate, flush-mounted at ground level.

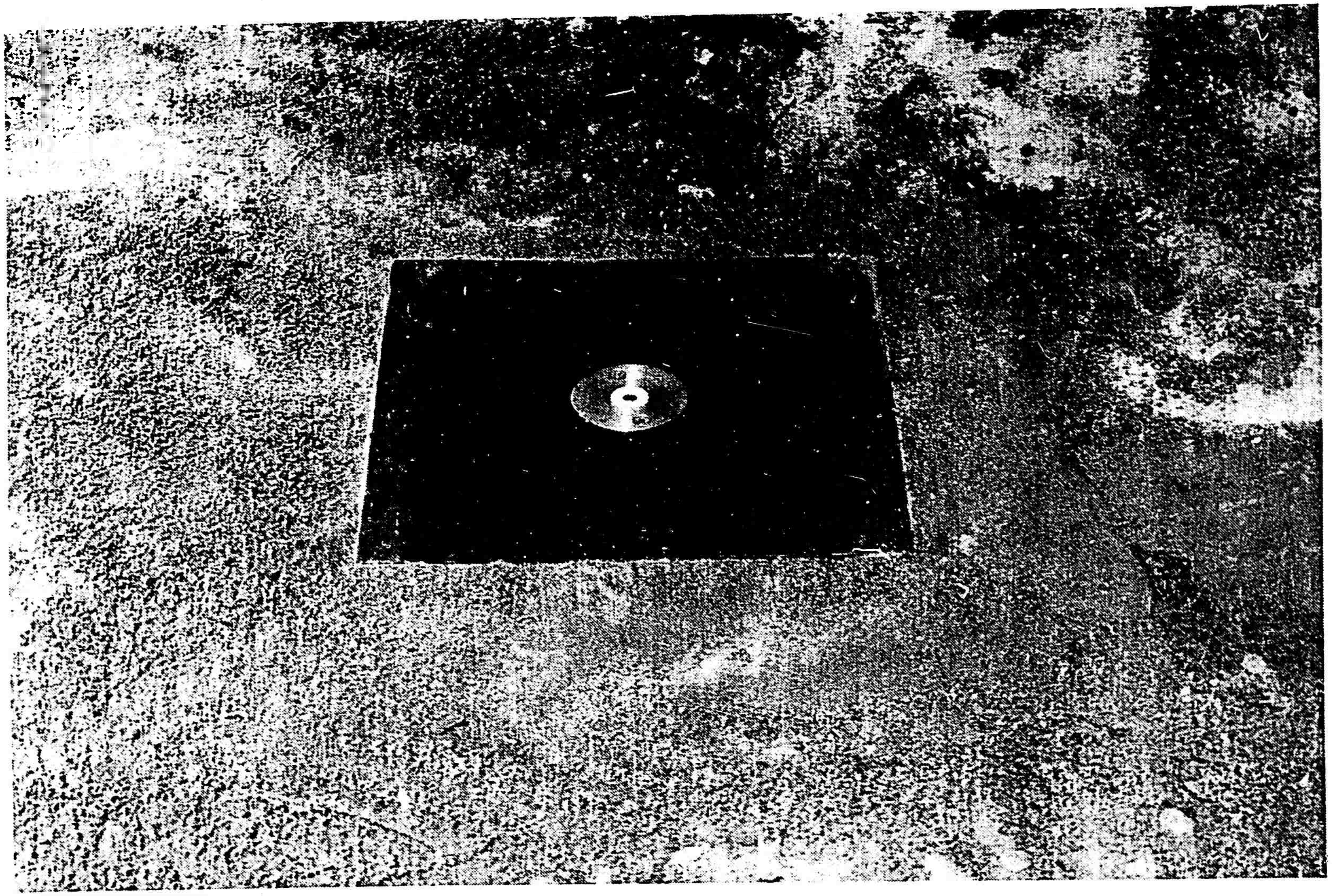


Figure 14. Steel plate transducer mount (installed)

3. Blast wave velocity data - steel plate, flush-mounted at ground level (if terrain is irregular, a probe or axhead mount must be used).

4. Targets - No "standard" mounts available. Mounts must be selected for each situation (see discussion under transducers).

Cabling. The guidelines for specific situations are outlined in Section VI.

Cameras (Static Tests). Figure 15 shows a suggested camera array and setup specifications. The 16 mm cameras are preferred over 35 mm cameras because of the range of camera speeds available and the availability of viewing facilities (projectors and film readers). A 1,000-Hz time code is required for all data film (IRIG A format preferred) to correlate event times with pressure data. Color film should be used in all cameras.

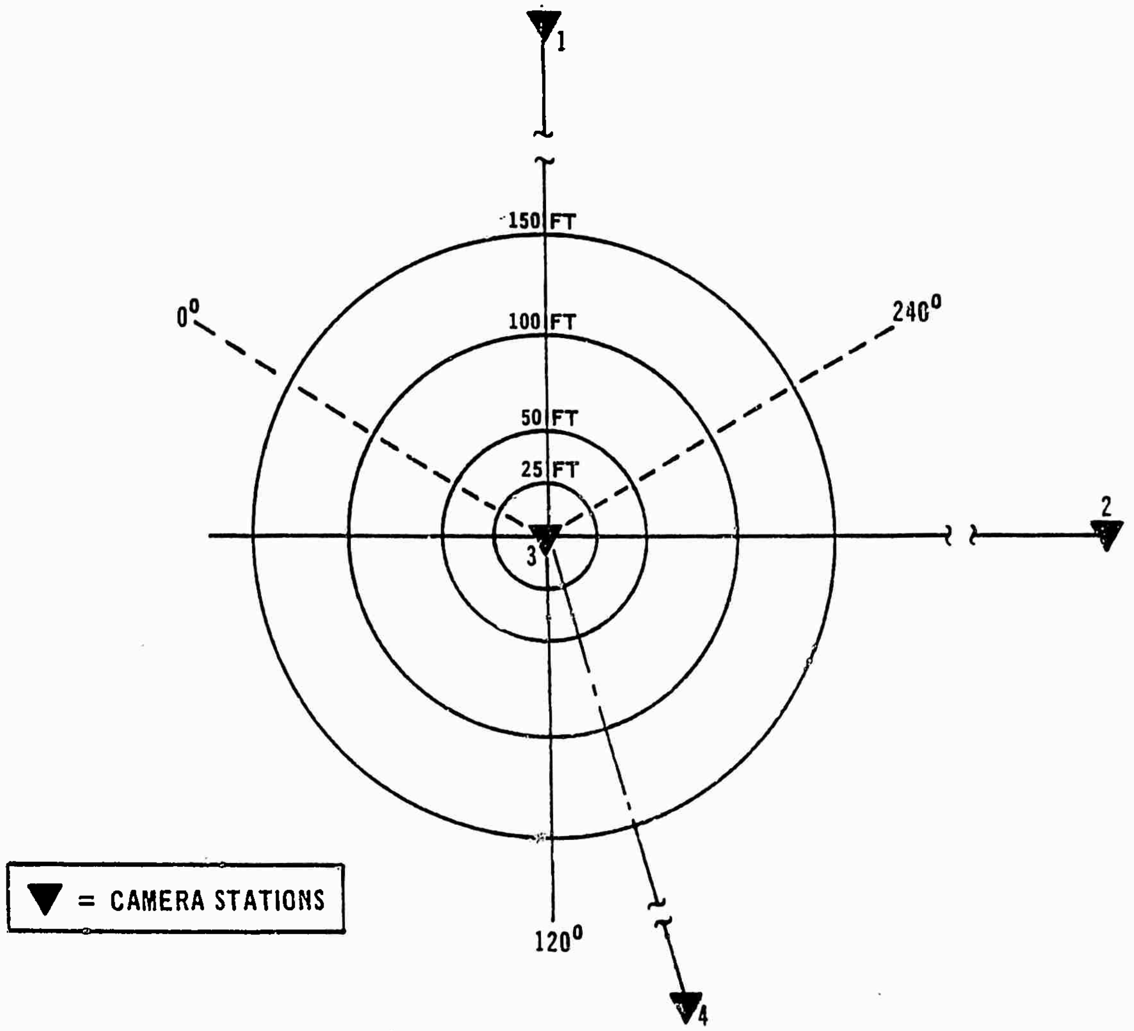
Cameras (Sled Tests). A suggested camera array is shown in Figure 16. For data cameras, use 16 mm cameras with color film. A 1,000-Hz time code (IRIG A format) is required.

Instrumentation Calibration. Procedures are as follows:

1. The entire blast pressure measuring system should be calibrated using Phase II procedures detailed in Section VI before each test shot where time and resources allow. If several test shots are to be conducted daily and the magnitude of the pressure is low (not expected to damage the transducer), then one Phase II calibration before the first shot of the day may be sufficient. Transducers should be thoroughly evaluated at the transducer evaluation laboratory (Phase I calibration) as specified in Section IV prior to commencing a test series. Also, any time a transducer is suspected of malfunctioning it should be subjected to a Phase I calibration/inspection.

2. Standardized conventional explosive charges such as pentolite spheres may be used to establish baseline reference data; however, this technique is not usually practical for large FAE tests due to the size and scope of such an exercise. To produce representative blast pressures at all transducer locations, either a single very large charge or multiple smaller charges must be detonated in the test area. Charges large enough to produce representative pressure at each transducer location are likely to cause some damage to the arena surface and possibly to the transducers

themselves; therefore, it is not advisable to use this as a technique for calibration prior to each test shot. Recalibration (Phase II type) of each transducer would be necessary after each firing of large reference charges.




| CAMERA STATION | CAMERA | DISTANCE GROUND ZERO (FT) | FRAME RATE (FPS) | REMARKS |
|---|---|---|---|---|
| 1 | A | AT LEAST 300 | 2–5000 | FOV~100 TO 200 FT DEPENDING ON PREDICTED CLOUD SIZE |
| | B | ↓ | ↓ | FOV~25 FT |
| 2 | A | ↓ | ↓ | FOV~100 TO 200 FT DEPENDING ON PREDICTED CLOUD SIZE (1/4 FRAME CAMERA) |
| | B | ↓ | 40,000 | |
| 3 | | OVERHEAD ~70 | 4,000 OR 40,000 | FOV~50 FT FRAME RATE DEPENDS ON DATA APPLICATION (1/4 FRAME CAMERA, 40,000 FRAMES PER SEC UNDEREXPOSE 2 TO 3 1/2 STOPS) |
| 4 | | AT LEAST 300 | 24–200 | FOV~100 TO 200 FT DEPENDING ON PREDICTED CLOUD SIZE |

Figure 15. Camera coverage for FAE static tests

| CAMERA NO. | FIELD OF VIEW (FT) | FRAMES PER SEC |
|---|---|---|
| 1 | 100-150 | 2-5000 |
| 2 | 100-150 | 40,000 |
| 3 | 10-20 | 2-5000 |
| 4 | 100-150 | 2-5000 |
| 5 | 10-20 | 2-5000 |
| 6 | 100-150 | 40,000 |
| 7 | 100-150 | 24-200 |

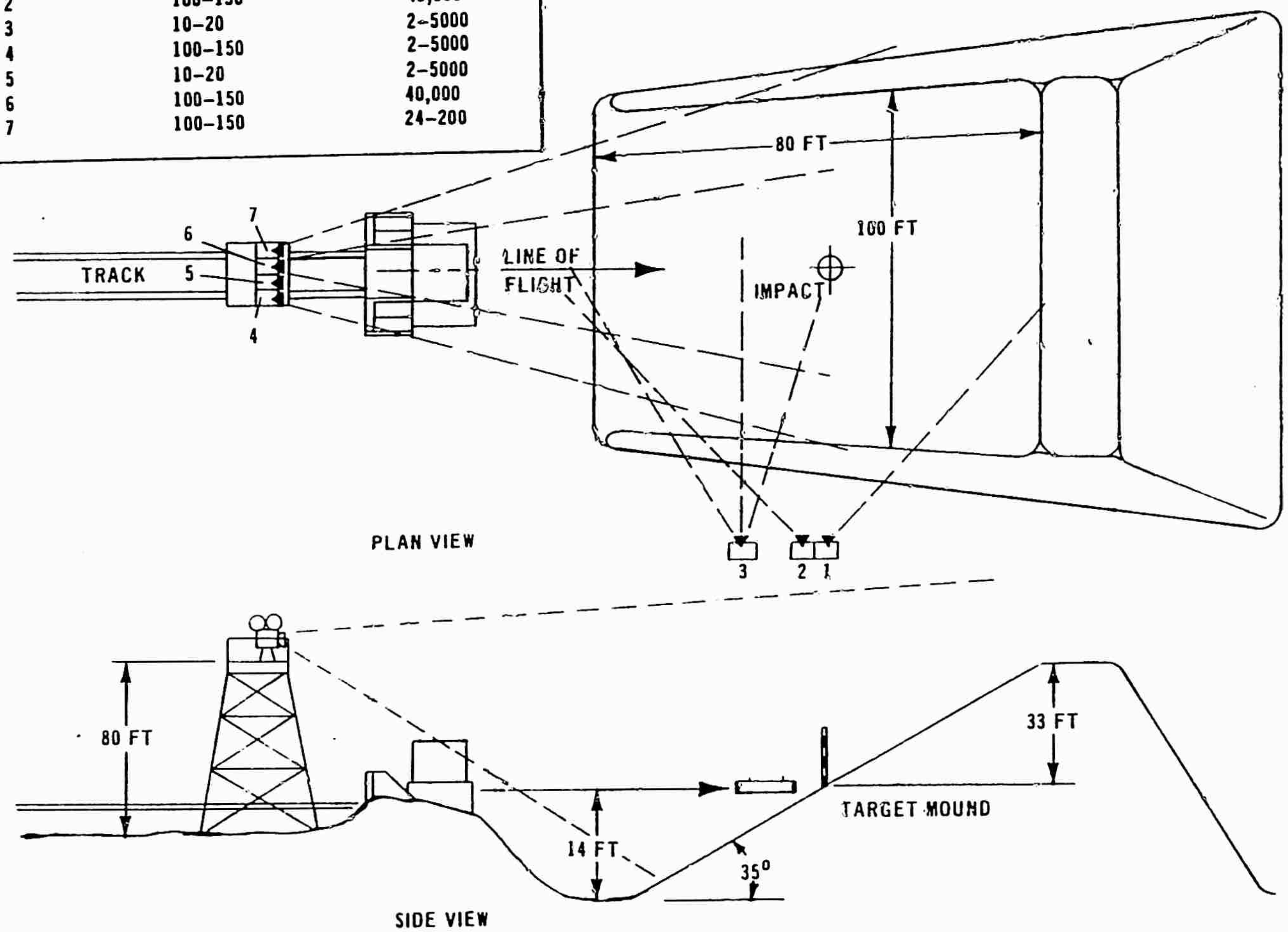



Figure 16. Suggested camera array for sled tests

## FREE AIR BLAST TESTS OF BARE AND CASED EXPLOSIVE CHARGES

OBJECTIVE. To collect blast pressure data to determine the relative effectiveness of candidate explosives in producing air blast parameters and to determine the equivalent weight of the explosive.

PARAMETERS TO BE MEASURED (PRIMARY DATA). These parameters are as follows:

1. Time of shock arrival at each transducer (in milliseconds) referenced to the initiation time of the charge.

2. Pressure versus time history of blast shock wave (side-on). From the pressure-time history and arrival time, the following may be determined:

a. Peak pressure (psi)

b. Maximum pressure (psi)

c. Shock wave velocity (average, fps)

d. Positive phase duration (msec)

e. Positive phase impulse (psi/msec)

f. Dynamic pressure (psi).

GENERAL INFORMATION REQUIREMENTS. Information required by the test engineer for test design, reporting, and data interpretation is as follows:

1. Test item technical data (to be provided by the test requester IAW AFATL Reg 136-1).

a. A complete and functional description of the test item as configured for the test including:

(1) Fuzing or detonator

(2) Explosive weight (actual and equivalent if known)

(3) Radiographs (if available)

(4) Explosive formulation

(5) Booster configuration

(6) Pertinent safety classification information

(7) Height of burst desired (feet above ground level) if different than specified below

(8) Predicted peak pressure at pertinent locations.

2. Meteorological data (taken at time and location of test if possible):

a. Barometric pressure (in. Hg)

b. Ambient temperature (°F)

c. Relative humidity (%)

d. Wind speed and direction (mph, degrees)

e. General observations (cloud ceiling, inversion, precipitation, etc.).

3. Soil characteristics (optional data):

a. Blast reflection coefficient

b. Moisture content

c. Soil composition

d. Penetrometer readings.

4. Description of test site/arena including:

a. Transducer specifications and location

b. Camera and lens specifications and location

c. Reference marker locations

d. Location and description of any above-ground obstructions which might perturb the blast wave.

(This information would normally be determined or specified by the test engineer and verified after the test by the Range Control Officer).

5. Block diagram or schematic of pressure instrumentation system (to be provided by Range Control Officer).

TEST ARENA DESIGN. The general guidelines outlined above apply. In addition, the following specific criteria also apply (Note: The following design was derived from a design developed at Ballistics Research Laboratory, Aberdeen Proving Ground, MD):

1. Testing should be conducted on a cleared, flat area with a hard-packed soil or concrete surface large enough to hold all instrumentation. Prime consideration should be given to locating the test charge high enough above ground level so most of the pressure measurements may be taken prior to the arrival of any reflected shock waves from the surface. Figure 17 shows a suggested arena design for 8-pound bare (uncased) spherical charges. It is impractical due to factors such as setup time, resources, and safety to place those transducers furthest from the charge (7, 8, 9, 10) in the free air region. Thus, they must be placed in the Mach stem region. To insure that all measurements are taken out of the Mach stem region it would be necessary to elevate either the charge or transducers very high above ground. The location of transducers shown is suitable only for small charge sizes (0 to 10 pounds). For larger charges, the design would be similar; however, the closest transducer must be placed farther from the experimental charge to avoid damage to the transducer and subsequent data loss. Specific locations for transducers used on charges larger than 10 pounds must be calculated on an individual basis to gather data in appropriate pressure ranges. If the experimental charges are cased (fragmenting), then precautions must be taken to avoid damage to transducers caused by fragment impact. Steel pipe, 2-1/2 inch, filled with sand and with angle iron attached has been successfully employed for this purpose. If a protective barrier such as this is required it should be placed far enough away from the transducer to allow the pressure wave to reform (10 diameters or more).

HARDWARE SELECTION. A pressure-time history and shock wave velocity data should be taken at several locations in the vicinity of the experimental charge. Table 2 provides a handy quick reference for transducer/mount selection. The transducers, mounts, stands and cabling recommended below are presented in order of preference.

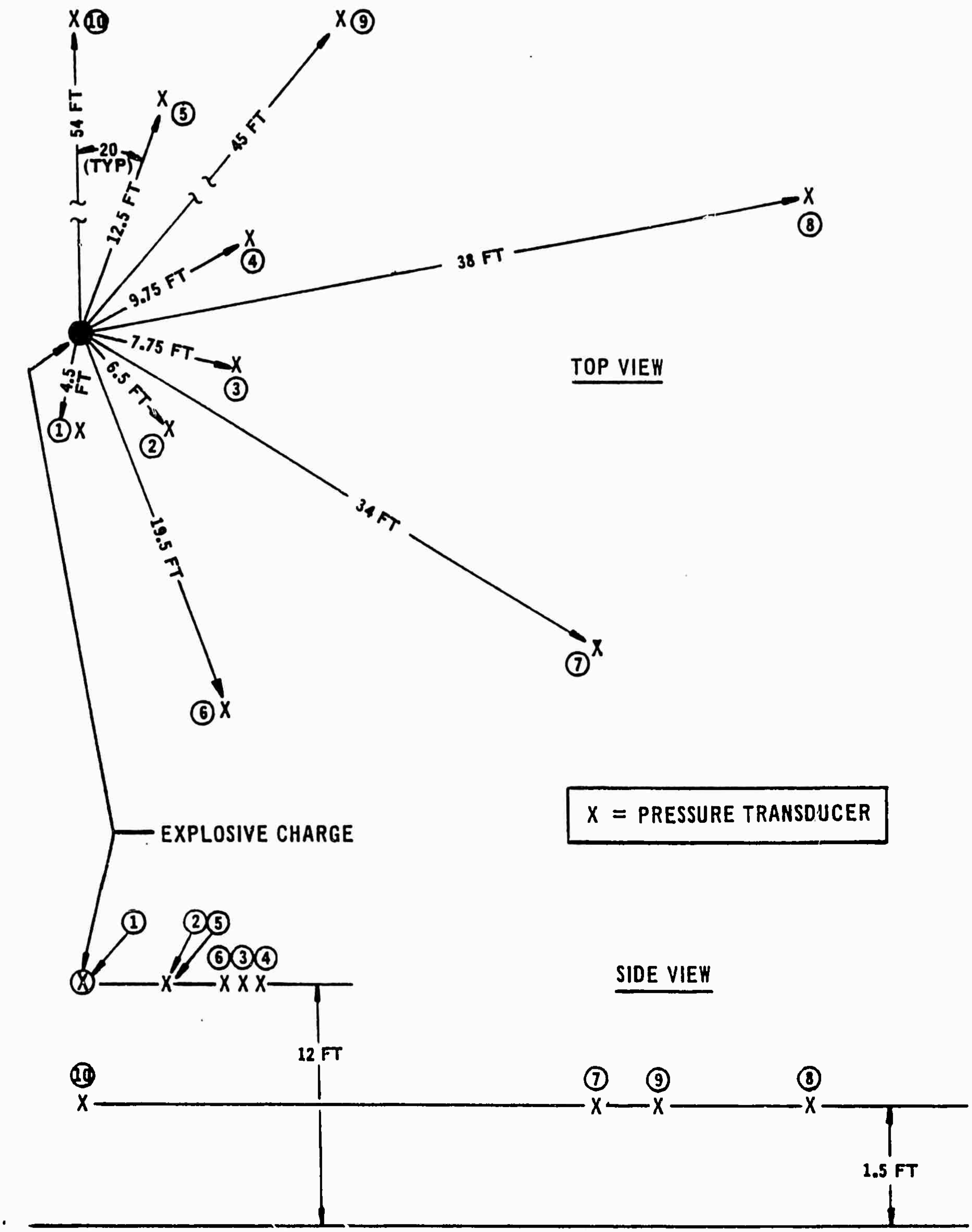



Figure 17. Transducer array for free airblast tests

Transducers. The recommended transducers are as follows:

1. For pressure-time histories

   a. 0 to 500 psi Susquehanna, ST-7

   b. 0 to 500 psi PCB, Model 102M25

   c. 0 to 500 psi Kistler, Model 202A2

   d. 0 to 5,000 psi PCB, Model 102M24

   e. 0 to 5,000 psi Kistler, Model 202A1

2. For measuring shock wave velocity and pressure versus time history,[9] 0 to 500 psi Susquehanna, ST-7 modified, two transducer elements 6 inches or more apart[10] (Figure 18).

3. If shock wave velocity alone is required, any TOA transducer will suffice. Also, if the measurement is to be taken in a high risk area, the less expensive transducer may be indicated.

Mounts and Stands. In general, the type of mount or stand required will be determined by the choice of transducer and its location. The following are recommended based on hardware now available (Note: No matter which transducer/mount/stand is chosen, care must be taken to insure that the assembly is oriented such that the shock wave is normal to the longitudinal axis of the transducer mount):

1. Pressure-time histories only (free air region):

   Susquehanna, ST-7 probe mount with 12-foot stand (Figure 3)

   Axhead mount on 12-foot stand.

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[9] The use of two reliable pressure transducers to measure time of arrival as well as pressure instead of two TOA transducers and one pressure transducer offers the obvious advantage of a backup pressure data channel in the event of failure of one of the transducers.

[10] Any convenient distance may be used which is commensurate with available data reduction resolution and desired average velocity accuracy requirements.

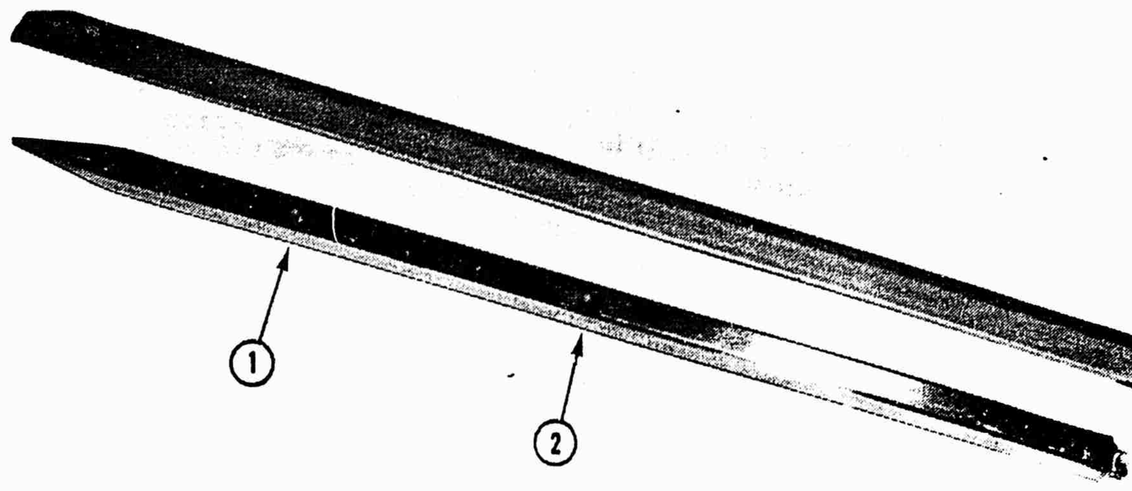


Figure 18. Modified ST-7 probe with two sensors for measuring shock wave velocity

2. Pressure - time histories only (Mach stem region):

Susquehanna, ST-7 probe mount attached to a 1-1/2 foot stand

Axhead mount attached to a 1-1/2 foot stand.

3. Pressure - time history and shock wave velocity. Modified Susquehanna, ST-7 (Figure 18) mounted at charge height on a 12-foot stand.

4. Shock wave velocity only. If shock wave velocity alone is required, any TOA transducer will suffice. If the measurement is to be made in a high risk area, the less expensive TOA transducer may be indicated.

Cabling. See Section VI.

Cameras. High speed photography of free airblast tests is generally optional; however, if a data record is required to confirm events, a 16 mm camera using color film and operating at 4,000 to 40,000 frames per second should be used. A 1,000-Hz time code must be printed on the film for event correlation (IRIG format A preferred).

Calibration. Procedures are as follows:

1. Transducers should be thoroughly examined at the transducer evaluation facility (Phase I) before beginning a test series. In addition, pressure transducers should be calibrated using Phase II procedures described in Section VI before every shot where time allows. If calibration prior to each shot is not practicable, the transducers must be calibrated before each daily series of shots begins.

2. Standard explosive charges such as pentolite spheres should be used to establish baseline data prior to each test series. These baseline data establish a reference against which the test charge performance may be judged.

CONVENTIONAL WARHEAD-SURFACE BLAST (JMEM-TH 61A1-3-7)

This section is intended to provide additional test design information to supplement procedures specified in JMEM-TH 61A1-3-7.

OBJECTIVE. To collect blast pressure data from surface or near surface detonation conventional warheads and bombs in the Mach stem region.

PARAMETERS TO BE MEASURED (PRIMARY DATA). These parameters are as follows:

1. Time of shock arrival of each transducer (in milliseconds) referred to time of detonation of warhead.

2. Pressure versus time history of the shock wave (side-on, face-on not usually required). From pressure time histories the following may be extracted:

a. Peak pressure (psi)

b. Maximum pressure (psi)

c. Shock wave velocity (fps)

d. Positive phase duration (msec)

e. Positive phase cumulative impulse (psi/msec)

f. Dynamic pressure (psi).

3. Photography (high speed) is optional for these tests.

GENERAL INFORMATION REQUIREMENTS. The following are required for test design, reporting, and data interpretation:

1. Test item technical data (Ref Section II).

2. Meteorological data (taken at time and location of test) Optional data, required only if data are to be corrected for ambient conditions:

a. Barometric pressure (in. Hg)

b. Ambient temperature (°F)

c. Relative humidity (%)

d. Wind speed and direction (mph, degrees)

e. General observations (cloud conditions, temperature inversions, etc.).

3. Soil characteristics:

a. Reflection coefficient

b. Composition

c. Moisture content

d. Penetrometer readings.

4. Description of test site/arena including location and identification of:

a. Transducers

b. Reference markers

c. Targets

d. Obstructions large enough to perturb blast wave.

(Information to be provided before each test by the test engineer and confirmed after each test by the Range Control Officer.)

TEST ARENA DESIGN. The general guidelines outlined above, and JMEM 61A1-3-7 apply.

Testing should be conducted on a cleared, level, flat area with hard-packed soil or concrete surface large enough to hold all required instrumentation. Transducer locations must be chosen to obtain data in particular regions of interest. In other words, transducers should be positioned at distances suitable to obtain data pertinent to the test purpose. The design recommended in this section (Figure 19 and description following) represents a typical test design which satisfies the requirements outlined in JMEM TH61A1-3-7 and has been demonstrated capable of providing satisfactory pressure data for large, high explosive bombs (500 to 3,000 pounds). General considerations for the design addressed below were:

1. Bomb and transducers should be placed so measurements are made in the Mach stem region.

2. The surface below the bomb should be packed and stabilized and preferably covered with a steel plate (recommended size, 4 inches by 8 feet by 8 feet) to prevent cratering.

3. Transducer locations should be chosen to place them in areas of least hazard; in the "null" area of low fragment density.

4. Transducers should be oriented for side-on pressure data.

The bomb/transducer array shown in Figure 19 was designed to provide optimum data with a minimum of equipment loss due to blast and fragmentation. The bomb should be oriented nose down with a backward axis tilt of 15° in the vertical plane bisecting the transducer lines. Transducers and transducer cables must be protected from fragments. Fragment stops should be placed far enough in front of the transducers (10 diameters of stop) so the shock wave is reformed before it reaches the transducers.

HARDWARE SELECTION. Table 2 provides a handy quick guide to transducer/mount selection. The transducers, mounts, stands, and cabling recommended below are presented in order of preference.

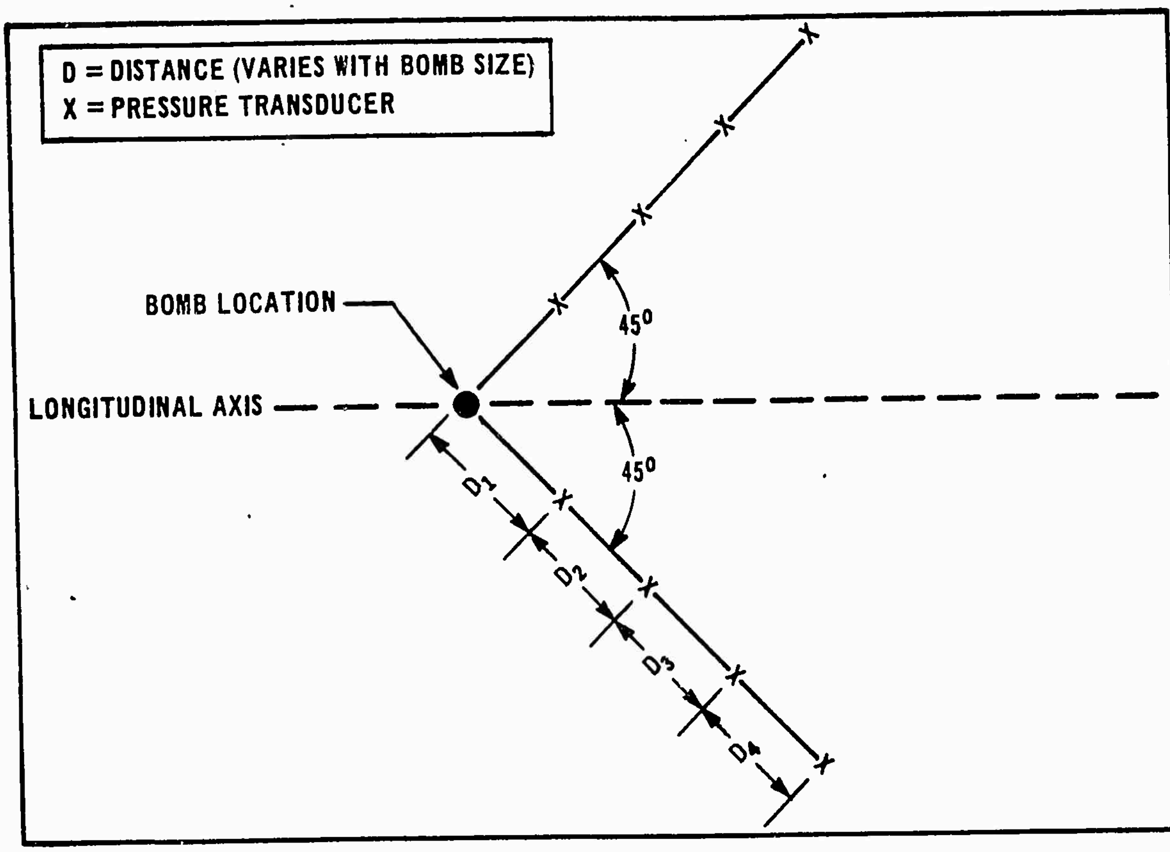


Figure 19. Conventional warhead surface blast arena (typical)

Transducers. The recommended transducers are as follows:

1. For pressure - time histories

   a. 0 to 500 psi Susquehanna, ST-7

   b. 0 to 500 psi PCB, Model 102M25

   c. 0 to 500 psi Kistler, Model 202A2

   d. 0 to 5,000 psi PCB, Model 102M24

   e. 0 to 5,000 psi Kistler, Model 202A1

2. For shock wave velocity and pressure data, 0 to 500 psi modified ST-7 (Ref Figure 18) or 0 to 500 psi PCB or Kistler transducers placed in axhead mounts and used in pairs one behind the other.[11,12]

3. For shock wave velocity data only (especially in high blast or fragment hazard regions), LD-25 TOA transducers used in pairs one behind the other.[12]

Mounts and Stands. The mounts and stands recommended are those currently available and in use at ADTC. In all cases, the transducer mount must be aimed directly at the test item and positioned at test item height.

1. Pressure-time histories only (side-on):

   a. Susquenhanna, ST-7 probe mount attached to top station of F-stand or T-stand.

   b. Axhead mount (PCB or Kistler transducer) attached to top station of F-stand or T-stand.

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[11] Any convient separation distance may be used commensurate with available data reduction resolution and average velocity accuracy requirements.

[12] The use of two reliable pressure transducers to measure shock wave TOA as well as pressure instead of two TOA transducers offers the advantage of an additional pressure data channel at that location in case of failure of either.

2. Shock wave velocity and pressure:

a. Modified Susquehanna, ST-7 probe (Ref Figure 18) attached to T-stand or F-stand (top station).

b. Axhead mounts (with PCB or Kistler transducers) attached to two T-stands placed one behind the other and separated by 5 feet horizontally).[12]

3. Shock wave velocity only. TOA transducer attached to two T-stands, one 5 feet behind the other (horizontal distance).[12]

Cameras. High speed photography of blast tests is optional; however, if a photographic record is required to confirm events, a 16 mm camera using color film and operating at 4,000 to 40,000 frames per second should be used. A 1,000-Hz time code must be printed on the film for event correlation (IRIG format A preferred).

Calibration. Procedures are as follows:

1. Phase I calibration of all transducers prior to each test program is recommended.

2. Phase II calibration of all transducers is recommended prior to each test shot.

3. Standard explosive charges such as pentolite or TNT may be used to establish baseline data for the test series. Such baseline data establish a reference against which the bomb performance may be compared. The charge should be placed at the same location as the warhead relative to the transducers. The charge should be large enough to produce representative pressures similar to those produced by the warhead.

## SECTION VI

## TEST CONDUCT

### TEST ARENA

GENERAL. Due to the severe environment encountered in blast pressure testing, strict compliance with proven procedures and techniques is necessary when conducting a test. Deviation from these established procedures must be thoroughly investigated and tested prior to implementing on a routine basis. The designated test arena must be clear of all unnecessary objects that could produce reflections of the blast pressure. Objects such as camera protection blocks, towers, etc., that cannot be relocated should be noted on the appropriate data transmittal forms in order that data analysts can interpret the effects.

Transducers should be positioned on the arena in relation to the test item center or impact point as specified by the project documentation The positions will be determined with a transit and measuring tape to within ±0.5 inch of the required location. Leveling of the arena, with a grader if necessary, is a requirement. This includes the trenches after installation of cabling.

When transducers are used in areas of high fragment concentration, protection must be provided. This protection may be in the form of pipe or angle iron mounted vertically between the munition and the transducer. Consideration must be given to the possibility that the fragment diverter may affect the pressure data if it is excessively large or located too close to the transducer. The rule of thumb for positioning the guard is a minimum of 10 diameters of the guard in front of the transducer. Experience has shown that 2 1/2- to 3-inch pipe filled with concrete or 2 1/2- to 3-inch pipe with angle iron facing is adequate. When a transducer or its mount has been hit by a fragment and damage is suspected, the transducer will be returned to the Phase I Evaluation Facility for recalibration.

All cabling within the blast area will be protected with conduit or buried to prevent cable disturbance due to the blast pressure wave. The cable should be buried 12 inches deep in areas that anticipate pressure exceeding 100 psi; a 6-inch depth has proven to be adequate in areas anticipating pressure less than 100 psi. The cables will be protected from fragments regardless of anticipated pressure levels. The following method of protecting above-ground cable ends from accumulation of moisture has proven satisfactory and is recommended: (1) the cable end is extended above the ground level and taped to a surveyor's stake, (2) a portion of heavy-duty aluminum foil is cut and formed into a bell-shaped cone and placed over the stake to prevent rain or condensation on the underside of the foil from coming into contact with the connector, (3) the connector is in the free air beneath the cone and any condensation on it dissipates into the air.

All connectors which are underground will be protected from moisture and dirt by wrapping tightly with electrical and/or splicing tape. Prior to installation of transducers, cabling will be checked with an insulation tester to ensure a resistance of 200 megohms or better. Ground loops will be avoided by using isolated transducers and insuring that all cable shields are ungrounded except at the measuring equipment end. When transducers are installed in their test configuration, the attached cables should not be pulled tight because of the strain that may occur during and after the pressure front passage. This strain is especially damaging at the transducer connection and may cause an intermittent or open circuit.

Exposed insulation in the transducer coaxial connector shall be cleaned with lint-free industrial paper wipes moistened with Freon TF or the entire transducer can be immersed in the solvent. After cleaning or use, the cap will be replaced on the transducer connector and the transducer will be placed in a protective storage container. All cable connectors will be cleaned with Freon TF or equivalent prior to use.

ABOVE GROUND SURFACE TRANSDUCERS.

Susquehanna ST-7 (Figure 20). Preparation of an ST-7 for a pressure mission is accomplished in three parts. First, the probe along with range capacitor and impedance converter is assembled. Second, the field stand with appropriate cabling is assembled. Third, the probe and stand are joined.

Probe Assembly. A separate impedance converter is required when using the ST-7. For certain applications it will also be necessary to use a range capacitor to reduce the voltage level from the transducer. The maximum input voltage level of impedance converters is limited to about 5 volts. A method for determining whether or not a range capacitor is required (and what value) is described in Reference 14. This determination must be made before probe assembly begins.

The range capacitor and impedance converter have mating connectors and will be connected first. Care will be exercised to avoid touching the center conductor of the impedance converter as damage to the solid state amplifier may result (from static discharge). The range capacitor and impedance converter are to be covered with heat-shrinkable tubing for isolation and rigidity before insertion into the ST-7 mount. Foam rubber (or other suitable material) will be utilized between the probe housing and the heat-shrinkable tubing to minimize vibration during passage of the shock wave. Six inches of low noise cable, Kistler part 121M, will be utilized between the transducer and the range capacitor (or impedance converter if range capacitor not used). Also, this same type of low noise cable will be utilized to provide a pigtail cable extending from the impedance converter out the end of the probe. That portion of the probe that is to be inserted in the stand will be wrapped with nonconducting tape for isolation.

Stand Assembly. The appropriate stand (Figure 3) will be positioned on the arena as required by project documentation. RG-62 coaxial cable is routed underground to the base of each stand. Low noise cable, Kistler part 121M or equivalent, is routed through the walls of the stand. The low noise cable will be joined to the RG-62 by using Kistler cable adaptor Model 102 (or equivalent). The other end of this low noise cable will have a short pigtail. The underground connection will be protected from moisture and dirt by wrapping tightly with electrical and/or splicing tape. A megohm test of the cable will be conducted at this point. This test will include all the RG-62 transmission line cabling plus the low noise cabling routed through the walls of the stand. Probe installation on stand may now be accomplished.

Probe Assemblv on Stand. Connection of the two low noise cable pigtails, (one from probe, one from stand) is accomplished using a Kistler Model 104 cable adaptor (or equivalent). For isolation, this connection will be wrapped tightly with electrical tape or covered with heat-shrinkable tubing. The probe is inserted 6 inches into the stand and secured with setscrews. Phenolic or Teflon spacers will be used between the setscrews and the probe to assure ground isolation.

When acquired from the manufacturer, the ST-7 contains a single layer of black electrical tape across the surface of the sensing element. If this thermal protection has been removed for any reason, it will be replaced (in the same manner as when purchased) at this point in the arena buildup e.g., before field calibration is accomplished.

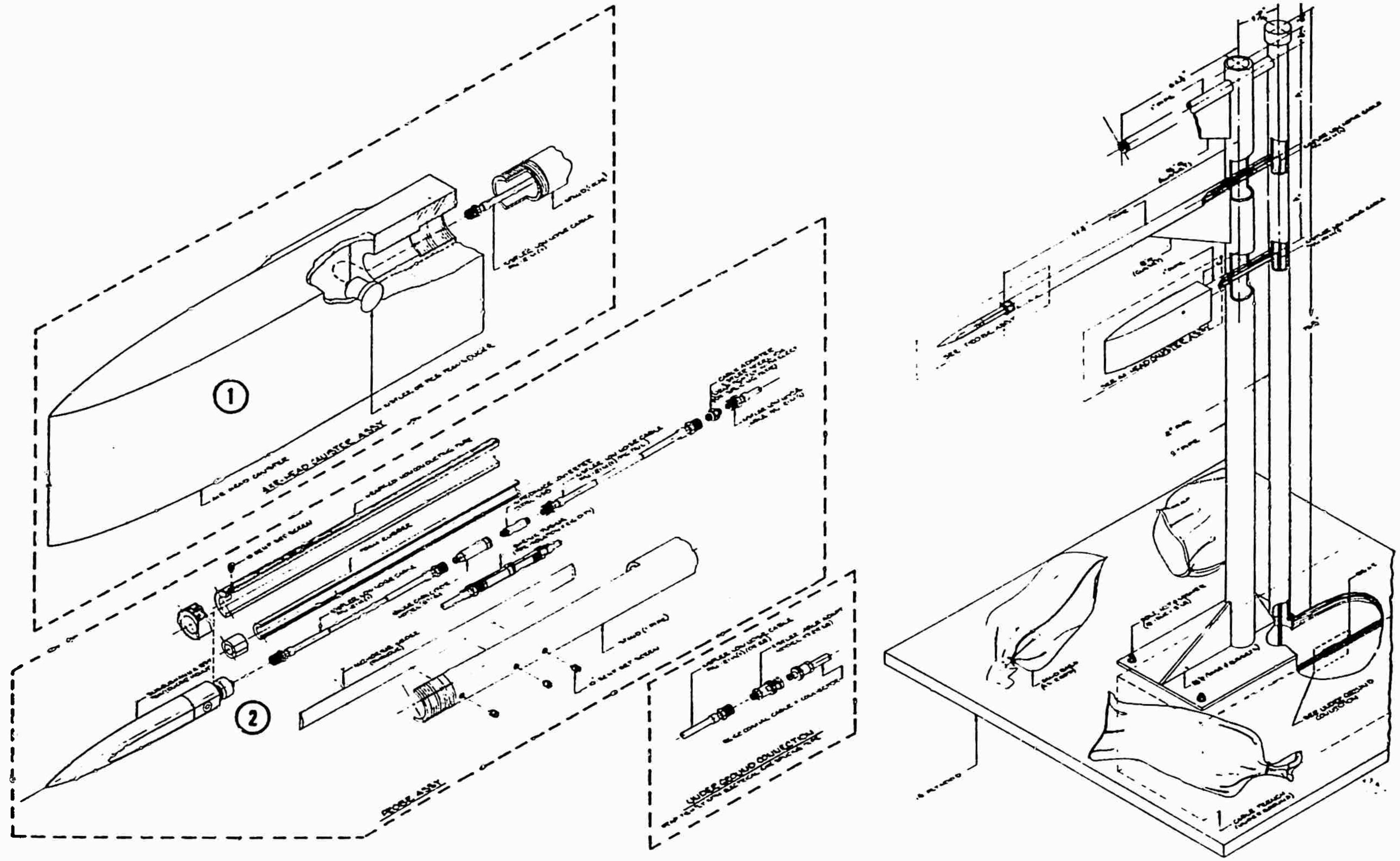

Figure 20. Pressure transducer probe assembly showing: (1) axhead mount and (2) ST-7 probe



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Axhead Mount With Kistler or PCB Transducers (Figure 20). Preparation of the axhead mount adapted with either the Kistler or PCB transducer is accomplished in three parts: (1) mount/transducer preparation, (2) stand preparation, and (3) assembly of mount/transducer with stand. Since the Kistler and PCB transducers are interchangeable (both electrically and mechanically), the following discussion applies to both.

Canister/Transducer Preparation. An RTV ablative coating, applied either by the manufacturer, or the Phase I evaluation facility, will be on each transducer. If for any reason, the ablative coating has been removed or physically damaged, the transducer will be routed to the Phase I Evaluation Facility for reapplication of this coating. Only ground-isolated transducers will be utilized in this mount because the mount/stand is not ground-isolated.

The axhead mount is designed such that one sidewall can be removed for insertion of the transducer. By using spacing washers, the transducer will be inserted into the mount so that the sensing surface of the transducer is flush with the mount surface to within ±1/32 inch. The transducer will be secured tightly but no more than 8 foot-pounds of torque are to be applied. The sidewall of the mount will then be replaced to prevent dust, moisture etc., from collecting inside. This sidewall must again be removed when assembly of mount onto the stand is accomplished.

Stand Preparation. The appropriate stand (Figure 3) will be positioned on the arena as required by project documentation. RG-62 coaxial cable is routed underground to the base of each stand. Low noise cable, Kistler part 121M or equivalent is routed through the walls of the stand. The low noise cable will be joined to the RG-62 by using Kistler cable adaptor Model 102 (or equivalent). The other end of this low noise cable will have a short pigtail extending from the end of the stand (for direct connection to the transducer in the axhead). The underground connection will be protected from moisture and dirt by wrapping tightly with electrical and/or splicing tape. A megohm test of the cable will be conducted at this point and will include all the RG-62 transmission line cabling plus the low noise cabling routed through the walls of the stand. Transducer mount installation on the stand may now be accomplished.

Assembly on Stand. The axhead mount has a 1-inch threaded hole for direct connection to the 1-inch threaded pipe on the stand. Before assembly of the mount on the stand is performed, the sidewall of the mount will be removed and the low noise pigtail cable routed through the threaded hole and out the sidewall hole. The mount can then be screwed onto the pipe without twisting the low noise cable. Connection of the low noise cable to the transducer is then accomplished and the sidewall replaced.

FLUSH WITH GROUND SURFACE TRANSDUCERS.

Susquehanna ST-2 and ST-4 Transducers (Figure 21). Preparation of the ST-2 or ST-4 transducer for a flush with the ground surface measurement is accomplished in three parts: (1) the transducer is installed in the insert assembly (which will in turn be installed in the 88-pound steel plate) and the range capacitor and impedance converter are assembled and mated to the transducer, (2) the 88-pound steel plate along with appropriate cabling is prepared on the arena, (3) the insert assembly along with transducer, range capacitor, and impedance converter are joined with the 88-pound steel plate and arena cabling.

Transducer/Insert Assembly. The transducer will be screwed into the insert assembly such that the sensing surface of the transducer is flush with the insert assembly surface to within ±1/32 inch. The ST-2 and ST-4 have no mechanical stops; therefore, lock-nuts, Teflon tape, or other appropriate methods will be used to assure that the transducer is tight in the insert assembly.

A separate impedance converter is required when using the ST-2 or ST-4. For certain applications, it will also be necessary to use a range capacitor. A method for determining whether or not a range capacitor is required (and what value) is described in Reference 14. This determination must be made before assembly begins.

The range capacitor and impedance converter have mating connectors. Care will be exercised to avoid touching the center conductor of the impedance converter as damage to the solid state amplifier may result. The range capacitor and impedance converter are to be covered with heat-shrinkable tubing for isolation and rigidity. One foot of low noise cable, Kistler part 121M, will be utilized between the transducer and the range capacitor (or impedance converter if range capacitor not used). Also, this same type of low noise cable will be used to provide a pigtail cable extending 1 foot from the impedance converter.

Field Preparation. The 88-pound, 1-foot-square, 2-inch-thick steel plates will be positioned on the arena in the location specified by project documentation. RG-62 coaxial cable is routed underground to each plate as described previously and this cabling will be checked with an insulation tester to ensure a resistance of 200 megohms or better. This plate will be positioned such that the top surface is flush with the surrounding ground. A form fitting wooden frame will be used to stabilize the steel plate.

Insert Assembly on Steel Plate. The insert assembly containing the transducer, the range capacitor, and the impedance converter is inserted into position on the plate and secured with lock screws. The low noise pigtail cable is connected to the RG-62 cable using a Kistler Model 102 cable adaptor (or equivalent). This connection will be wrapped tightly with electrical tape or covered with heat-shrinkable tubing.

When acquired from the manufacturer, the ST-2 and ST-4 have a single layer of black electrical tape across the surface of the sensing element. If this thermal protection has been removed for any reason, it will be replaced (in the same manner as when purchased) at this point in the arena buildup e.g., before field calibration is accomplished.

Care will be exercised in replacing the dirt around the steel plates. The cable immediately following the transducer will be routed directly downward to the bottom of the trench with a small amount of slack left in the cable at the transducer end. This will allow for slight movement of the plate as the shock wave passes over.

Kistler/PCB Transducers (Figure 21). Preparation of the Kistler or PCB transducers for surface pressure measurements flush with the ground is also accomplished in three parts: (1) the transducer is installed in the insert assembly, (2) the 88-pound steel plate along with appropriate cabling is positioned/installed on the field arena, (3) the insert assembly and the steel plate are joined.

Insert Assembly. The selected transducer will first be inspected to assure that the ablative coating on the sensing surface has not been damaged or removed. If for any reason this thermal protection needs replacing, the transducer will be routed to the Phase I Evaluation Facility for reapplication.

By use of spacing washers the transducer will be installed in the insert assembly such that the sensing surface is flush with the surface of the insert to within ±1/32 inch. The transducer will be secured tightly but no more than 8 foot-pounds of torque will be applied.

Plate Assembly. Plate and cable installation on the arena will be accomplished in the same manner as described for ST-2 and ST-4 flush with ground surface pressure measurements.

Plate and Insert Assembly Joined. The insert assembly, along with the transducer, are installed in the steel plate in the same manner as the ST-2 and ST-4. A 3-foot length of low noise cable, Kistler part 121M or equivalent, will be used between the transducer and the RG-62 coaxial cable. The precautions, protection and cable adaptors described for the ST-2 and ST-4 flush with ground surface sensors will be used.

TIME OF ARRIVAL (TOA) TRANSDUCERS. Although any of the above described transducer mounting configurations can be used to measure the pressure wave TOA (reference Section IV), the Atlantic Research Model LD-25 transducer is often used for strictly TOA measurements especially in high fragmentation areas. This transducer is positioned in a face-on configuration and an appropriate adaptor for placing the transducer on a stand is available (Figure 22). As with other mounting configurations, preparation of the LD-25 is accomplished in three parts: (1) the transducer is installed in the adaptor and the range capacitor and impedance converter are assembled and mated to the transducer, (2) the stand with appropriate cabling is prepared on the arena, (3) the adaptor assembly along with transducer, range capacitor, and impedance converter are joined with the stand and arena cabling.

Transducer/Adaptor Assembly. A separate impedance converter is required with the LD-25 transducer. For certain applications, it will also be necessary to use a range capacitor. A method for determining whether or not a range capacitor is required (and what value) is described in Reference 14. This determination must be made before adaptor assembly proceeds.

The range capacitor and impedance converter have mating connectors and will be connected first. Care will be exercised to avoid touching the center conductor of the impedance converter as damage to the solid state amplifier may result. Six inches of low noise cable, Kistler part 121M, will be utilized between the transducer and the range capacitor (or impedance converter if no range capacitor used). Also, another 6-inch cable of the same type will be connected to the impedance converter. The range capacitor and impedance converter along with one end of each of the two 6-inch cables are to be covered with heat-shrinkable tubing for isolation and rigidity. The transducer is then installed in the adaptor and

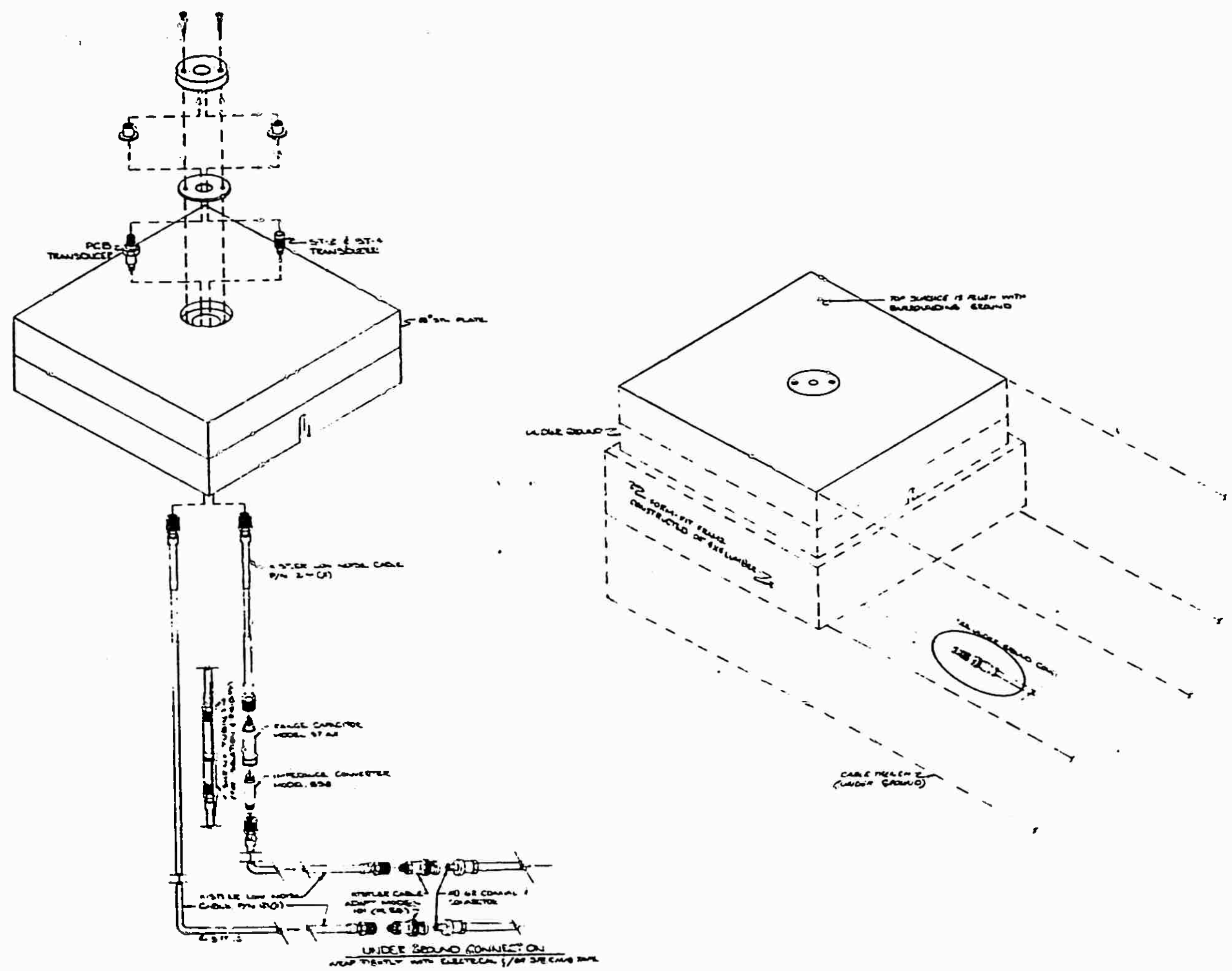


Figure 21. Installation assembly for PCB, Susquehanna, or Kistler transducers in flush mount

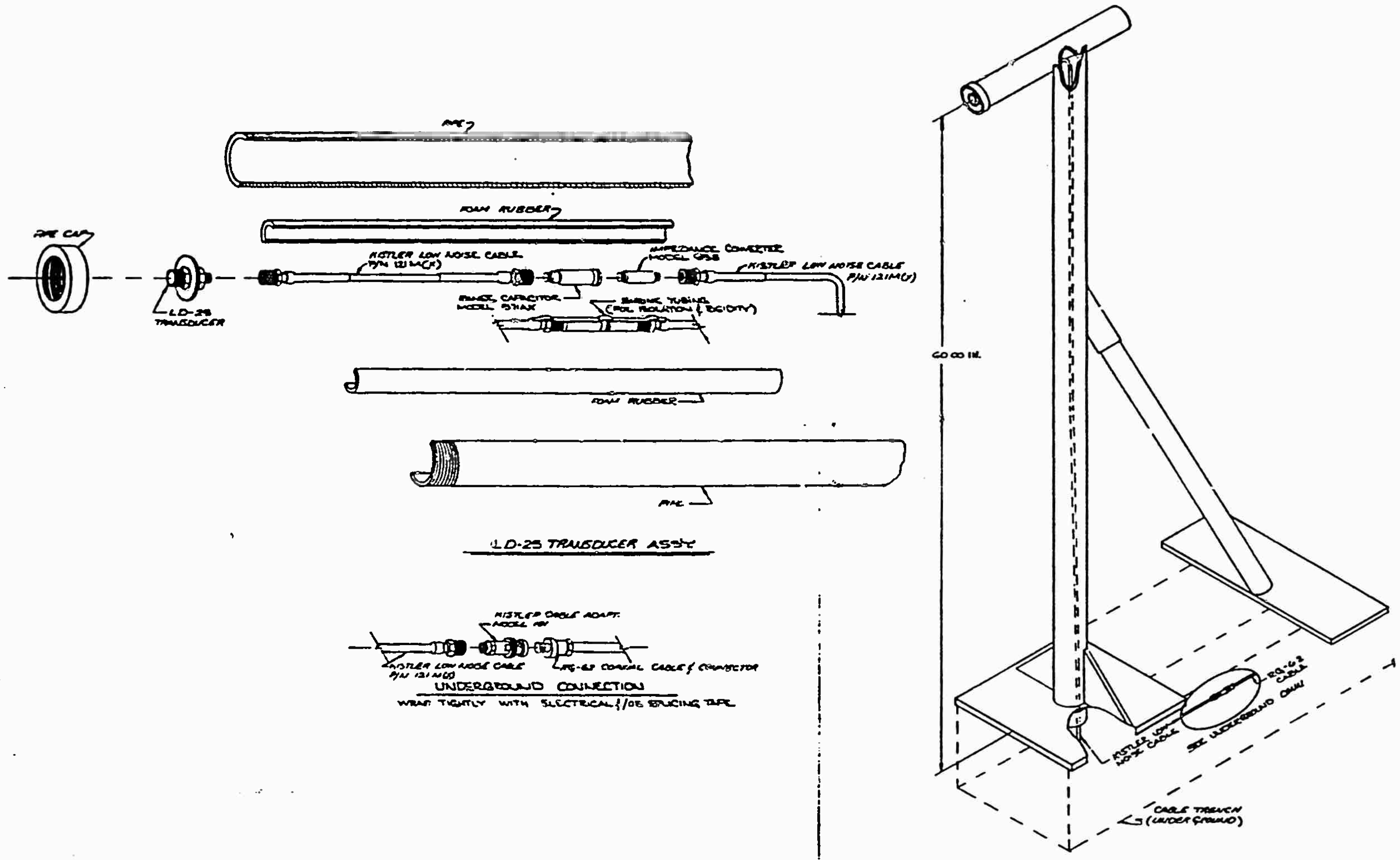


Figure 22. Typical installation assembly for the LD-25 TOA transducer

at this point, the transducer along with the adaptor, matching range capacitor, impedance converter, and low noise cable are ready for installation on the field stand.

Stand Assembly. The appropriate stand (Figure 3) will be positioned on the arena as required by project documentation. RG-62 coaxial cable is routed underground to the base of each stand. Low noise cable, Kistler part 121M or equivalent is routed through the walls of the stand. The low noise cable will be joined to the RG-62 by using Kistler cable adaptor Model 102 (or equivalent). This underground connection will be protected from moisture and dirt by wrapping tightly with electrical and/or splicing tape. The other end of this low noise cable will have a short pigtail. A megohm test of the cable will be conducted at this point. This test will include all the RG-62 transmission line cabling plus the low noise cabling routed through the walls of the stand. Sensor installation on the stand may now be accomplished.

Assembly on Stand. Connection of the two low noise cable pigtails (one from transducer/adaptor assembly, one from stand) is accomplished using a Kistler Model 104 cable adaptor (or equivalent). For isolation, this connection will be wrapped tightly with electrical tape or covered with heat-shrinkable tubing. Foam rubber (or other similar material) will be utilized between the walls of the stand and the range capacitor, impedance converter, and the 104 cable connections to minimize vibrations during passage of the shock wave or vibrations caused from fragments hitting the stand. Care will be exercised in attaching the transducer adaptor onto the stand to avoid twisting the cables and cable connections.

A single layer of black electrical tape will be placed across the surface of the sensing element to provide thermal protection.

OTHER TRANSDUCER MOUNTING CONFIGURATION. Obviously, the techniques described above for mounting transducers will not be applicable to every blast pressure test conducted on Eglin. For example, tests are being conducted at Eglin which require transducers to be mounted on concrete beams, in aircraft shelters, and on targets (such as airplanes, tanks, etc). Project documentation will address these special transducer mounting configurations and identify the agency (or agencies) responsible for developing the transducer mounting configurations. Personnel involved only in the test conduct will not be required to design new transducer mounting configurations.

## CALIBRATION

GENERAL. All transducers must be calibrated by the Phase I Evaluation Facility prior to use. Transducers that have been hit by fragments or exposed to over-range pressures will be recalibrated. Transducers that produce questionable data such as baseline shift or high-frequency oscillations will also be recertified in the Phase I Evaluation Facility prior to reuse.

PULSE CALIBRATOR. Prior to mission support, and preferably the morning of the mission, each pressure transducer will be subjected to a pressure pulse from the portable pressure calibrator on the arena. All cabling and system hookup will be intact. Once the sensitivity of a pressure channel has been checked with the portable calibrator, the same transducer/cable assembly shall be used for the actual test. System calibration at TA C-74 presents a unique problem in that the calibrator is much too heavy and bulky to handle on the inclined mound. The most practical method is to place the pulse calibrator at the bottom of the mound. The transducer and its low noise cable, range capacitor, and impedance converter (if used) will be installed on the calibrator. An additional length of cable of the same type used in the conduit will be attached between the transducer mount cable on the hill and the transducer low noise cable assembly. This additional cable will be of sufficient length to reach all transducer locations.

SYSTEM SENSITIVITY DETERMINATION. The pressure data gathering system should be subjected to a sensitivity check using the portable pulse calibrator to inject a pulse, slightly greater in amplitude (when possible) than the predicted pressure, into each data channel. The check should start at the transducer and be monitored at the Model 504D amplifier output terminal. The calibration pulse will be monitored with a peak reading digital voltmeter. The calibration pulse will simultaneously be stored in a transient recorder and subsequently displayed on an oscilloscope or X-Y plotter for verification of the peak meter reading. Using procedures identified in Section VI, the 504D amplifier is set up to give 5 volts output for the selected expected peak pressure. The electrical calibration voltage is set up as described in Section VI. The selected peak pressure is then applied to the transducer (using the pneumatic pulse calibrator) and the output of the 504D is monitored. If this output is not precisely 5 volts ±1 millivolt, then the "sensitivity" control knob of the amplifier is adjusted so that 5 volts ±1 millivolt output is obtained. The 5-volt output is obtained by repeatedly applying the selected peak pressure (from pulse calibrator) to the transducer and adjusting the sensitivity knob until the desired output is reached. Thus, by adjusting the gain of the 504D, the system sensitivity is "forced" to be the selected peak pressure divided by 5 volts. At this point, the electrical calibration voltage level must be adjusted so that 5 volts ±1 millivolt output is obtained with the new selected amplifier gain. This desired output is obtained by repeatedly applying different voltage levels from the electrical calibration chassis to the amplifier input until the desired output is reached. To complete calibration and sensitivity determination of a channel, the selected peak pressure is again applied to the transducer to verify that 5 volts ±1 millivolt output is obtained. The amplitude of the electrical calibration pulse represents the selected peak pressure. As noted before, this calibration pulse is utilized during the data reduction process. The pulse calibrator peak pressure is 300 psi. Thus, if the expected peak pressure exceeds 300 psi, this technique must be slightly altered. For example, when the selected expected peak pressure is 500 psi, the pulse calibrator will be used to apply 250 psi to the transducer and 2.5 volts ±1 millivolt will be the desired output from the 504D amplifier. Setup of the electrical calibration voltage level will be accomplished similarly. After system sensitivity has been determined, it is important that the same cable connectors and system components be used on each individual channel that were used during the calibration. It is also important that no adjustments be made to any equipment involved which could possibly affect gain. The time duration between the time of the calibration and the time of actual test is important in system sensitivity determinations because often gain can change due to aging of components, temperature changes, humidity variations, and other factors; therefore, the actual test should follow the calibration as soon as practicable.

## OPERATION OF INSTRUMENTATION SYSTEM

EQUIPMENT OPERATION DURING DATA COLLECTION. During conduct of a mission, all unnecessary electronic and electromechanical equipment should be de-energized to prevent the possibility of recording unwanted signals caused by the electromechanical operation.

Recorder. Speed. In the analog recorder, the frequency response is relative to the speed of the tape. The recorder frequency response increases as the tape speed is increased. Unless specific directions are received to the contrary, the maximum available tape speed should be utiiized.

Input Voltage for 40% Deviation. All ADTC pressure measuring systems are normally aligned to produce 40% deviation with a 5-volt peak input signal. Care must be exercised not to exceed the maximum input voltage for 40% deviation because this condition can overdrive the tape recorder and cause it to break into oscillation which will appear as cross talk or electrical noise on adjacent channels.

Tape Desired. New tape, if available, will be used. It is necessary to use precision tape reels for all pressure tests recorded on an analog recorder. The recommended tape for intermediate band recording is 3M Type 871 or equivalent. The recommended tape for wide-band recording is 3M Type 888 or equivalent.

Warmup Time. The Model 3700B and 4010 Bell and Howell recorders will stabilize sufficiently within 15 minutes to begin premission adjustments and calibration.

Premission Checks. The record amplifier card for each channel should be checked with no signal in for the proper center frequency at the speed data are to be recorded. A dc signal level, equal to the desired plus and minus 40% deviation, should be applied to each data channel and the record amplifier should be checked for proper frequency deviation.

Recording Function Times. It is necessary that time of detonation be recorded on the analog recorder along with the pressure data. All pressure instrumentation currently in use has the capability of initiating the calibration pulse at detonation time as detected by either a breakwire device or a photocell light detector. This pulse is adjusted to 320 microseconds in duration. Due to the width of this pulse and the additional 125 microseconds required in the data reduction process, care should be exercised in the placement of transducers to prevent simultaneous occurrence of the calibration pulse and pressure data. Any time a transducer is located closer than 3 feet to the test charge, the possibility of recording the calibration signal over data exists and the Test Engineer should be notified.

Signal Conditioning Amplifiers. General. Kistler Model 504D dual-mode amplifiers serve as the power source and signal conditioning amplifier for the piezoelectric transducers for all blast pressure systems at ADTC. The 504D amplifiers have two modes of operation for use in pressure measurements. One mode is a charge mode which will handle the charge from a piezoelectric transducer. The other mode is the piezotron mode in which it provides dc power to an impedance converter at the transducer as well as accepting pressure pulse from the transducer. The piezotron mode is normally utilized at ADTC.

Sensitivity Selection. Sensitivity of the Model 504D dual-mode amplifiers is variable from 0.1 to 10 millivolts/psi with a variable range of 1 psi to 5K psi/volt. The amplifier gain is variable. Several factors must be considered prior to selecting a specific gain. The predicted pressure and transducer sensitivity must be known. The output level or amplifier gain setting is determined by the requirements of the equipment that follows the amplifier (recorder, peak meter, storage scope, etc.). However, the normal output of the amplifiers is 1 volt with an overrange of ±10 volts. The output level can be adjusted by the interaction of the two control switches.

An example would be as follows: The expected peak pressure is 100 psi. The transducer with a sensitivity of 0.010 volt/psi produces an output of 1.00 volt at 100 psi. The recorder is set up to record a maximum voltage of 5 volts. The gain must be set to X5 to provide a 5-volt output to the recorder.

The 504D conditioning amplifiers have two control switches. One controls the transducer sensitivity, the other provides an output of psi per volt. Using the above example, this type would have the sensitivity control switch set to 10 millivolts and the other set to a range of one-fifth of the expected pressure (20 psi) to give an output of 5 volts for the expected input pressure of 100 psi.

Warmup Time. Thirty minutes warmup is sufficient to stabilize the signal conditioning amplifier when operating in an environmental-controlled building. When operating in a humid environment, additional time will be required. Special measures such as the use of the dehumidifiers, heat lamps, and/or additional warmup time will be employed to minimize the stability problems created by a humid environment.

Premission Checks. Premission checks will include inserting a known voltage from the electrical calibration chassis in the range of the expected transducer peak output and checking the conditioning amplifier output for the expected level. It should be checked for noise levels, amplitude, rise time, and wave shape. The zero offset of the amplifier will also be checked. An additional amplifier premission check is performed using the portable pressure calibrator during field calibration. This technique was described in Section VI.

Time Constant. The 504D has three selectable time constants - short, medium, and long with possible theoretical values varying from 0.01 to 5,000,000 seconds. The time constant for each of the three selectable positions depends on the range and sensitivity selected for each amplifier. Table 2 in Reference 15 identifies the various time constants available. A time constant will be selected which is the shortest possible and is a minimum of 50 times as long as the expected duration of the pressure pulse.

Line Voltage Monitoring. Pressure line monitoring panels are supplied with all pressure systems for the purpose of ascertaining measuring line and transducer readiness. Data lines are checked by monitoring the impedance converter voltage. Full power supply voltage indicates an open line or missing transducer. A zero reading indicates a shorted line or impedance converter. Approximately 11- to 13-volt readings indicate a good system. All measuring lines can be monitored in a matter of seconds prior to premission checkout or, if trouble is suspected, before or after a mission. All pressure lines should be checked as soon as is practicable after a mission to assure that the lines are electrically intact and the transducers are within their normal supply voltage range.

Electrical Calibration Voltage Setup. The level of each channel must be determined individually based on the expected peak pressure on the transducer and expected voltage level generated by the transducer associated with this channel. Knowing the peak pressure expected, a convenient reference level is chosen which is somewhat greater than the expected peak pressure. The calibration signal level is adjusted to equal this reference pressure level. For instance, if the expected peak pressure is 425 psi, then a pressure of 500 psi might be chosen as the reference pressure. The value chosen as the reference pressure is irrelevant as long as the calibrator is adjusted using this value and the value is used to evaluate the data. Basically, the calibration voltage level is derived by multiplying the transducer sensitivity by the chosen reference pressure. The ratio of the calibration signal to the chosen reference pressure must be the same as the ratio of expected peak voltage level from the transducer to the expected peak pressure on the transducer. Mathematically this can be written as:

$$\frac{Vp}{Pp} = \frac{Vr}{Pr} \tag{1}$$

Where:

Vp = Peak voltage expected from the transdicer

Pp = Peak pressure expected on the transducer face

Vr = Reference voltage to be set on calibrator

Pr = Reference pressure chosen

Since Vp = Pp x transducer sensitivity

$$\frac{\text{Pp x transducer sensitivity}}{\text{Pp}} = \frac{\text{Vr}}{\text{Pr}} \qquad (2)$$

$$\text{Transducer sensitivity} = \frac{\text{Vr}}{\text{Pr}} \qquad (3)$$

Therefore:

$$\text{Vr} = \text{Pr x transducer sensitivity} \qquad (4)$$

Adjust the 10-turn potentiometer on the front panel associated with the channel of interest until the dc voltmeter reads the calculated value Vr ±1 millivolt.

EXAMPLE:

Transducer sensitivity is 10.8 mv/psi. Expected pressure at transducer is 425 psi. 450 psi is chosen as the reference pressure.

Vr = 450 psi x 10.8 mv/psi = 4860 mv

Vr = 4.860 volts

With the dc voltmeter connected to the CAL SIG terminal on the INPUT/OUTPUT panel, the CAL/LEVEL switch in "LEVEL" position, and CHANNEL SELECT switch turned to channel being calibrated, adjust the 10-turn potentiometer until the voltmeter reads 4.860 volts ±1 millivolt. This completes the setup procedure for a single channel of the pressure system.

A check of the amplifier operation can be made by applying the calibration signal to the amplifier and checking the amplifier output for the expected volt/psi indication.

## EQUIPMENT OPERATION DURING DATA PLAYBACK

General. Data can be played back and recorded on an oscillograph or an X-Y plotter immediately after each test. Analysis of these data may reveal system or test item malfunctions that should be corrected before proceeding.

Recorder Speed. The recorder playback speed is determined by the time base expansion desired. Pressure data are normally recorded at the maximum speed (120 or 60 ips) and on-site playback for quick-look review is accomplished at 3-3/4 ips.

Oscillograph. Speed. The speed at which the oscillograph operates is directly proportional to the time base expansion of the signal being recorded. The oscillograph paper speed is planned in conjunction with the recorder speed to give a properly proportioned amplitude in relation to duration of the displayed wave shape. Generally, it is preferred to run the oscillograph at the lowest speed which will give the desired display. The time base can be expanded with the recorder. This method saves oscillograph paper and provides satisfactory results. It is recommended the oscillograph be operated at 1 ips when reproducing a complete time frame and 16 ips when reproducing data signals that are 1 to 5 milliseconds in duration. It may be desirable to reduce the oscillograph speed when reproducing data signals exceeding 5 milliseconds in duration and increase the oscillograph speed for data signals less than 1 millisecond in duration.

Vertical Deflection. Vertical deflection is variable and may be set to any level between 0 and 1 inch. It is recommended the vertical deflection be adjusted to provide approximately 1 inch deflection of the electrical calibration pulse which has previously been adjusted to a specific level based on the predicted pressure level on each data channel.

Paper Desired. Many types of paper are produced for oscillographs. Some of the older types fade easily and provide a poor quality record. Many of the newer types of paper provide a sharp, clear record and are nearly permanent. They will not lose the image data even if exposed to direct sunlight. Dataflash 70 (Bell & Howell) seems to provide the clearest trace with excellent lasting ability. Dataflash DP1 provides a good trace with good lasting ability. Dupont-produced MRK010 Spec 1 produces a good trace but fades with exposure to light after an extended period. It is recommended that the best paper available be used so the quick-look data are usable and permanent.

Digitizing. Analog data that are stored on magnetic tape can be digitized on site for storage or processing (at Test Areas C-80A and C-80C only). The present method of digitizing is as follows:

Each analog recorder-reproduce channel is set up so the electrical calibrate pulse recorded on that channel will be within the range that is acceptable to the temporary storage memory. Example: The memory can handle an input of from 0 to 1 volt dc. The reproduce output of the analog recorder is set so the calibration pulse "0" zero level is approximately 0.1 volt and the upper level of the calibration pulse is approximately 0.9 volt. This will enable the memory to store pressure data that are slightly higher than the calibration pulse as well as enable it to show data excursions below the zero level of the calibration pulse.

The stored information in the memory is then transferred to and recorded on digital tape.

Quick-Look Data Available. All ADTC pressure instrumentation systems are equipped to provide oscillograph records and X-Y plots of the analog pressure data. In addition, these data can be stored in a transient recorder and displayed on an oscilloscope for observation of the high-frequency component and other characteristics of the pressure data.

Time. The IRIG B time code is used to provide a 1,000-Hz time-coded frequency that can be played back along with the recorded event and pressure data for a time reference.

Calibration Level. Calibration pulses are recorded which correspond to a known peak pressure. This calibration can be compared to the data pulse to determine its amplitude.

Pressure-Time. Immediate playback of pressure-time on the oscillograph or X-Y plotter is available. All ADTC pressure instrumentation systems are equipped with 12-channel recording oscillographs and X-Y plotters for post-mission, quick-look review of pressure data collected on analog tape. Pressure profiles, calibration, T-O signals, and IRIG B time are displayed. Immediate analysis of pressure amplitude, velocity, and events are possible. The oscillograph at TA C-64A can adequately display 12 channels at 1-inch deflection. The oscillographs at TA C-80A and C-80C can adequately display seven channels at 1-inch deflection.

## DOCUMENTATION

DATA ACQUISITION/REDUCTION. The test engineer/officer will provide the test area personnel with an information sheet which will be used in conjunction with the test management document. This information will enable the range personnel to acquire the necessary mission support equipment (transducers, cables, mounts, firing lines, and test item stands). For a mission that has been run a few days prior to the desired mission and all the cabling and transducers are on site, 1-day notice may be sufficient; however, if parts and items need to be ordered, sometimes several months notice may be required. The information sheet will provide the following information.

1. Type transducer desired at each location.

2. Type transducer mount desired at each location.

3. Maximum expected pressure at each location.

4. Desired frequency response or filtering.

5. Desired quick-look data - special time base expansion requirements.

6. Time intervals between primary firing and second-event-event firings (if used).

7. Desired recorded event marks.

8. Location of breakwire or light detector.

9. Desired fragment protection.

10. Weather information required and weather limitations.

11. Miscellaneous.

12. Remarks.

On the mission day, the site personnel will complete an analog tape form for pressure data (Appendix A) . These personnel will also fill out and attach to the edge and side of the analog tape reel box an ADTC Form 81 for magnetic tape data (Appendix A).

If a digital tape is used, a VF-7550-3, Digital and Video Tape Label (Appendix A) will be filled out and attached to the digital tape reel.

Site personnel will also complete an ADTC Form 63 during the mission. A copy of this form will be kept on site. It will contain information pertaining to starting and stopping of data and mission functions. If this form contains information that will be relevant to interpreting or processing the tape recording, a copy will be included with the tape (Appendix A).

A Data Acquisition Form, VF-7909-3B, will be completed if a digital tape is recorded (Appendix A). One copy will accompany the digital tape, another copy will be kept on site.

All forms and copies of mission data that are kept on site will be placed in a folder with the project number, mission number, and date visible on the identifying tab. These copies will be retained until the project is completed or their usefulness has terminated as determined by the Test Officer and/or Site Supervisor.

All forms and miscellaneous unclassified documents sent from one area to another for processing will be indicated on and transferred by a hand receipt for miscellaneous unclassified documents. This releasing party will then place this receipt on file (Appendix A).

DATA DISPOSITION

Magnetic Tapes. After the test site has completed using the analog tape for quick-look data and for any necessary problem area determinations, the tape, accompanied by an analog tape form for pressure data and an ADTC Form 81, will be sent to the Computer Sciences Laboratory (TSX) for further processing of the recorded data.

Oscillographs. An oscillograph copy of data reproduced at 16 inches per second will be provided to the project personnel for quick-look data. Another copy will be kept on site. A third copy will accompany the analog tape. An additional oscillograph trace reproduced at 1 inch per second and annotated with the data and calibration times will accompany the analog tape to aid the Computer Science Laboratory personnel in determining the time of day from the recorded IRIG B time code. All oscillograph traces provided by a test site will be enclosed in a folder, box, or other method of handling to prevent excess exposure to sunlight or fluorescent lighting during transit or handling.

Other Data. Occasionally, other data such as a recorded test or recorded system calibration may be requested. All other data will be prepared as closely as possible to the desires of the requester. Where practical, the forms and methods described above will be used.

DATA FOR TRANSDUCER DIARY. On each test site that uses pressure transducers, a transducer diary will be kept. The purpose of this transducer record book will be to provide on-site personnel with a quick reference as to an individual transducer's serial number, sensitivity, type, and history.

Whenever a transducer is acquired by the site for mission purposes, the transducer specifications are recorded in the diary. An index of transducers by page number will be included in the front of the book. After the index, a section of transducer type, serial number, and sensitivities will be included. Following this section, an entire page will be reserved for each transducer.

After each mission, the mission date, pressure range in which the transducer was operating, and any other pertinent information will be included. If the transducer has suffered fragment hits, extreme temperature, or been subjected to pressures beyond its rating, these facts will also be included. This information will also be available to the Phase I Evaluation Facility and will accompany transducer returned to this facility for recertification.

# SECTION VII

# DATA HANDLING AND REDUCTION

## COORDINATION

Before any project requiring the services of the Computer Sciences Laboratory begins, a coordination meeting will be held with an appropriate Computer Sciences Laboratory representative, project officer, and test engineer present. Data requirements and reduction techniques will be established to the fullest extent possible. This allows the Computer Sciences Laboratory representative to inform project personnel of current techniques available and reduction procedures; these may change as equipment and software are updated. To insure that data recording and reduction techniques are adequate, the first test of a project will be processed and the data reviewed before conducting additional tests. Changes in requirements or additional requirements not covered in the project documentation will be approved through formal channels before requesting the support of the Computer Sciences Laboratory to meet such requirements.

## DATA RECEIPT

MAGNETIC TAPES. Magnetic tapes from the range, digital or analog, will be submitted for data reduction at the film and tape vault, Room 207, Building 380. Analog tapes shall bear an ADTC Form 81 for format and track identification. Digital tapes shall be accompanied by Form VF-7909-3B for file identification and format. Appendix A presents examples of these forms.

FORMS AND OSCILLOGRAPHS. Oscillographs and other data forms will be submitted along with the magnetic tapes. Oscillographs will be formatted and identified as described in Section VI. Data forms will be completed and submitted for each test as described in Section VI.

PROJECT MATHEMATICIAN NOTIFICATION. The project mathematician will be notified by film and tape vault personnel of the receipt of tapes on his project. Oscillographs and data forms are forwarded to him and he initiates the data reduction process.

## PROCESSING TECHNIQUES

ANALOG TAPES (Figure 23). To process analog tapes, calibration signals must be recorded on tape for each mission along with time in IRIG format for the duration of the calibrations and data. Calibration signals must be step functions or pulses of at least 200-microsecond duration. The signal may be from two levels up to five levels.

The FM signals from analog tape are played back through programmable demodulation to recover the data signal. Appropriate low-pass filters are set up to cover the frequency range of the data. Some error will be introduced in this process. When using FM recording for data containing high frequency components near the bandwidth of the recorder, typically errors of up to 10% may be expected. For blast pressure data, errors of this type would have the most effect on peak pressure values. This would have little effect on impulse data for blast pressure wave lasting several milliseconds.

The project mathematician will read the time of calibrations and data from oscillographs and supply these to the data reduction group in Telemag. This group will set up the computer program for the DEC PDP-15 computer to be used in the data reduction process.

Analog-to-digital conversion will be performed using the PDP-15 computer and related equipment. Effective sampling rates of 400K are presently in use for digitizing blast pressure data covering less than 15 milliseconds. Proportionately lower rates are used for data covering more than 15 milliseconds. When possible, sampling rates should be determined and agreed upon by the data reduction group, project mathematician, and project officer prior to the processing data of the first mission of each project. Adjustments in the rate may be necessary after reviewing the data. Sampling rates should be based on the maximum frequency of interest, not the frequency response of the recording system. A sampling rate of 3 to 5 times the maximum data frequency is normally selected to minimize errors introduced in the analog to digital conversion process.

Calibration signals are digitized first. The data reduction program stores 2,000 samples and then displays these on the Tektronix 4012 graphics terminal; 50 samples are averaged and stored at each calibration level. The levels represent the engineering units provided by test site personnel. The program contains options for eliminating noise spikes or overshoot from the 50 samples averaged.

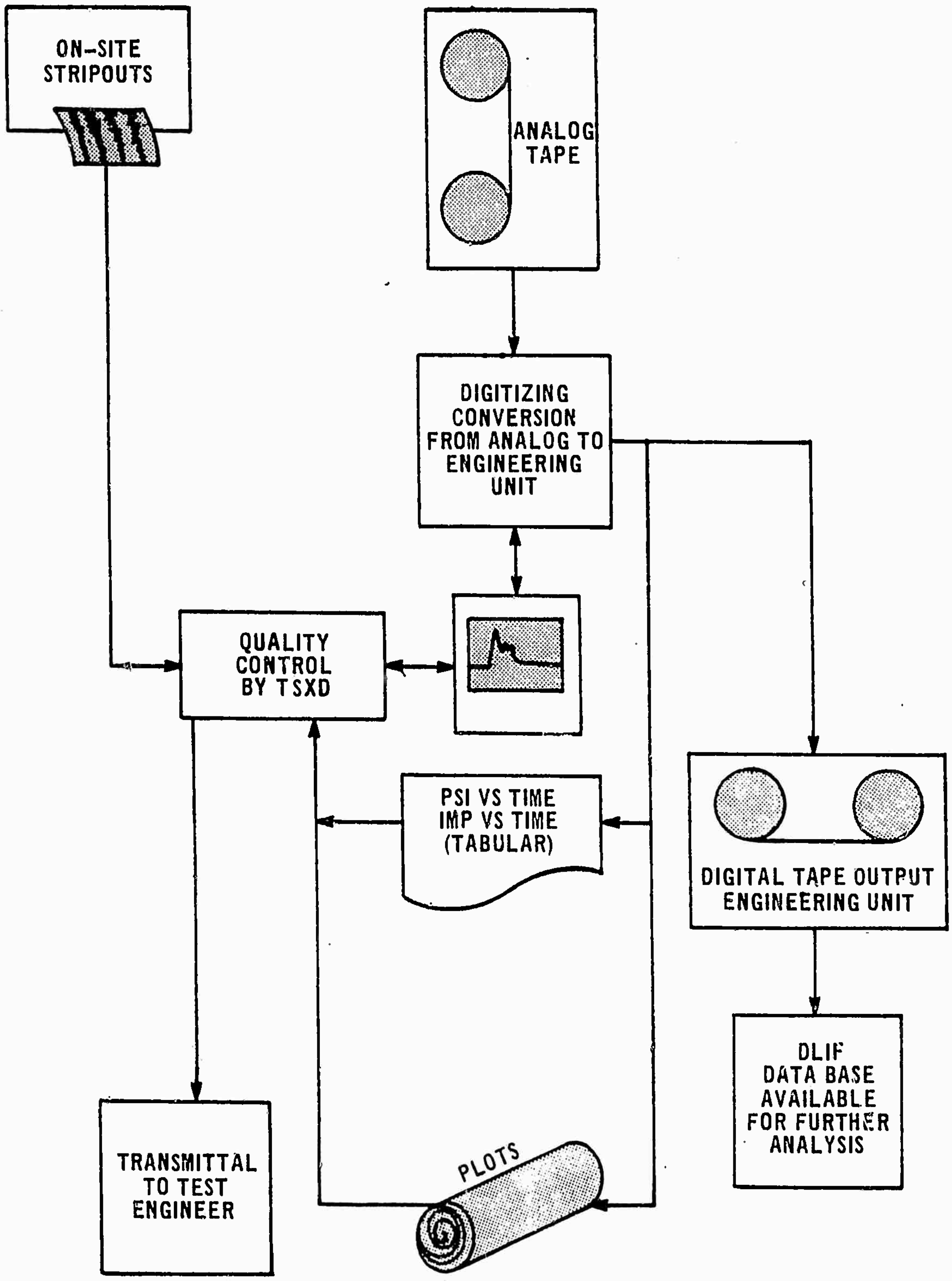


Figure 23. Functional block diagram of automatic pressure reduction system

The data signal is then digitized and stored. The program stores 6,000 samples and applies the calibration levels to convert to engineering units. The data are then displayed in engineering units versus time. The program contains options to expand the display over any interval desired.

Digitizing of data may be delayed from the T-O signal or start time to recover data that occur beyond the range of 6,000 samples taken immediately. Delays of up to 130 milliseconds may be used. Each channel of data will be referenced to this T-O or start time for the purpose of determining shock wave arrival time. To obtain the best possible accuracy for shock wave arrival time, a T-O signal should be recorded on each recorder data channel. During playback for data reduction, the T-O signal that corresponds to the data channel to be processed will be used to initiate digitizing.

Impulse, or area under the data curve, calculations are made by the program over the same interval chosen for display. The "trapezoidal rule" is used in this computation. All samples or only positive samples may be used.

$$AREA = H \; X(Y(\emptyset) + 2 \; X \; Y(1) + 2 \; X \; Y(2) + \ldots 2 \; X \; Y \; (N-1) + Y(N)/2$$

where

Y = Successive samples

H = Delta time between samples

N = Number of data points

The impulse curve is displayed immediately after clearing the pressure profile plot.

Program P5237 is utilized in performing the conversion process just described. This program contains the following output options:

1. Plot of calibration signal
2. Plot of pressure versus time (show SWA time)
3. Plot of impulse curve
4. Tabular data
5. Digital tape record.

It is recommended that only 2, 3, and 5 from above be chosen for output to reduce computer time. Tabular data are output more efficiently and expeditiously by the CDC 6600 computer.

DIGITAL TAPES. Digital tapes, whether produced at the test site or in Telemag, will be identified by project number, date, and file content. Tapes from the test site will be processed by the project mathematician using the CDC 6600. Program P1222 converts the data to engineering units and produces profile and impulse plots on the FR80 photographic plotter. This program plots and lists all samples for each file chosen for processing.

Digital tapes produced in Telemag will be filed for only as long as necessary for possible further processing on the CDC 6600 and FR80. These tapes will contain all 6,000 samples, in engineering units, taken during the analog-to-digital conversion process. Digital tapes can be made available for open shop programming or may be used by the proj -t mathematician depending on the requirements of a particular project. Tabular data, if required, will normally be listed from these tapes using the CDC 6600. Plotting from these tapes may be accomplished using the FR80 plot programs.

DATA FORMATS.

PDP-15. The format of calibration plots will be counts versus sample number (Figure 24).

The format of pressure profile data produced using the PDP-15 will be a plot of pressure versus time in milliseconds. The scale for pressure will be based on the calibration levels or minimum and maximum values of data for that channel. The time base will vary depending on the time interval chosen for display, but will always be referenced to a time, T-O, for correlation of data on separate channels. Peak pressure, time of shock wave arrival, and total impulse will be printed above the plot. A 75-character line of Hollerith information will be printed above the plot. This information may be whatever the project officer desires. Pressure profile plots will be compared to oscillograph records for wave shape and time of arrival, not to verify accuracy (Figure 25).

Impulse-time plots will be scaled to the smallest and largest impulse values and will cover the same time interval as the pressure-time plot (Figure 26).

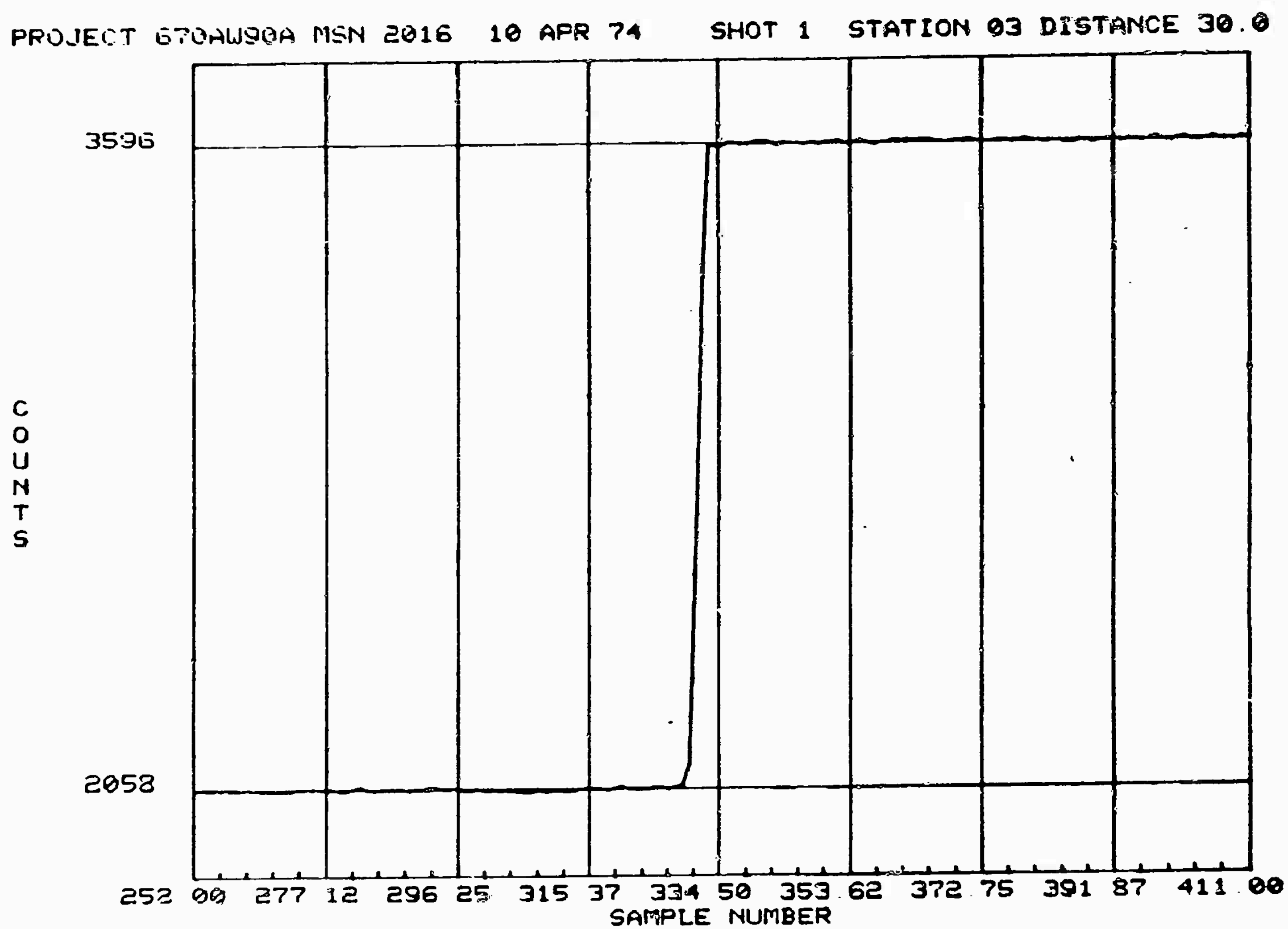


Figure 24. Typical plot of calibration pulse

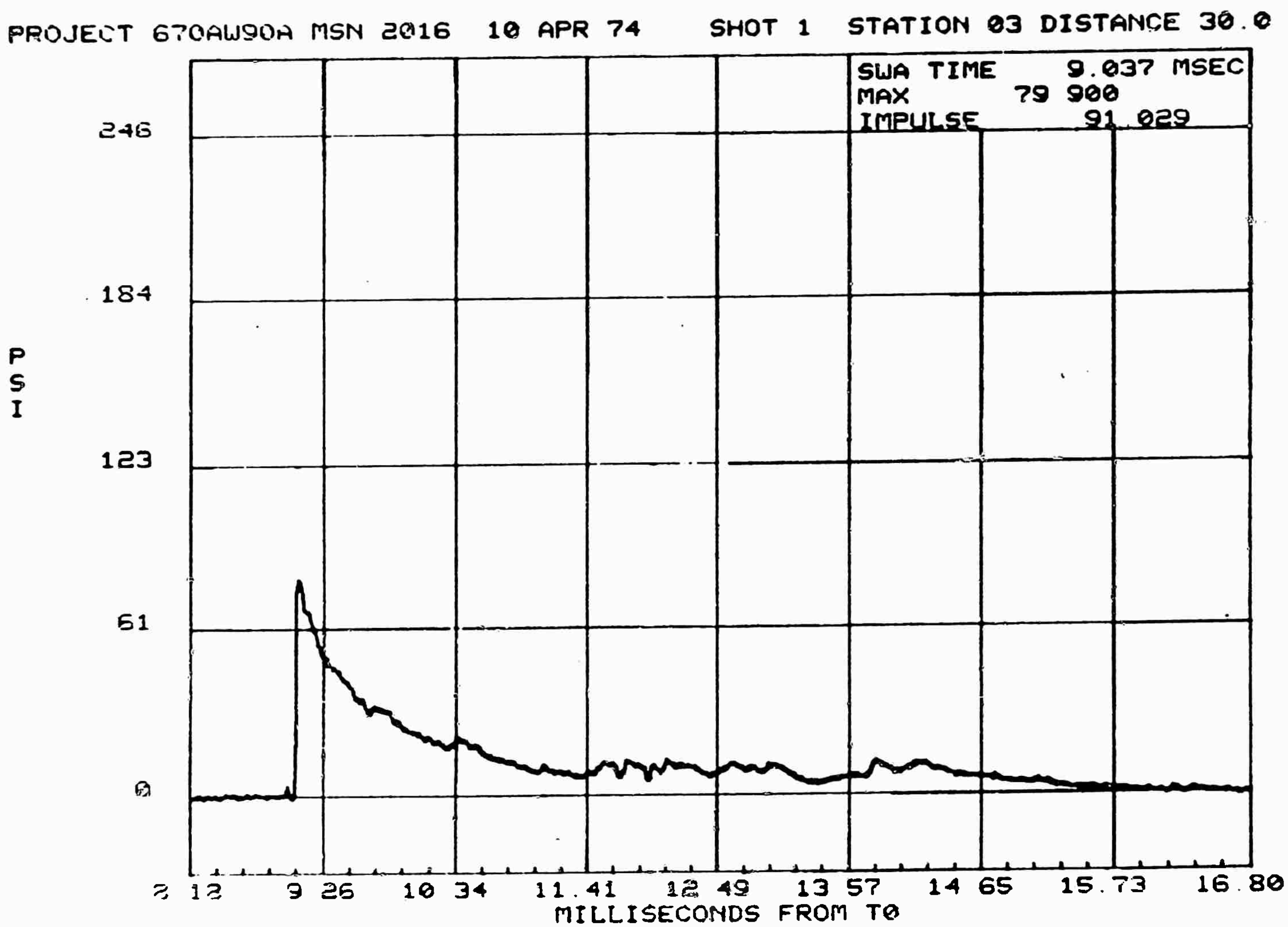


Figure 25. Pressure versus time plot (typical format)

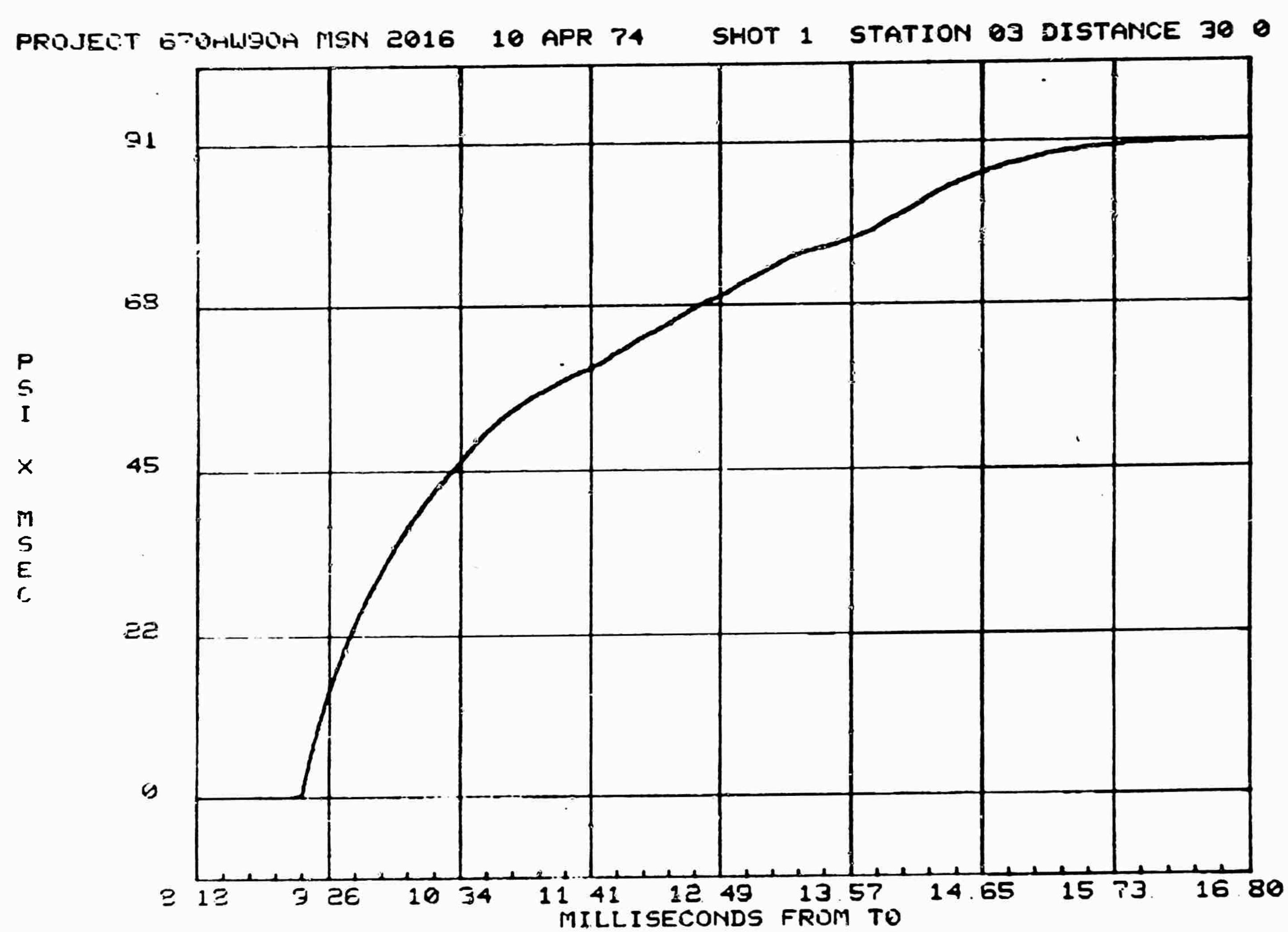


Figure 26. Impulse versus time plot (typical format)

Tabular data listings will consist of pressure-time, impulse-time, and time of shock wave arrival. The data will be listed in engineering units. The program has the option to list every sample or every Nth sample. The amount of tabular data output should be minimized to save computer time and paper.

CDC 6600. Output formats using the CDC 6600 are essentially the same as those described using the PDP-15. Plot formats are somewhat more flexible in that the amplitude scaling may vary from the calibration levels. This requires another step in the reduction process; therefore, turnaround times are longer than when plotting on the PDP-15 for data being digitized from analog tape.

SPECIAL DATA REDUCTION TECHNIQUES.

PDP-15 Computer. At present, the only technique available for data correction on the PDP-15 is for baseline offset. This is computed by averaging the first 50 samples from the start time and, if desired, this value is subtracted from each data sample before further processing.

CDC 6600 Computer. Techniques such as logarithmic plotting, smoothing through the use of low-pass and high-pass software filters, and meteorological correction (Ref Appendix C of Reference 16) can be made available if there is a valid requirement. This may necessitate software development or obtaining software from other agencies. In any case, the project mathematician should be consulted before each new project to determine what the requirements are and what techniques are available.

## DATA DISPOSITION

Data will be transmitted from the Computer Sciences Laboratory, project mathematician, to those organizations specified in the project documentation. The number of copies to be supplied to each recipient will be stated in the project documentation. Data recipients will be notified by the project mathematician when their data are ready.

## REFERENCES


1. Air Blast Pressure Measurement System and Technique, Gigliotos and Linnenbrink, Ballistic Research Laboratory, Aberdeen Proving Ground, MD.

2. Ballistic Research Laboratory, Aberdeen Proving Ground, MD Memorandum Report No. 1638, C.N. Kingery, R.C. Keller, March 1973.

3. Ballistic Research Laboratory, Aberdeen Proving Ground, MD Memorandum Report No. 1518, C.N. Kingery, B.F. Pannihill, April 1964.

4. JMEM Air to Surface Test Procedures for HE Bombs USAF TH 61A1-3-7.

5. Ballistic Research Laboratory, Aberdeen Proving Ground, MD Memorandum Report No. 1425, R.E. Shear, Edwin Wright, August 1962.

6. Ballistic Research Laboratory, Aberdeen Proving Ground, MD Memorandum Report No. 1807, N.H. Ethridge, December 1966.

7. Ballistic Research Laboratory, Aberdeen Proving Ground, MD Memorandum Report No. 1092, Goodman, 1960.

8. IEEE Standard Dictionary of Electrical and Electronic Terms, IEEE Standard 100-1972.

9. The Bell and Howell Pressure Transducer Handbook, CEC/ Instruments Division, Bell and Howell.

10. Introduction to Transducers for Instrumentation, Statham Instruments, Inc.

11. Safety and Performance Tests for Qualification of Explosives, Published by Direction of Commander, Naval Ordnance Systems Command, 1 January 1972.

12. Dynamic Calibrations of Pressure Transducers at the Ballistic Research Laboratory Shock Tube Facility, George A. Coulter, May 1967.

13. Piezotron® Couplers, Kistler Instrument Company, brochure, date code 223-6/173R.

REFERENCES (Concluded)

14. Impedance Converters for Piezoelectric Transducers, Kistler Instrument Company, brochure, date code 222-4/771.

15. Instruction Manual Models 504D and 504D3 Dual Mode Amplifiers, Kistler Instrument Company, April 1971.

16. Ballistic Research Laboratory, Aberdeen Proving Ground, MD Memorandum Report No. 2236, Charles N. Kingery, October 1972.

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APPENDIX A

FORMS FOR MAGNETIC TAPE DESCRIPTION AND MISSION REPORT

| TAPE REEL | BOX EDGE | | MAGNETIC TAPE DATA | | | |
|---|---|---|---|---|---|---|
| PROJ | PROJ | PROJ | TRACK A | | TRACK 8 | |
| DATE | DATE | DATE | 1 | | 9 | |
| MISSION | MISSION | MISSION | 2 | | 10 | |
| TIME | TIME | TIME | 3 | | 11 | |
| SITE | SITE | SITE | 4 | | 12 | |
| CLASS | CLASS | CLASS | 5 | | 13 | |
| ☐ ORIGINAL ☐ COPY | ☐ ORIGINAL ☐ COPY | ☐ ORIGINAL ☐ COPY | 6 | | 14 | |
| SPEED IPS | SPEED IPS | SPEED IPS | 7 | | 8 | |
| REWOUND ☐ YES ☐ NO | REWOUND ☐ YES ☐ NO | REWOUND ☐ YES ☐ NO | | | | |
| REEL NO | REEL NO. | REEL NO. | TYPE RECORD RECORDER | REMARKS | | Operator(s) |

ADTC FORM 81 — PREVIOUS EDITION MAY BE USED UNTIL STOCK IS EXHAUSTED — AFSC EGLIN AFB FLA

Figure A-1. Magnetic tape data form

| Tape No. | Date | | Recorder |
|---|---|---|---|
| Classification | | | Group No. |
| | | | Density H L |
| Project Number | | | Msn. No. |
| Site No. | Radar Pad No. | | No. Files |
| | | | Reel____ of____ |
| VF-7550-3 | DIGITAL AND VIDEO TAPE LABEL | | |

Figure A-2. Digital and video tape label

VITRO SERVICES

Eglin Air Force Base, Fla.

HAND RECEIPT FOR MISCELLANEOUS UNCLASSIFIED DOCUMENTS

TO______________________________ FROM______________________________

RECEIVED BY______________________________ RELEASED BY______________________________

DATE & TIME______________________________ DATE & TIME______________________________

| DESCRIPTION OR TYPE OF DOCUMENT | PROJECT OR IDENTIFYING NUMBER |
|---|---|

NOTE: This form is to be used as a receipt for any unclassified Documents or Data for which another form has not been prescribed. Signed copies may be destroyed after 90 days retention.

VF-7901-1

AFSC - EGLIN AFB, FLA.

Figure A-3. Form for hand receipt for miscellaneous unclassified documents

| DATA COLLECTION REPORT | | | | | *Page of Pages* |
|---|---|---|---|---|---|
| 1. MISSION DATE | 2. MISSION NO. | 3. PROJECT NO. | 4. SUPPORTED (*Zulu Time*) FROM | TO | 5. SITE EQUIPMENT LOCATION<br>POSITION |
| 6. INSTRUMENT | 7. PAD NO. | 8. REEL NO. | 9. ITEM TRACKED (*Tail No., if aircraft*) | | |
| 10. SKIN OR BEACON TRACKING | | 11. OTHER | | 12. OPERATOR | |

| 13. DATA CONCERNING MISSION OPERATIONS, INCLUDING PREMISSION AND POSTMISSION CALIBRATIONS | | | |
|---|---|---|---|
| A. RUN NO. | B. 'Z' TIME START | STOP | C. REMARKS |
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ADTC FORM 63 JUL 69 PREVIOUS EDITION WILL BE USED UNTIL STOCK IS EXHAUSTED

Figure A-4. Data collection report form

DATA ACQUISITION FORM, TEST AREA C-80 COMPLEX

PRESSURE

Date__________ Mission Number__________ Project__________ T/A__________

Type Munitions____________________ Type Test____________________

Tape Serial Number____________________ Temperature____________________

| FILE | STATION | CAL | GAIN | SENSITIVITY |
|---|---|---|---|---|
| | | | | |
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Remarks________________________________________

________________________________________________

________________________________________________

____________________

Signature

VF-7909-3B (Rev 13 September 1971)

Figure A-5. Data acquisition form, Test Area C-80 complex

# APPENDIX B

## EXAMPLES OF DATA ANOMALIES

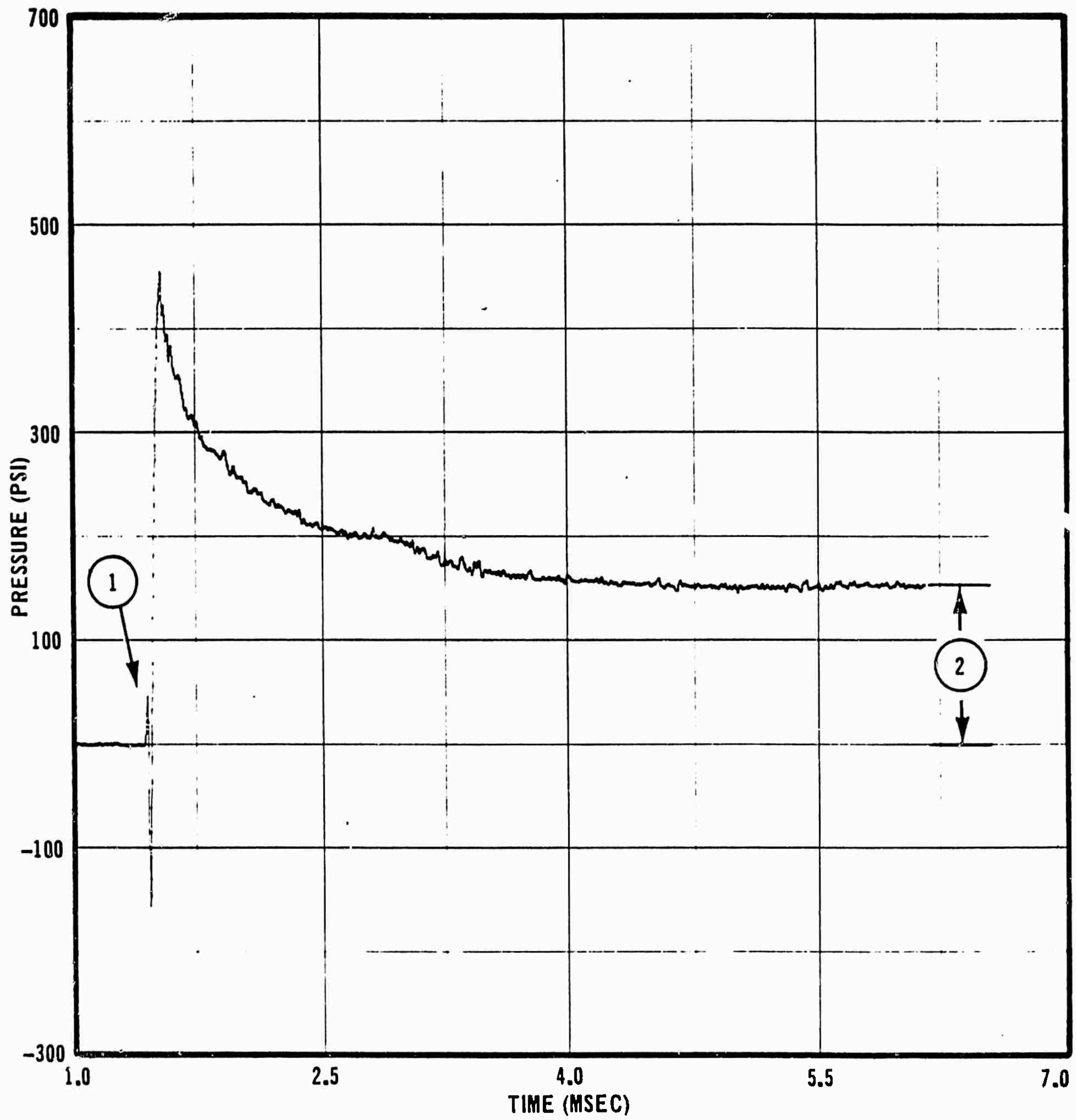



Figure B-1. Plot showing: (1) preshoot and (2) baseline shift

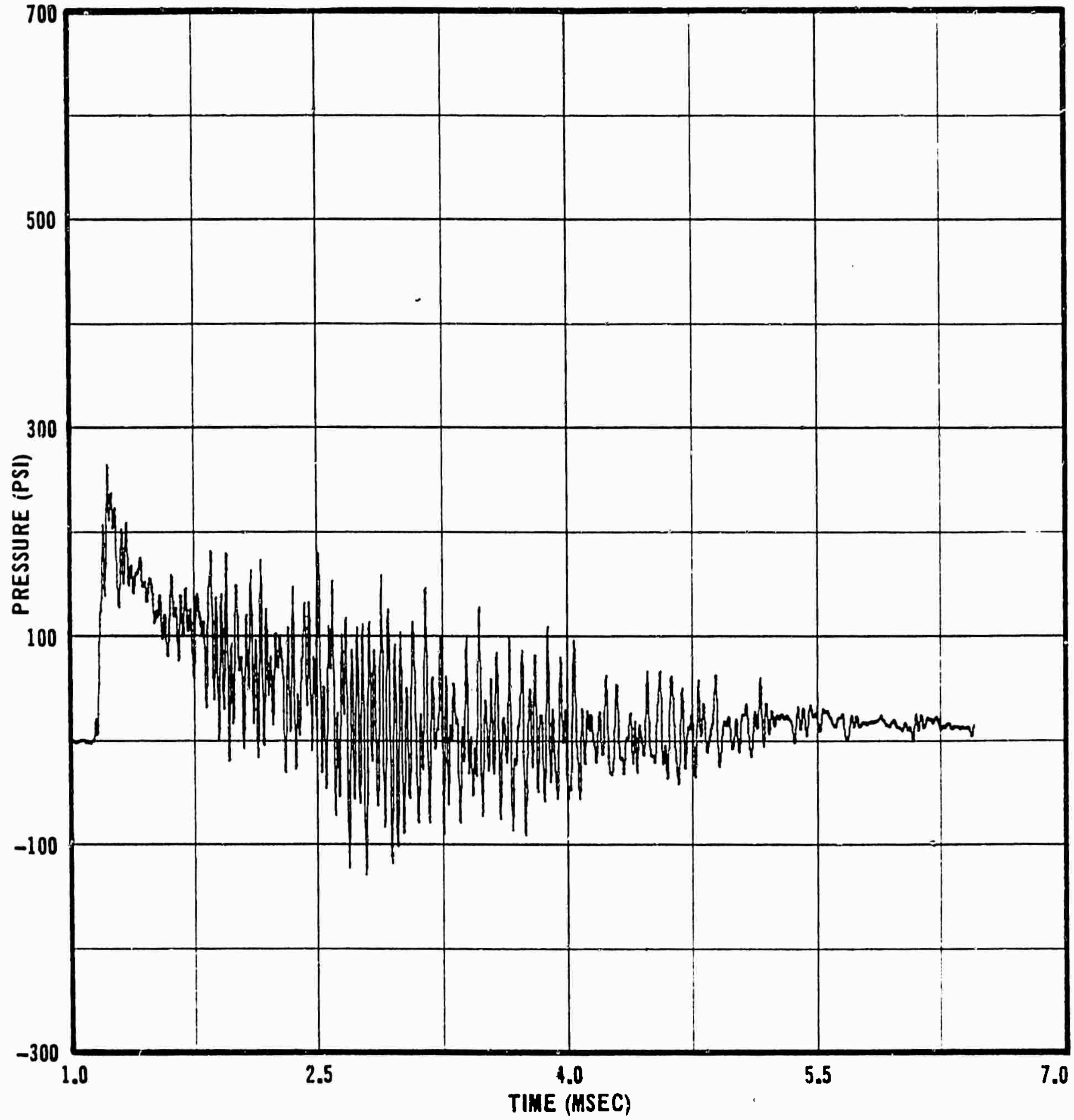



Figure B-2. Example of defective transducer probably caused by "cracked" crystal

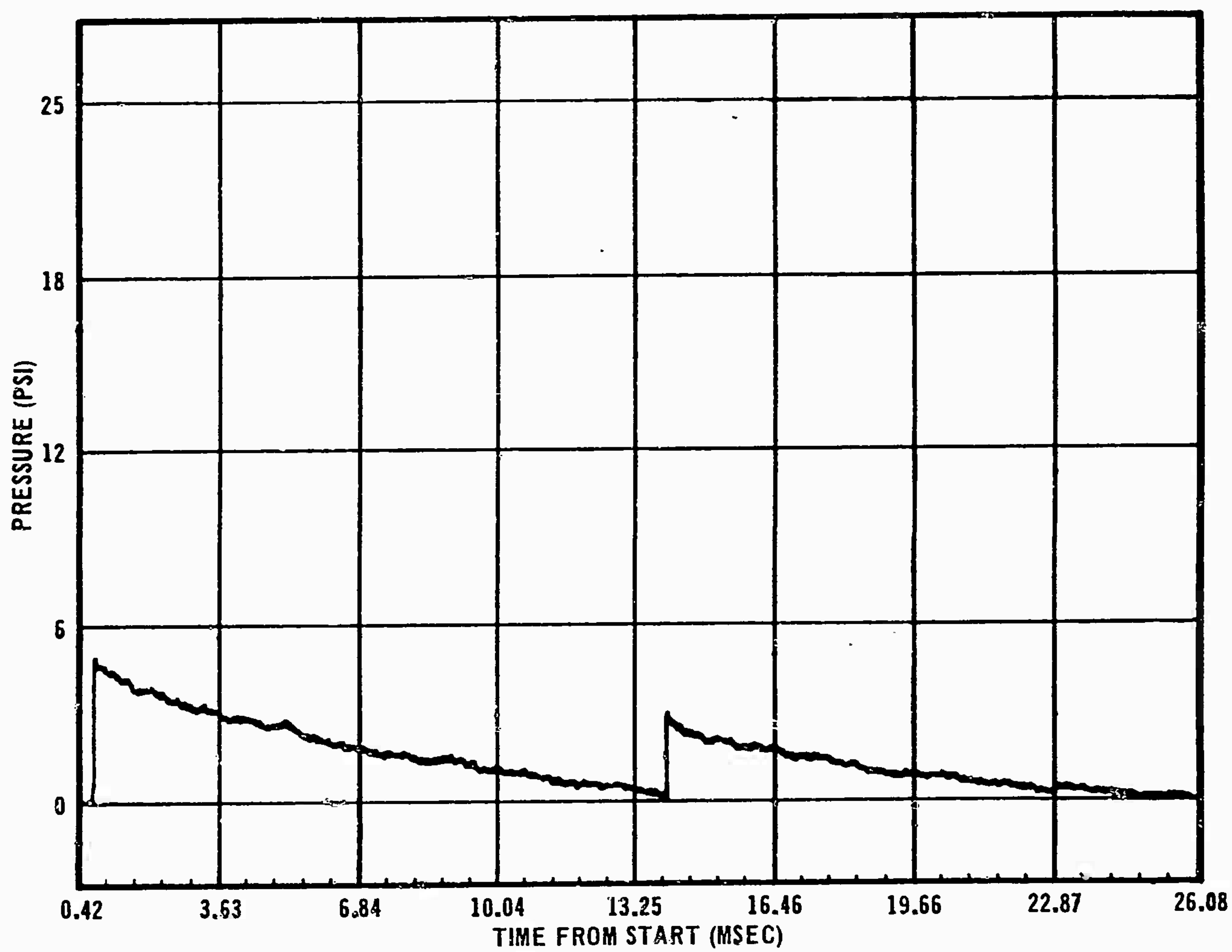



Figure B-3. Example of reflected pressure following the initial pressure

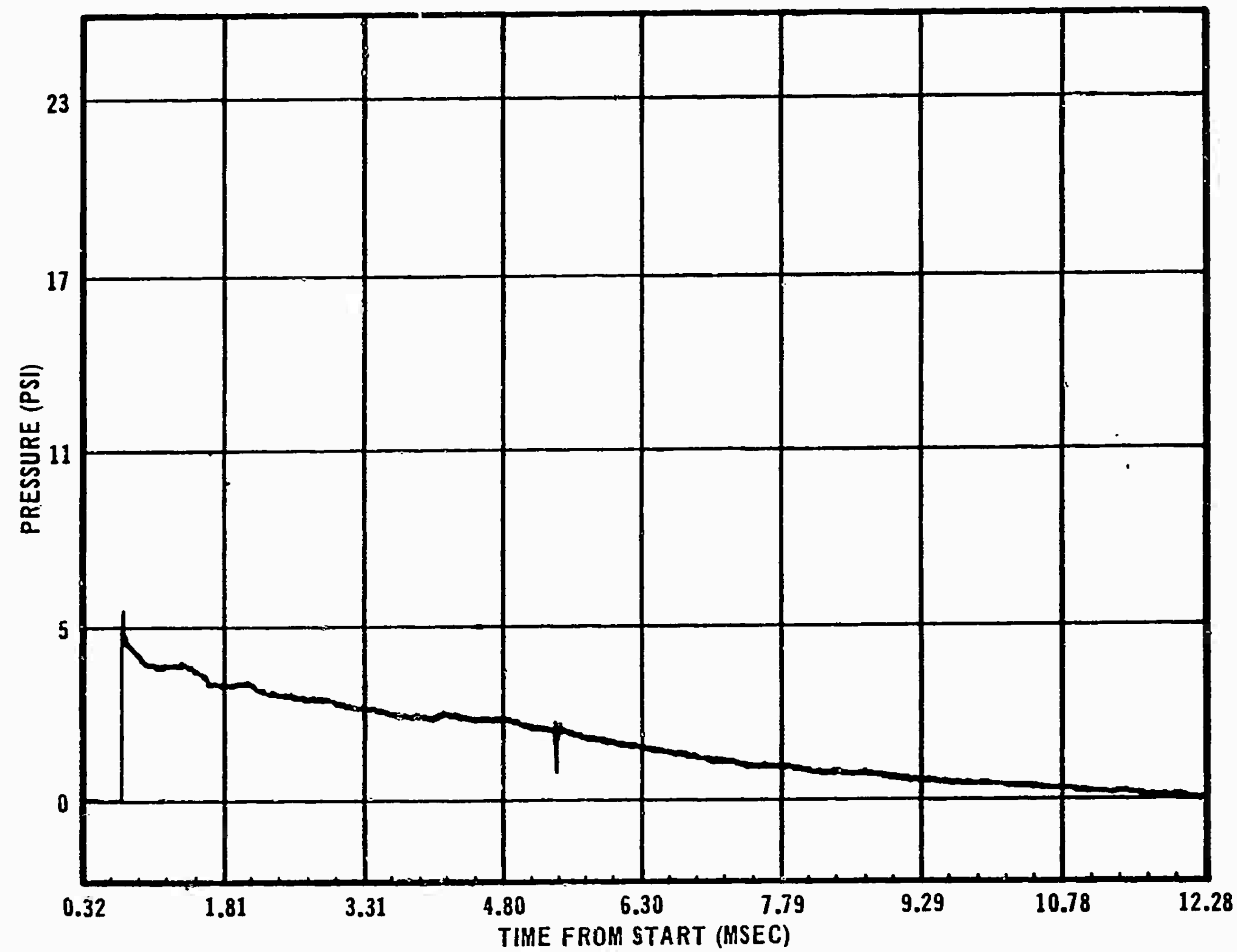



Figure B-4. Example of noise glitch on pressure-time plot

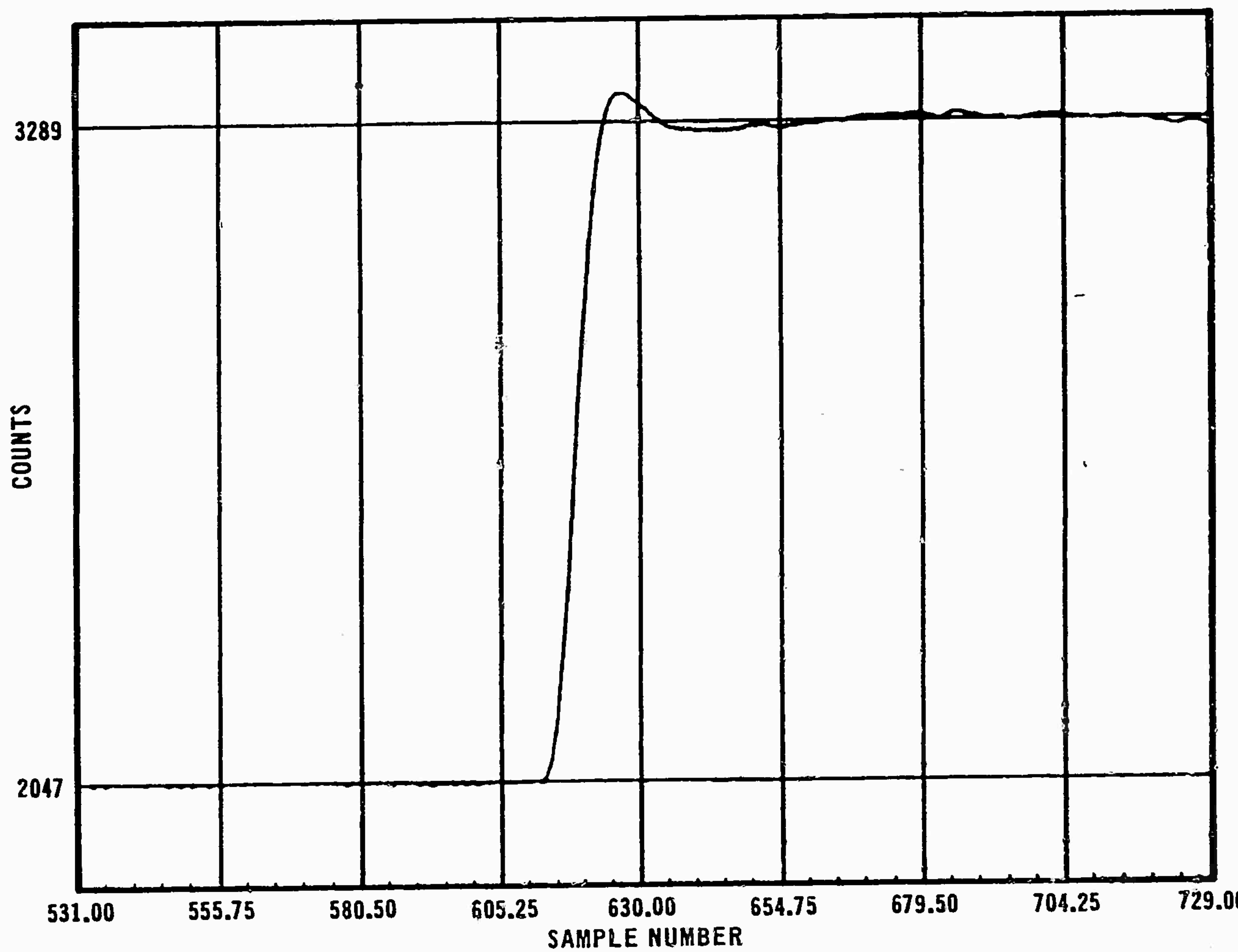



Figure B-5. Example of overshoot on plot of calibration pulse

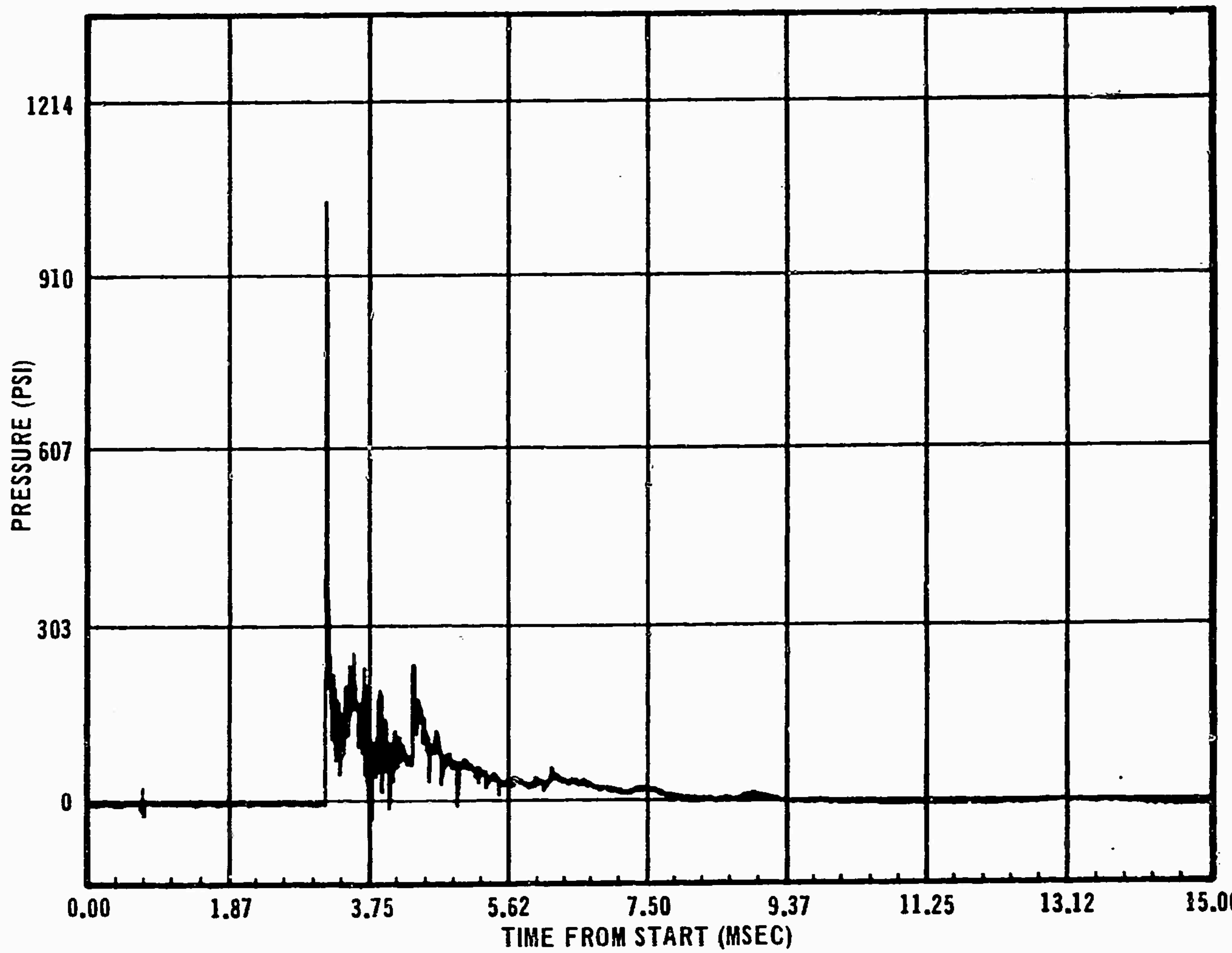



Figure B-6. Example of overshoot and ringing probably caused by exciting transducer into resonance

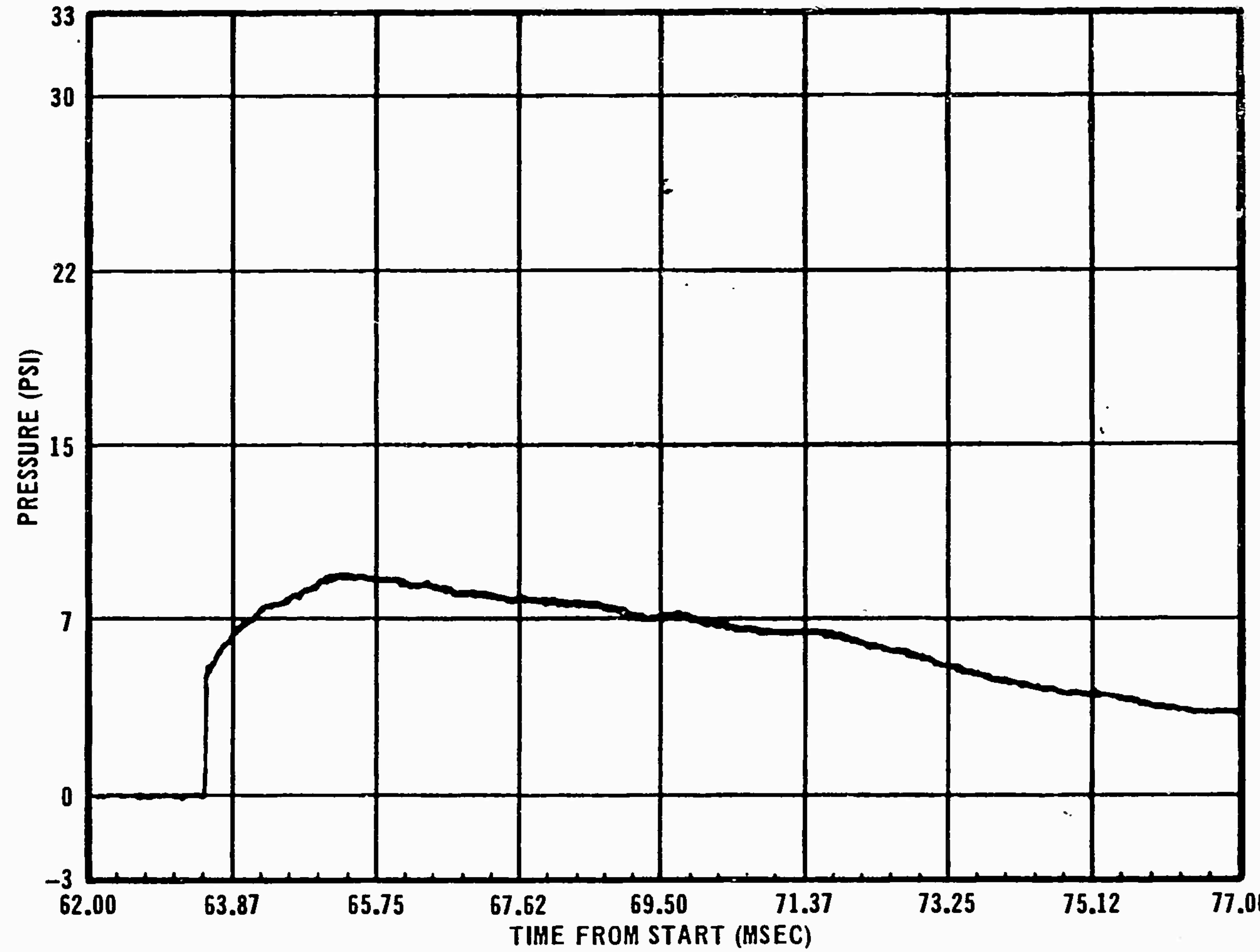



Figure B-7. Example of pressure-time plot when defective impedance converter is used with transducer

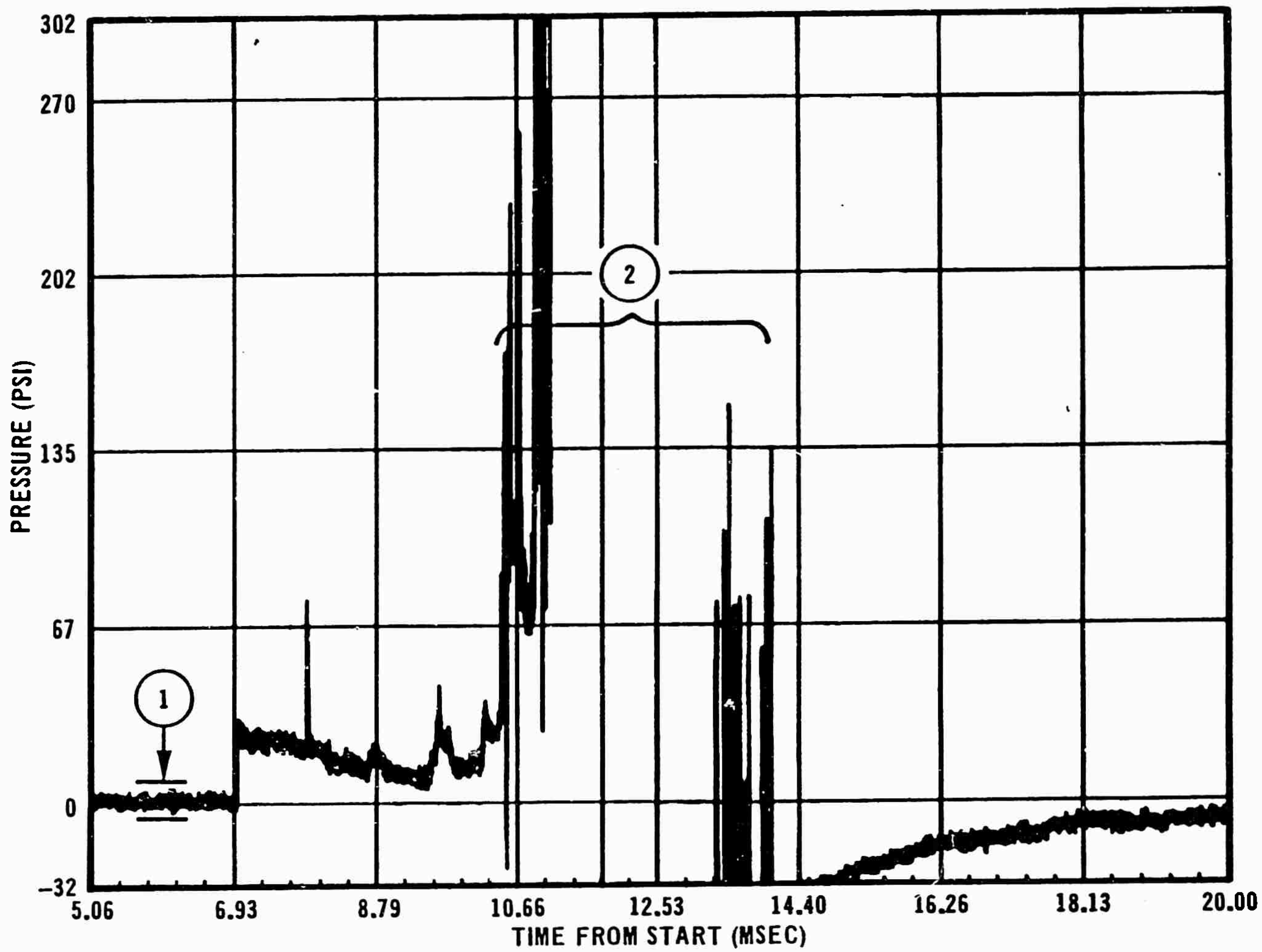



Figure B-8. Plot showing: (1) excessive ambient noise level and (2) broken transducer cable or poor connection

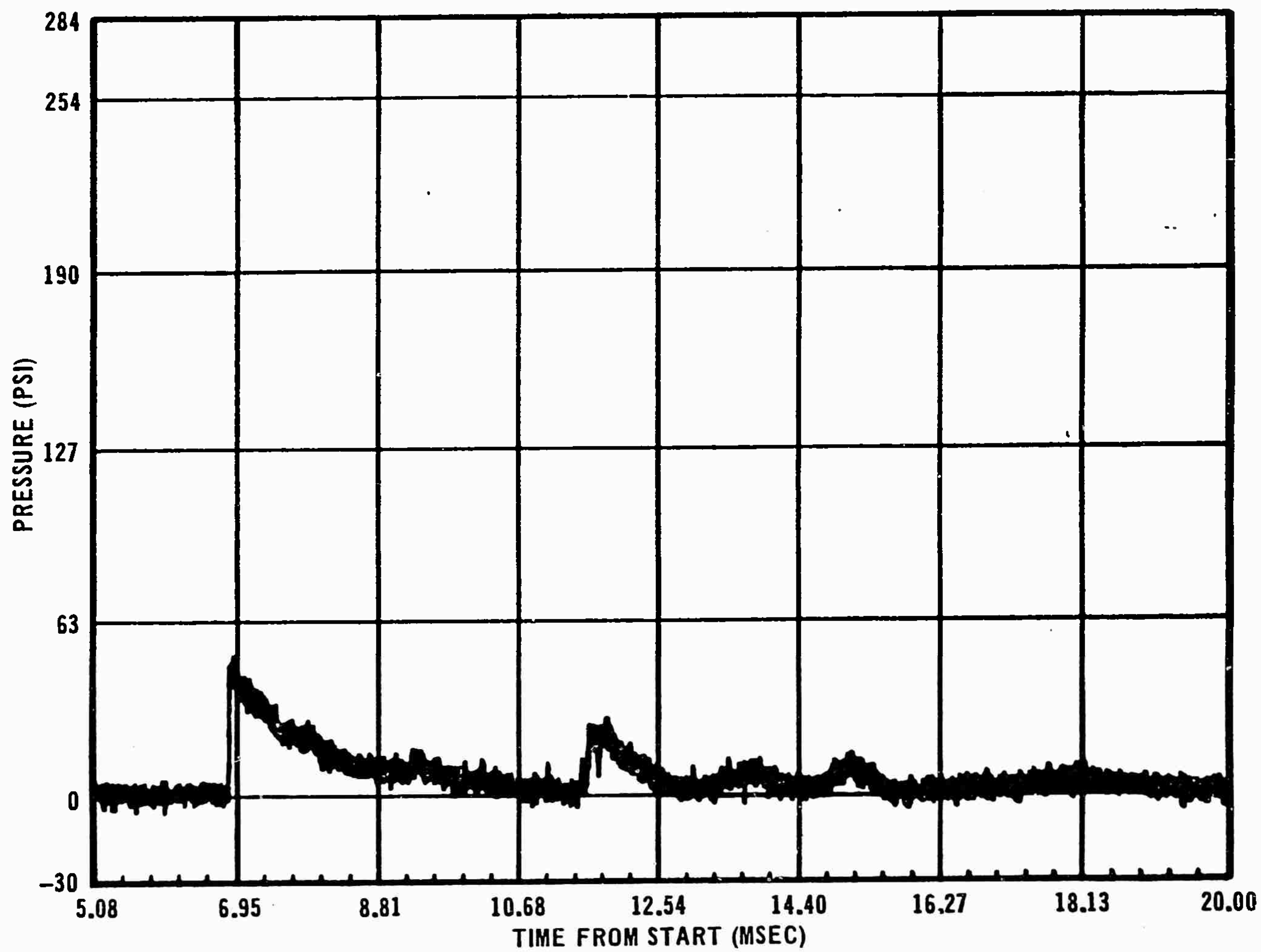



Figure B-9. Example of excessive ambient noise level probably caused by improper alignment of playback tare recorder

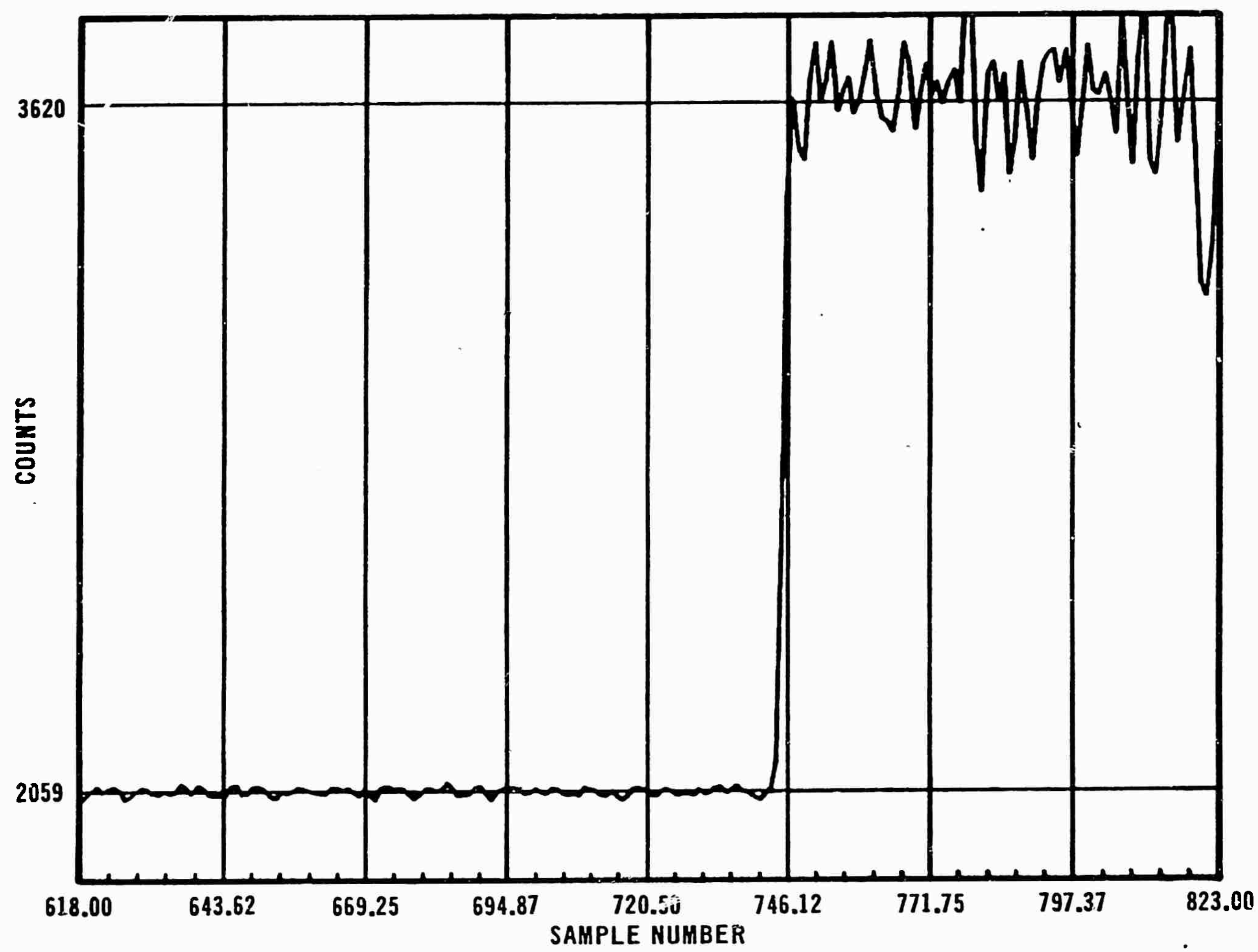



Figure B-10. Example of poor calibration waveform probably caused by malfunction or misalignment of di criminator

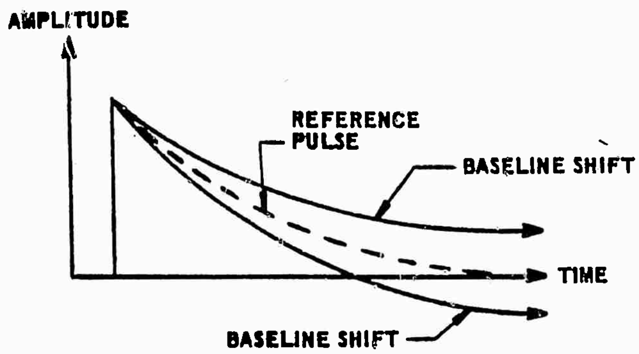
## GLOSSARY

AIR BLAST. The disturbance (shock wave) propagated through the air arising from a source of suddenly expanding gases (as from explosions, bursting diaphragms, sparks, etc.).

BANDWIDTH. The bandwidth is the frequency at which the function falls to -3 db below its value at zero frequency.

BARE CHARGE. A charge which is not in a case.

BASELINE SHIFT. The deviation as shown of a pulse waveform from a reference waveform.




CALIBRATION. The process of relating a sensor or system output to an absolute physical or electrical input. For a complete understanding of the system, calibrations are performed which cover the usable range of the systems and include both steady-state and transient response.

DETONATION. The extremely rapid chemical reaction which occurs in the explosion of high explosives. Detonation is characterized by its propagation through the mass of explosives as a wave, by its great velocity, by the fact that it can be initiated by a shock or blow, and by the extremely high pressures developed.

DYNAMIC PRESSURE (Q). Pressure due to particle flow behind a shock, $Q = 1/2\ pv^2$ - where p is the air density and v is the particle flow velocity behind the shock.

EXCITATION. The external electrical voltage and/or current applied to a transducer.

FACE-ON PRESSURE. See reflected pressure.

FAR FIELD. That region beyond an explosion in which an air shock is well defined in the atmosphere; the chemical energy is no longer contributing to the environment.

FREE AIR SHOCK. A shock moving through the atmosphere with no chemical or physical outside influences affecting it.

GLITCH. A perturbation of the pulse waveform of relatively short duration and of uncertain origin.

GROUND ZERO. Origin of a coordinate system usually located on the centroid of an explosive device being tested.

IMPULSE. Area under the pressure-time history curve (psi-ms) usually assumed to be cumulative positive impulse.

INCIDENT (SIDE-ON) PRESSURE. Free field pressure measured in the blast wave without interference to the flow behind the shock (psi).

LINE. The cable used to condition and transmit information from the transducer to the recording system.

MACH STEM. The single shock wave which, under the proper conditions, is produced by the reflection of a shock wave from a surface, or by the interaction of two shock waves. The incident and reflected shock waves are coalesced in the Mach stem.

MEASURAND. A physical quantity, property, or condition which is measurable.

MOUNT. The housing used to protect and couple the transducer to the medium being measured.

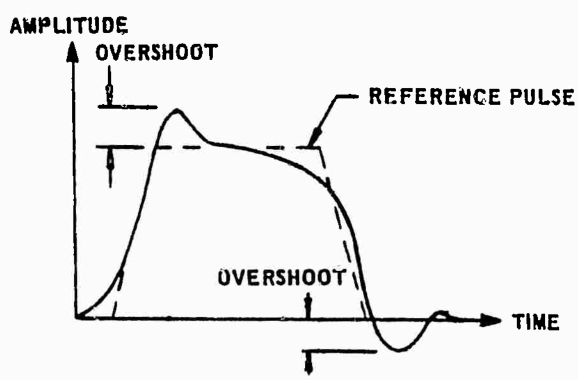
NATURAL FREQUENCY. The frequency at which a system with a single degree of freedom will oscillate from the rest position when displaced by a transient force. Sometimes used synonymously with damped natural frequency.

NEAR FIELD. That region near or inside an explosion where a detonation process is occurring or chemical energy is being transmitted to the atmosphere.

OUTPUT MONITORING EQUIPMENT. The electronic apparatus employed to provide indications and/or recordings of a transducer output.

OVER-RANGE PRESSURE. Pressure applied in excess of the rated range of a pressure transducer.

OVERSHOOT. The deviation as shown of a pulse waveform from a reference waveform. (Definition obtained from IEEE Standard Dictionary of Electrical and Electronic Terms.)




PEAK PRESSURE. The pressure in the initial part of a shock wave. It is usually, but not always, the highest pressure in the wave.

PIEZOELECTRIC. The property, exhibited by certain crystals, of generating an electric charge when subjected to pressure.

PIEZOELECTRIC TRANSDUCER. A transducer that depends for its operation on the interaction between electrical charge and the deformation of certain materials having piezoelectric properties.

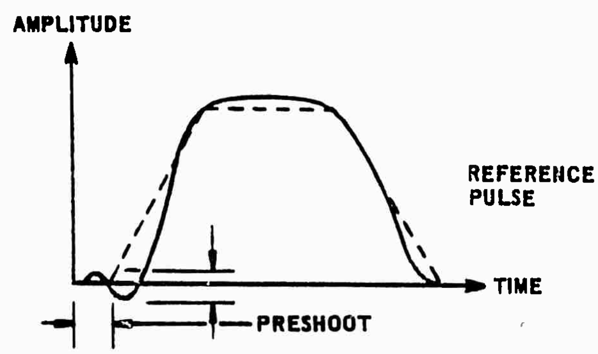
PIEZORESISTIVE STRAIN GAGE. A device consisting of an electrical conducting filament which exhibits the property of changing electrical resistance under the influence of mechanical strain.

POSITIVE DURATION. The time during which the pressure in a shock wave is greater than that of the atmosphere.

POSITIVE IMPULSE. The integral $\int_{t}^{t_c}$ pdt, where p is the pressure at the time t and $t_c$ is the positive duration of the wave, measured from the zero of time of the arrival of the shock wave at a gage; hence, the area under the positive pressure part of the pressure-time curve; hence, the average pressure in this time, times the positive duration.

POSITIVE PHASE. The part of the shock wave whose pressure is greater than that of the atmosphere.

PRESHOOT. The deviation as shown of a pulse waveform from a reference waveform. (Definition obtained from IEEE Standard Dictionary of Electrical and Electronic Terms.).




PYROELECTRICITY. The electrical charge produced on the faces of some crystals when they are strained (by application of heat).

RANGE. The spectrum of measurand values which exists between the upper and lower limits of the transducer's measuring capability.

RECORDING. The process of storing information. Some processes used today include magnetic tape, punched paper tape, oscillographs, magnetic disks, oscilloscopes, film, and magnetic memories.

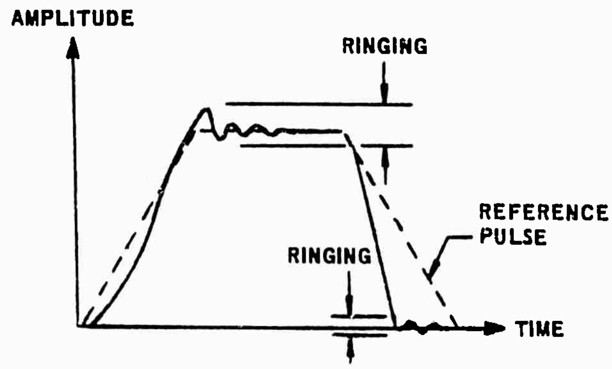
REFLECTED (FACE-ON) PRESSURE. Pressure measured on a rigid plane surface oriented normal to the shock velocity vector (psi).

REFLECTION COEFFICIENT. The ratio of reflected pressure over incident pressure.

RESISTANCE STRAIN GAGE. A device consisting of an electrical conducting filament which exhibits the property of changing electrical resistance under the influence of mechanical strain.

RESONANT FREQUENCY. The measurand frequency at which a transducer responds with maximum output amplitude.

RINGING. The deviation as shown of a pulse waveform from a reference waveform. (Definition obtained from IEEE Standard Dictionary of Electrical and Electronic Terms.)




SECOND EVENT CHARGE. Small charges of high explosive used to detonate the cloud of a fuel air explosive device.

SENSITIVITY. The ratio of the change in output to a change in the input.

SHOCK. A pressure discontinuity in a compressible fluid. A shock always advances into the low-pressure medium.

SHOCK WAVE. A region of compression, propagated through the medium (gas, liquid, or solid) in the front of which the pressure rise is almost infinitely steep.

SHOCK WAVE. In gas, a wave of increasing pressure characterized by its very abrupt rise. Normally of finite intensity (not infinitesimal).

SHOCK WAVE VELOCITY. Velocity or speed of the shock front.

SIGNAL CONDITIONING. The process of preparation of the electrical signals from the transducer for recording. Some types of conditioners use AM, FM, FM-multiplex, digital, amplification principles in preparation of the signals for recording.

STRAIN GAGE. Converting the measurand into a change of resistance due to strain, usually in two or four legs of a Wheatstone Bridge.

TIME CONSTANT. For linear systems, the time it takes for the response function to fall from any value R to R/e where e = 2.72.

TIME OF ARRIVAL. The time a shock wave arrives at a given point in space usually referred to time of detonation.

TRANSDUCER. A device which provides a usable output in response to a specified measurand. Usually output is in voltage and the input is a mechanical parameter.

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