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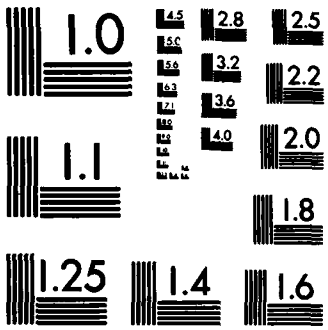
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NOISE ABATEMENT INVESTIGATION FOR THE BLOODSWORTH ISLAND TARGET RANGE: DESCRIPTION OF TEST PROGRAM AND NEW LONG RANGE AIRBLAST OVERPRESSURE PREDICTION METHOD

AD A122292

BY RICHARD A. LORENZ

RESEARCH AND TECHNOLOGY DEPARTMENT

1 NOVEMBER 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A new airblast magnitude prediction method has been developed in an effort to reduce the impact of naval explosive exercises (both airdrops and naval gunfire) on the communities surrounding the Bloodsworth Island target range in the Chesapeake Bay. This method uses measured or forecast upper air meteorological data to predict the airblast levels to be expected in the neighboring communities from explosions of any size. The maximum, median, and minimum expected airblast levels, as well as

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20. ABSTRACT (Cont.)

the statistical distribution, can be determined. The method is applicable to both positive and negative sound velocity gradients and should be adaptable to other explosive operations.

Typical range operations were monitored in the communities surrounding the target area and the airblast measurements were correlated with weather data taken during the exercises. This report describes the test program and the acquired data. Justification for the new airblast magnitude prediction method is given. General directions for programming the prediction method on any computer are provided. A shoot/no shoot decision procedure is proposed which should eliminate noise and damage complaints from Navy exercises on Bloodsworth Island. Finally a new and simple method to estimate the locations of caustics is described.

FOREWORD

In response to community complaints and damage claims, an extensive investigation was conducted by the Naval Surface Weapons Center on the effects of naval activities (bomb drops and gunnery exercises) at the Bloodsworth Island target range on adjacent Eastern Shore populated areas. It is important to know the physical airblast phenomena that cause these complaints and to develop operational techniques and procedures that will reduce and hopefully eliminate future complaints. This effort stemmed from the Navy's commitment and concern for the impact of its operations on the environment and for the maintenance of good relations with its neighbors. Funding for this work was provided by CINCLANTFLT through Work Request No. V0006078WR00313.

The author would like to acknowledge the efforts of Joseph E. Berry, who planned, organized, and supervised the experimental test program, who supervised the overpressure and ground motion data digitization, and who was at all times responsible for the good health of the instrumentation. The author would also like to thank Roy W. Huff, who performed the bulk of the very tedious data reduction. The professional guidance and leadership of James F. Proctor are also recognized and appreciated.

The mention of proprietary items or company names in this report is for technical information purposes only. No endorsement or criticism is intended.

J. F. Proctor

J. F. PROCTOR

By direction

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CHAPTER I

INTRODUCTION

BACKGROUND

During the early and mid 70's, the Naval Surface Weapons Center (NSWC) was requested on numerous occasions by the Navy Judge Advocate General's Office (JAG) and Commander, Naval Surface Force, U.S. Atlantic Fleet (COMNAVSURFLANT) to evaluate the validity of damage claims and nuisance complaints from airdrop and gunnery exercises on Bloodsworth Island. On the surface it appeared that the possibility and probability of naval exercises causing damage were remote, but the number, frequency, and documentation of the complaints certainly added credence to their validity. In September 1976 NSWC acknowledged this fact and recommended to JAG that a technical investigation be made of the Bloodsworth Island range operations that included measurements of sound pressure levels and ground motion from typical airdrop and gunnery exercises with supporting upper air meteorological measurements. The recommendation was accepted with Commander-in-Chief, U.S. Atlantic Fleet (CINCLANTFLT) as the sponsoring and directing organization.

OBJECTIVES

In an effort to reduce the impact of naval airdrop and gunnery exercises on the neighboring communities, an extensive investigation was conducted in the Bloodsworth Island area between mid-September and mid-October 1978. The objectives of this investigation were as follows:

TASK 1. DATA BASE. Measure airblast levels and ground motion from naval gunfire and aerial bombing under known meteorological conditions to form a data base from which a shoot/no shoot decision procedure can be formulated.

Characterize the records obtained in terms of parameters such as peak overpressure, peak velocity, impulse, energy, and frequency content in an effort to determine which parameters are the main cause of damage and nuisance complaints.

TASK 2. FOCUSING PREDICTION METHODS. Examine existing airblast foc sing prediction methods to determine the optimum prediction technique in terms of accuracy and ease of use.

Determine the best geographic locations from which to take meteorological soundings that most accurately represent airblast focusing conditions in the areas surrounding Bloodsworth Island.

TASK 3. DAMAGE AND NUISANCE CRITERIA. Identify the airblast and ground motion parameters that cause damage and nuisance complaints. Define the threshold values of these parameters.

Compare the data base to local, State, and Federal Environmental Protection Agency (EPA) noise regulations and determine the status of Navy compliance for the Bloodsworth Island operations.

TASK 4. SHOOT/NO SHOOT PROCEDURE. Formulate and recommend a shoot/no shoot decision procedure for Navy explosion exercises on Bloodsworth Island that will provide minimum noise levels to citizens living near the range. The procedure should consider weather forecasts, focusing predictions, noise and damage criteria, and specific Navy priorities and needs.

SCOPE OF THE REPORT

This report updates and completes the material presented in the interim report.[1,2] Chapter 2 summarizes the data acquisition test program. Chapter 3 describes the airblast and ground motion data obtained. Chapter 4 describes the weather data that was taken. Chapter 5 discusses and compares several airblast magnitude prediction methods, including the new NSWC method which was developed as a result of this investigation. A simple approximation to estimate the locations of caustics is also mentioned. Chapter 6 investigates the Navy's compliance with the local noise regulations. Chapter 7 outlines the shoot/no shoot decision procedure recommended for Navy exercises on Bloodsworth Island.

DATA BASE REPORT

The data base acquired during the test program is being published as a separate report.[3] This data report primarily contains plots of the digitized overpressure-time and ground velocity-time records and their corresponding Fourier amplitude spectra. A number of plots show the effects of filtering analog records through A-, B-, C-weighted systems.

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[1] Berry, J. E., Lorenz, R. A., and Proctor, J. F., "Bloodsworth Island Investigation, Phase I - Interim Report," enclosure (1) of NAVSWC ltr R15:JFP:jbb 3900 Ser 1747 to CINCLANTFLT of 8 May 1979.

[2] "Corrections to Bloodsworth Island Investigation Interim Report," enclosure (1) of NAVSWC ltr R15:JEB:jbb 5800 Ser 3093 to CINCLANTFLT of 15 Aug 1979.

[3] Lorenz, Richard A., "Noise Abatement Investigation for the Bloodsworth Island Target Range: Data Report," NSWC TR 81-433 (to be published).

CHAPTER 2

TEST PROGRAM

TYPES OF DATA

Time-resolved and peak sound pressure levels as well as ground motion recordings were taken for typical target range exercises. Two types of ordnance were used: air-delivered Mk 82 bombs (110 kg TNT equivalent) which are the largest single munition item used on Bloodsworth Island, and 5" naval projectiles (4.1 kg TNT equivalent) which represent the most common type of gun firings from ships. The muzzle blast from 5" naval gunfire was found to be equivalent to 30 kg TNT (see Chapter 5). Table 2-1 shows the types of exercises covered in the test series. It was possible to monitor eight days of gunfire and eight days of bomb tests. Table 2-2 lists actual test days, type of exercises, ordnance tests, and the Navy units providing support.

Upper air weather soundings were made during all the test exercises. A wide variety of weather conditions were experienced during the 16 days of tests.

MONITORING STATION LOCATIONS

Stations to monitor overpressure and ground motion levels were placed at sites on or near locations of previous complaints and damage claims. Monitoring points were representative of the larger population centers and those areas most likely to be impacted by range operations. Five fixed stations were established in or near the Eastern Shore communities (Figure 2-1). A mobile or rover station was prepared to move to locations of predicted blast focusing. All stations were manned by NSWC personnel. Table 2-3 gives the exact location of the various stations. Leasing arrangements for the use of private property were made with the assistance of the Naval Facilities Engineering Command (NAVFACENGCOM).

TABLE 2-1 EVENT SCHEDULE

GUNFIRE TESTS

Gunfire of interest:

Single gun - illumination round - muzzle blast only

Single gun - standard round

Counter battery - single gun

Fire for effect - single gun

Fire for effect - multiple guns

2 series three times a day (0800-0900 and 1000-1100 EDT; 1300-1400 and 1500-1600 EDT; 1800-1900 and 2100-2200 EDT); 5 shots/series

Total in 8 days - 292 rounds

BOMB TESTS

5 series per day with 2 Mk 82 drops per series

Drops at 0800, 1000, 1300, 1500, 1700 EDT

Total in 8 days - 59 explosions

WEATHER DATA

Soundings at 0600, 1000, 1400, 1800, 2200 EDT at Deal Island and NATC, Patuxent River. No 2200 EDT sounding on Bomb Tests.

Soundings at Wallops Island at 0700 and 1900 EDT

Total in 16 days - 153 soundings

TABLE 2-2 TEST ACTIVITIES

DATE	EXERCISE			UNIT
9/13	Air Drops	Mk 82 Bombs	4 each	MATWING 1*
9/14			10 each	
9/16	Naval Gunfire	5"/38 Shells	56 each	USS HAWKINS
9/17			32 each	
9/18			60 each	
9/19	Air Drops	Mk 82 Bombs	11 each	MATWING 1
9/20			7 each	
9/21			8 each	
9/22			5 each	
9/30	Naval Gunfire	5"/38 Shells	40 each	USS ELLISON
10/1			38 each	
10/2	Air Drops	Mk 82 Bombs	8 each	MATWING 1
10/3			6 each	
10/4	Naval Gunfire	5"/54 Shells	6 each	USS BEARY
10/5			33 each	
10/6			27 each	

*Medium Attack Wing One

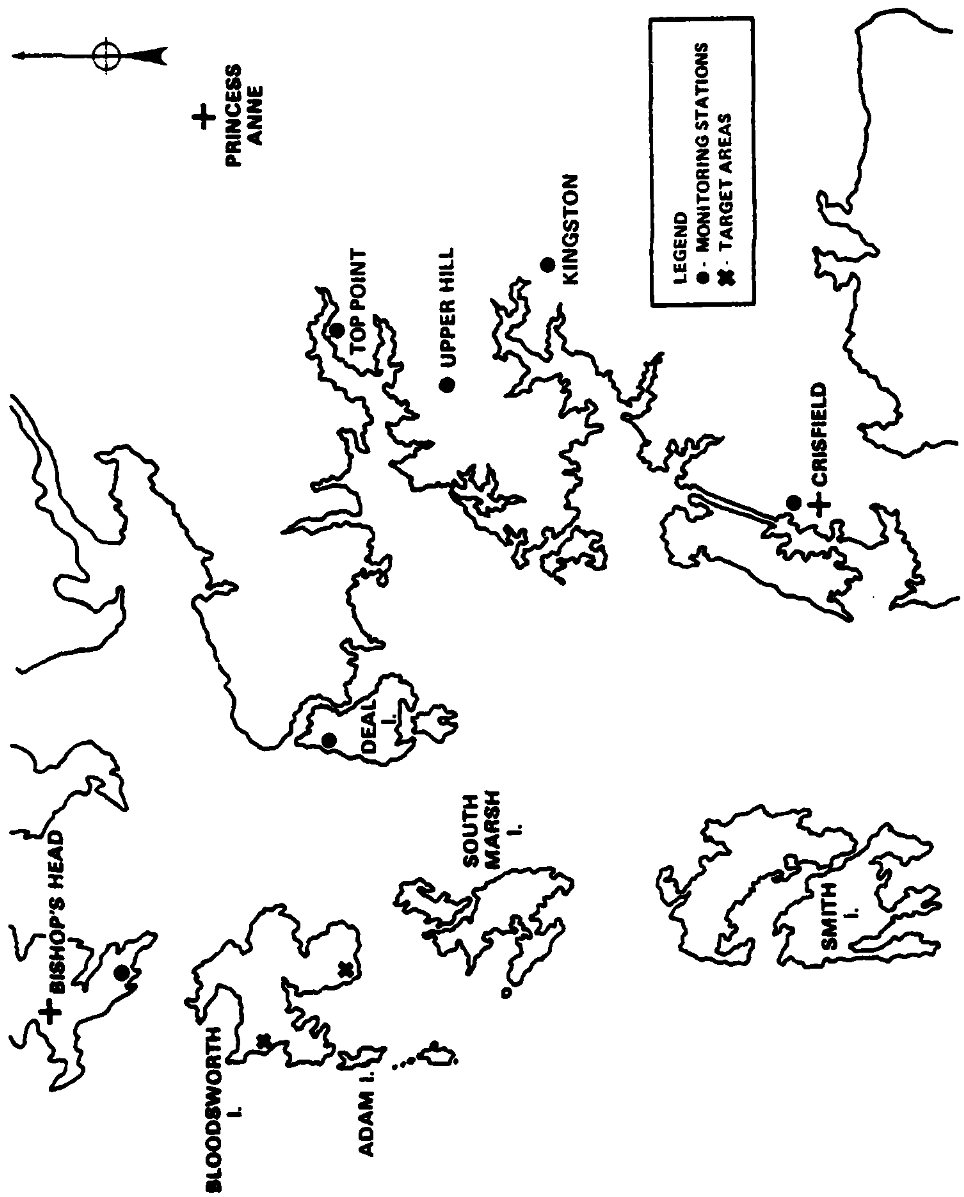

FIGURE 2-1 MONITORING STATIONS

TABLE 2-3 MONITORING STATION IDENTIFICATION

Station No.	Station	Location	Record Types
1	Bishops Head	Crocheron Hunt Club Bishops Head	peak pressure
2	Deal Island	Webster Rd. & Tangier Sound Deal Island	pressure history ground motion
3	Top Point	Revels Neck Rd. Top Point	pressure history ground motion
4	Upper Hill	Fairmont Rd. & Fishing Island Rd., Rt. 361 Upper Hill	peak pressure
5	Rover (Kingston)	(1) Rt. 314 & Revells Neck Rd. (2) Rumbley Point (3) Kingston	pressure history
6	Crisfield	Somerset Ave. & Columbia Rd. Crisfield	pressure history ground motion

The intended impact area for the Mk 82 bombs was at the southern end of Bloodsworth Island (Figure 2-1), while the target area for naval gunfire was located on the western side of the island. The nominal ship firing position was taken to be 9 km due west of the naval gunfire target area. Table 2-4 locates each monitoring station relative to the above three explosion sources.

WEATHER STATIONS

Under certain conditions the atmosphere acts like a lens and refracts the blast energy downward toward the ground, concentrating it in specific local areas. This is known as sound focusing and can occur whenever the temperature and wind velocity above the ground combine to produce a horizontal sound velocity component which is greater than that at ground level. The minimum weather data necessary to determine focusing conditions are the temperature, wind speed, and wind direction as functions of altitude.

Weather soundings were taken at three locations as shown in Figure 2-2. A mobile weather team from Fleet Weather Center, Norfolk (FWC) was stationed at the field headquarters and monitoring station on Deal Island, approximately 9 km ESE of Bloodsworth Island. Arrangements were made for soundings to be taken at the Naval Air Test Center (NATC), Patuxent River, approximately 34 km WNW of Bloodsworth Island. Regularly scheduled meteorological soundings were available from Wallops Island, approximately 55 km ESE of Bloodsworth Island.

Each of the three weather stations acquired its temperature data via the radiosonde technique; however, there were substantial differences in the wind data acquisition methods. Both NATC and Wallops Island use a method based on the LORAN-C navigational system and, therefore, these stations could be relied on to give wind data in any kind of weather. Deal Island used the pibal method of visually tracking a balloon to obtain wind data. As a result, when there was a low cloud ceiling or on days of poor visibility (e.g., fog, rain, balloon flying into sun), the Deal Island station could not provide wind data.

TABLE 2-4 MONITORING STATION ORIENTATION

Station No.	Station	Mk 82 Bomb Target Distance*/Azimuth**	5" Gunfire Target Distance*/Azimuth**	Nominal Ship Position Distance*/Azimuth**
1	Bishops Head	9.1 km/10°	6.1 km/40°	14 km/70°
2	Deal Island	9.0 km/80°	12 km/100°	21 km/95°
3	Top Point	25 km/90°	28 km/95°	37 km/95°
4	Upper Hill	23 km/100°	27 km/105°	36 km/105°
5	Kingston	29 km/105°	33 km/110°	42 km/105°
6	Crisfield	25 km/135°	30 km/135°	36 km/125°

*Distance from station to expected impact area or ship position.

**Azimuth angle toward station as seen from explosion source, clockwise from true North.

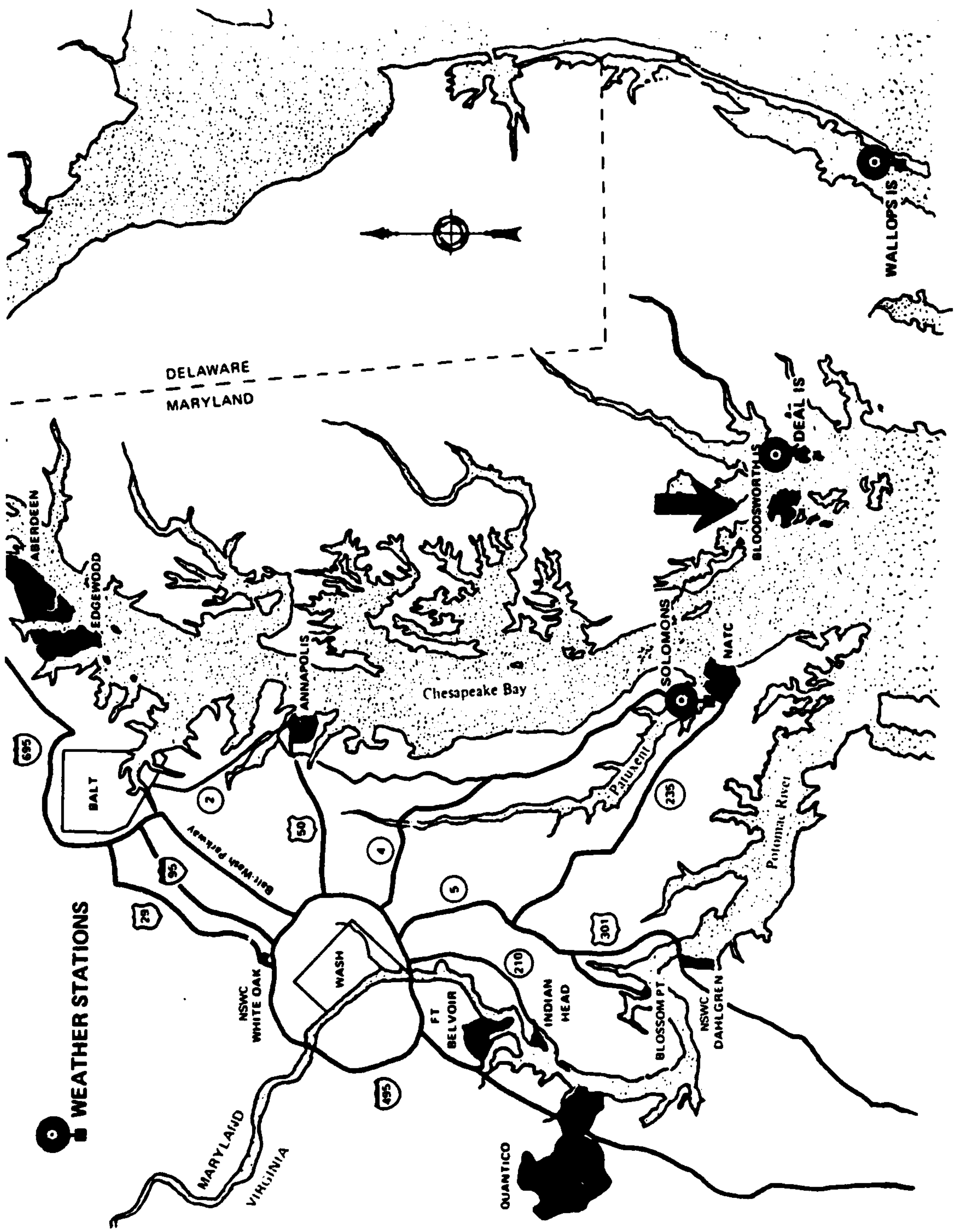

FIGURE 2-2 CHESAPEAKE BAY AREA

COORDINATION

Figure 2-3 shows the various units that made up the field test organization and indicates the need that existed for close coordination between the units. Synchronization of the exercises with the monitoring stations was accomplished with a station radio network and a spotter link. On airdrops a Tactical Squadron (TACRON) ground/aircraft communications team at the Deal Island recording station was notified by the bomber pilot of: (1) bomb run in progress--coming in hot, (2) bomb release--off safe, and (3) bomb impact--bomb performance. Monitoring stations began recording at "off safe" to detect ground/water transmitted shock.

On good visibility days the plumes from bombs and shells could be observed from the Deal Island monitoring station. During naval gunfire, a Naval Amphibious School, Norfolk (NAVPHIBSCOL) spotter on Adam Island, with the aid of an NSWC communicator, broadcasted over the monitoring station radio network the scheduled exercise and shell impact time.

As upper air sounding weather data became available, they were immediately telephoned from NATC, Patuxent River, and Deal Island to NSWC for computer processing with the SIPS (Sound Intensity Prediction System) computer program.[4,5,6] Any region of sound focusing indicated by SIPS was relayed to the rover station, which could move near that region if it was accessible by road. In practice, however, timely prediction of focusing regions was not possible with the system described above. As a result, the rover station spent most of its time at the Kingston location.

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[4]Pollet, D. A., "Sound Intensity Prediction System for the Island of Kahoolawe; Program Maintenance Manual," NSWC/DL TR 3786, Mar 1978.

[5]Gholson, N. H., "An Analysis of Sound Ray Focusing," NWL-TR-2834, Jan 1973.

[6]Gholson, N. H., "Evaluation and Utilization of the NWL Sound Intensity Prediction System," NWL-TN-T-4/74, Oct 1974.

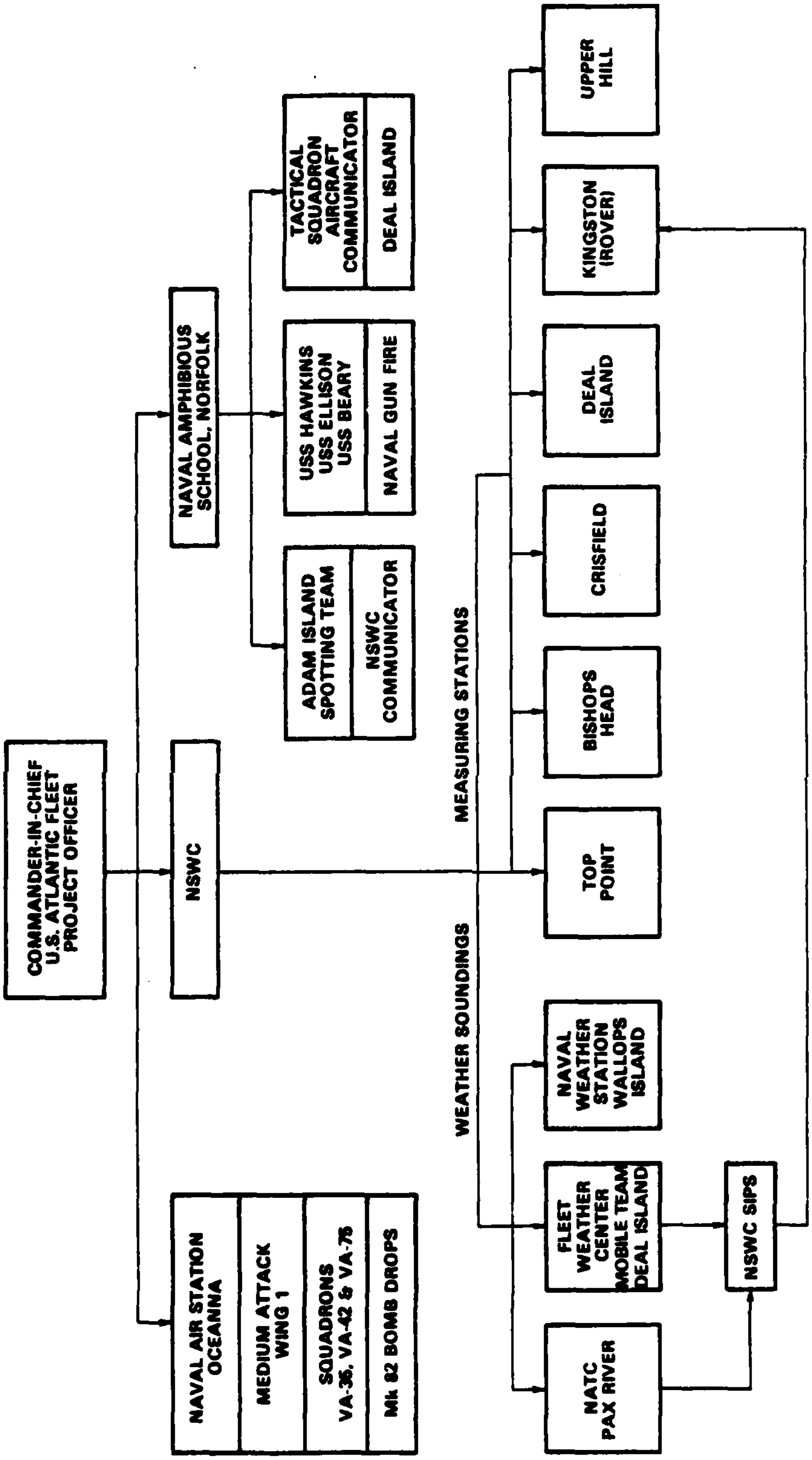


FIGURE 2-3 BLOODSWORTH ISLAND NOISE INVESTIGATION FIELD ORGANIZATION

INSTRUMENTATION

The primary sensor placed at each of the six monitoring stations was a pressure gage which had suitable characteristics to respond to sound pressure levels generated by munitions exploded on Bloodsworth Island. Ground velocity sensors were installed at three monitoring stations to sense any directly transmitted ground motion and/or airblast induced peak particle velocity of the soil.

Bruel and Kjaer (B & K) Type 4147 microphones were used with B & K model 2631 FM Carrier Systems at stations 2, 3, 5, and 6 of Table 2-3. The sound pressure level recordings were made in compliance with ISO Draft Proposal 43/1N11 for sonic boom measurements. Blast signatures recorded in this manner, when the angle of attack is uncertain, are representative of the incident blast wave which will be acting on structures in the blast field. Redundant measurements of overpressure levels (L)* were made at stations 2, 3, and 6 by using two B & K systems to ensure against equipment malfunction and/or loss of data. The pressure range covered by the B & K systems extended from 80 dB to 145 dB (0.20 Pa to 360 Pa). The system frequency response was essentially flat from 1 Hz to 16 kHz (down 1 dB at the end points).

A single microphone-carrier system was used at Kingston (station 5) since the Lockheed Store 4 tape recorder used with this system was limited to three data channels.

A Sangamo Sabre II, a Honeywell Model 5600, and a Honeywell Model 101 fourteen channel magnetic tape recorder were used at Deal Island, Top Point, and Crisfield (stations 2, 3, and 6) respectively for recording sensor signatures

*Instantaneous overpressure levels L in this report are expressed in units of decibels (dB) defined by:

$$L\ (\mathrm{dB}) = 20 \log_{10} (p/p_o)$$

where p is the instantaneous overpressure and p_o = 20 micropascals.

and calibrations. The recorders were operated at 30 ips in the IRIG Wideband 1 mode for DC to 20 kHz frequency response. A variety of signal conditioners were used as amplifiers to apply proper signal levels to the tape recorder channels. Either IRIG "A" or "B" time code was recorded simultaneously on each tape recorder.

Three-component ground motion gages (Vibra-Metrics Model M-320) were used at Deal Island, Top Point, and Crisfield (stations 2, 3, and 6) to monitor the transverse, radial, and vertical components of motion. Each axis was recorded on two data channels with suitable signal conditioning to sense levels of motion from 0.25 mm/sec to 25.4 mm/sec in the 4 Hz to 500 Hz transducer passband. For these tests the radial axis was oriented toward the impact area.

On test days, a Dallas Instruments Inc. Model AR-2 Acoustic Monitor was placed at the Upper Hill recording station (station 4). This instrument recorded the peak flat sound pressure level on a strip chart recorder over the 90 dB to 130 dB (0.6 Pa to 60 Pa) range. This instrument is designed to meet ANSI-1.4-1971 and IEC 123, 1961 specifications for monitoring impulse noise levels.

Bishops Head was a manned station (station 1), where the operator monitored three positive peak, "read and hold," General Radio Type 1556B Noise Impact Analyzers that were used in conjunction with the General Radio Type 1551B Sound Level Meters.

Daily calibrations of the microphone carrier systems were recorded as a system test and for later data processing. Similarly, simulated laboratory calibration levels of the ground motion transducers output were recorded. B & K pistonphone calibrations of 124 dB (32 Pa) at 250 Hz and Hewlett Packard Type 15117A sound pressure levels of 124 dB (32 Pa), 114 dB (10 Pa), 104 dB (3.2 Pa), and 94 dB (1.0 Pa) at 1 kHz were used. Other calibrators employed were B & K type 4230 and General Radio Type 1562. The General Radio Type 1562 produced a 114 dB (10 Pa) calibration at five test frequencies and the B & K 4230 generated 94 dB (1.0 Pa) at 1 kHz. The Upper Hill and Bishops Head station sensors were calibrated daily with one of the above type calibrators.

Table 2-5 summarizes the general types of intrumentation used at the various stations and the typical number of records obtained for each shot.

TABLE 2-5 MEASUREMENTS

THREE STATIONS (DEAL, CRISFIELD, TOP POINT)

2 MICROPHONES................3 GAINS................................6 RECORDS

1 VELOCITY METER............3 DIRECTIONS.........2 GAINS............6 RECORDS

ROVER STATION (KINGSTON)

1 MICROPHONE................3 GAINS.................................3 RECORDS

BISHOP'S HEAD STATION

3 IMPACT NOISE ANALYZERS...3 RECORDS

UPPER HILL STATION

1 PEAK NOISE - CONTINUOUS RECORD....................................1 RECORD

TOTAL - 43 RECORDS/SHOT

351 SHOTS - 15,093 RECORDS

CHAPTER 3

AIRBLAST OVERPRESSURE AND GROUND MOTION DATA

AMOUNT OF DATA

During the 16 days of tests, recordings were taken on 59 Mk 82 bomb drops and 292 rounds of 5" naval gunfire. On each event a total of 43 recordings normally were taken by the six monitoring stations (see Table 2-5) which resulted in a volume of data consisting of over 15,000 individual records. This total is misleading on the low side because each of the some 12,000 gunfire recordings have two or three pulses (bow wave, shell explosion, and muzzle blast) that must be evaluated separately.

DATA REDUCTION

The first process in the data reduction task was a preliminary screening of the records. The analog tapes were played back and recorded on an oscillograph. These playouts were then evaluated to determine which records would require detailed analysis. Consider, for example, the typical data from the Deal Island station for a specific event. Here two pressure gages using three gains each monitored the event and produced six records. Only one requires detailed analysis, but it was necessary to play back and examine all six records in order to select the best one to represent the pressure pulse that impacted the station. The same process had to be applied to the ground motion records. The second data reduction step was to digitize the selected record for subsequent computer analysis.

As a result of the above exercise, approximately 880 pressure records and 150 velocity records were selected for digitization and detailed analysis. A Nicolet Explorer III oscilloscope was used to digitize the analog recordings. The resulting 1024- or 2048-point digital waveforms were then stored on a 9 track magnetic tape for subsequent processing. A number of the pressure records were also processed through a General Radio Type 1933 Precision Sound Level Meter to determine the effect of Flat, C-, B-, and A-weighting (Figure 3-1) on the pressure signatures. Approximately 130 weighted pressure histories were digitized and analyzed.

MK 82 BOMB DATA

Figure 3-2 is characteristic of the MK 82 bomb overpressure and ground motion records when strong focusing conditions exist. Rise times are relatively slow (tens of milliseconds). Multiple pulses are observed with the positive and negative peak overpressures approximately equal in magnitude. The ground motion sensor begins responding during airblast arrival, indicating that the ground motion was airblast induced. No directly transmitted ground shock was ever positively identified in the test series. Two strong frequencies can typically be seen in the ground motion records, about 33 Hz and 10 Hz.

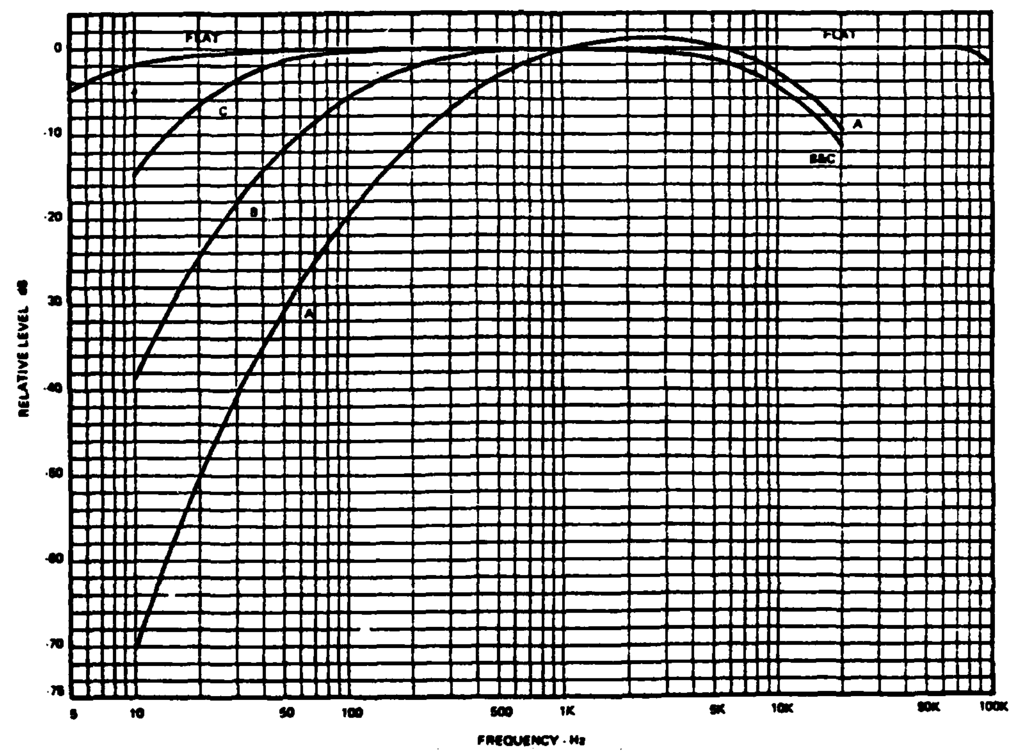
Sample digitized MK 82 records taken under weak to moderate focusing conditions are shown in Figure 3-3. The pressure pulses become irregular and deviate from the classical shock wave form. The bulk of the airblast energy is typically concentrated in frequencies below 12 Hz. The 33 Hz frequency component is seen to be dominant in the two related velocity records.

A detailed examination of ground motion data was not made because all records indicate that the maximum velocities were two orders of magnitude below the documented 25 mm/sec threshold for structural damage.[7,8,9] It does not appear that ground motion from MK 82 bombs contributes significantly to possible damage in the communities near the Bloodsworth Island target range.

[7] Liu, T. K., Kinner, E. B., and Yegian, M. K., "Ground Vibrations," Sound and Vibration, Oct 1974, pp. 26-32.

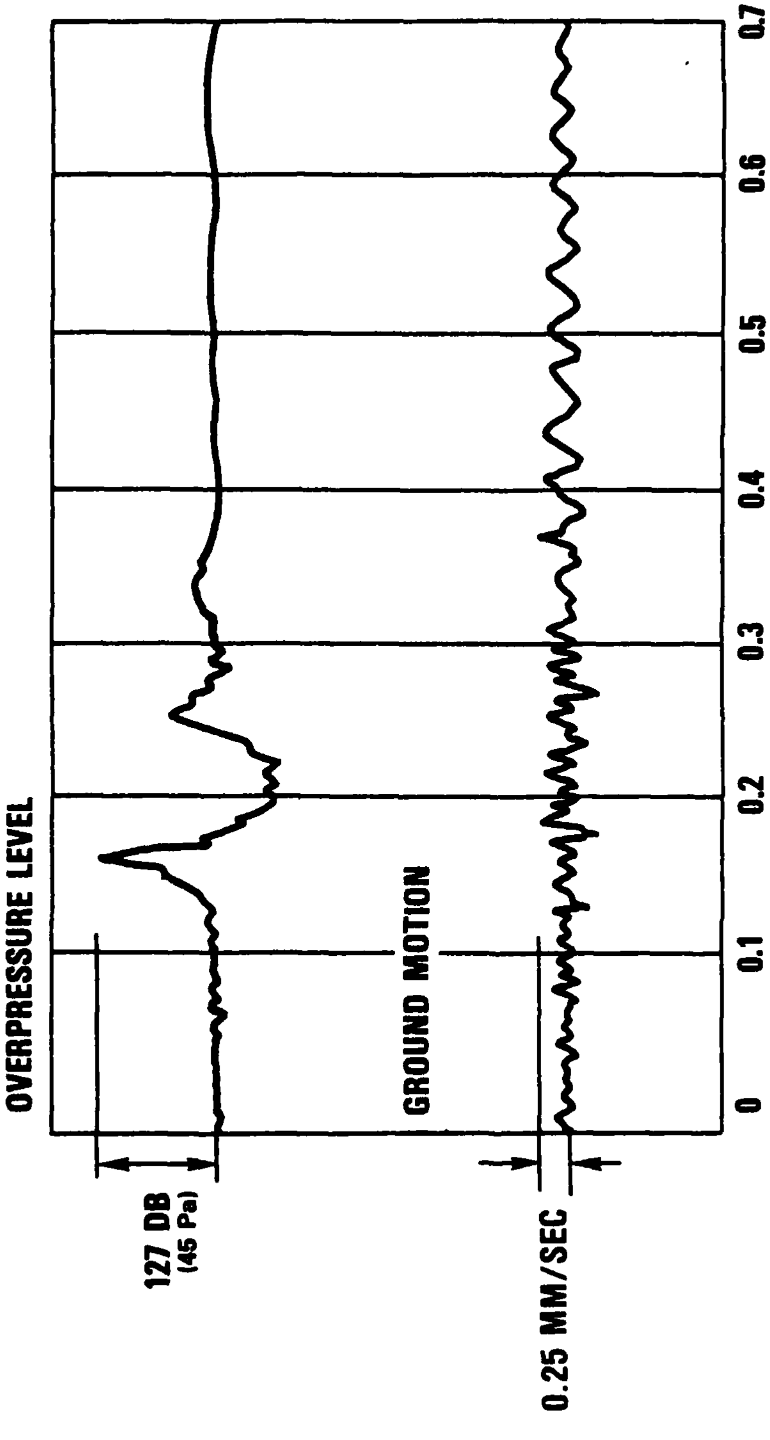
[8] Nicholle, H. R., Johnson, C. F., and Duvall, W. I., "Blasting Vibrations and Their Effects on Structures," Bureau of Mines Bulletin 656, 1971.

[9] Von Gierke, H. E., Chairman, Working Group 69 on Evaluation of Environmental Impact of Noise, "Guidelines for Preparing Environmental Impact Statements on Noise," Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), Assembly of Behavioral and Social Sciences, National Research Council, Jun 1977.



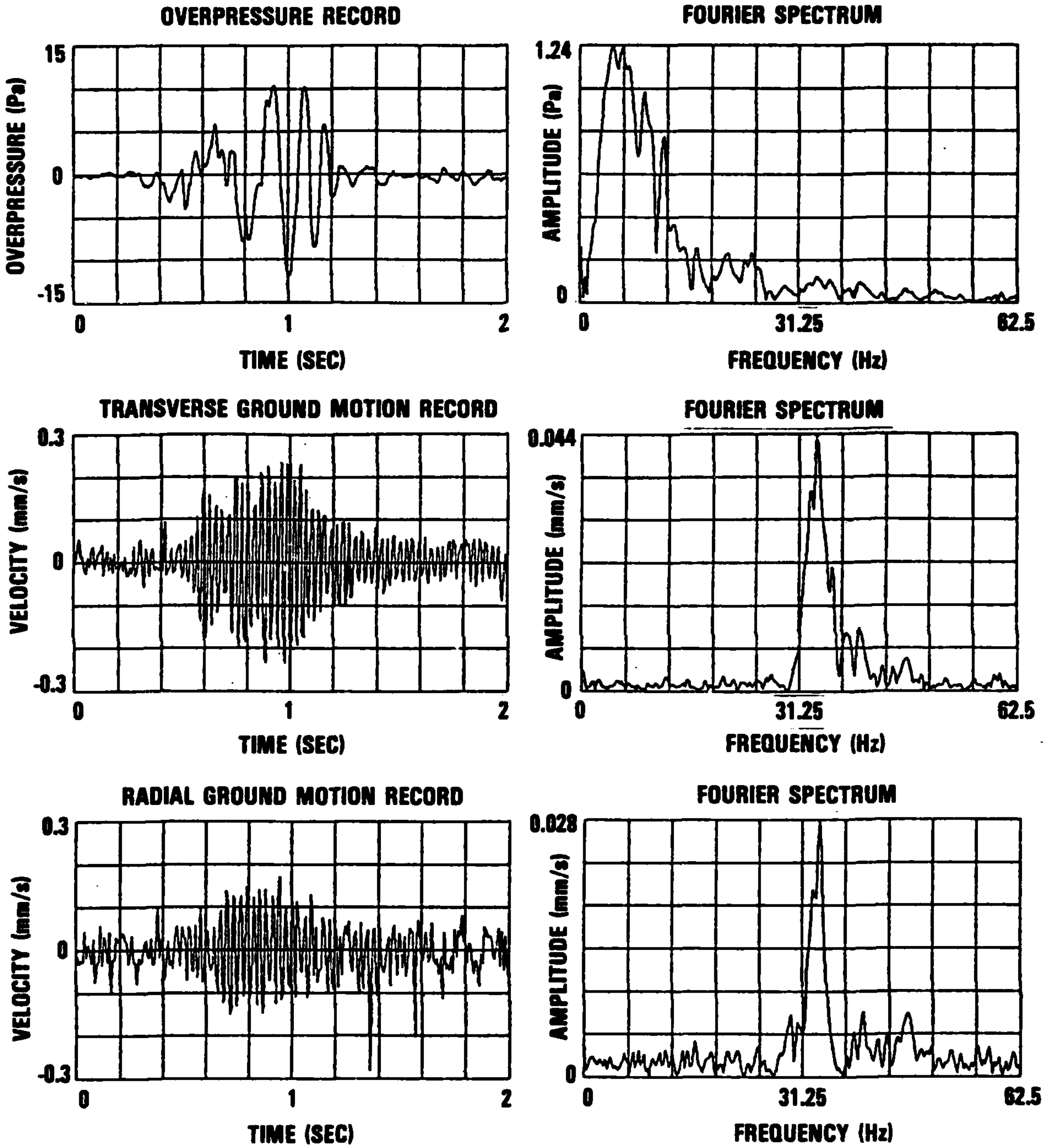
CURVES EXCLUDE THE POSSIBLE ACOUSTICAL EFFECTS OF A MICROPHONE AND ARE BASED ON A 36-pF-SOURCE IMPEDANCE

FIGURE 3-1 FREQUENCY-RESPONSE CHARACTERISTICS FOR 1933 SLM, WITH AND WITHOUT STANDARD WEIGHTING NETWORKS



DEAL ISLAND STATION RECORDING

FIGURE 3-2 TYPICAL ANALOG RECORDS OF MK 82 BOMB EVENTS



TOP POINT STATION RECORDING

FIGURE 3-3 TYPICAL DIGITIZED RECORDS OF MK 82 BOMB EVENTS

5" GUNFIRE DATA

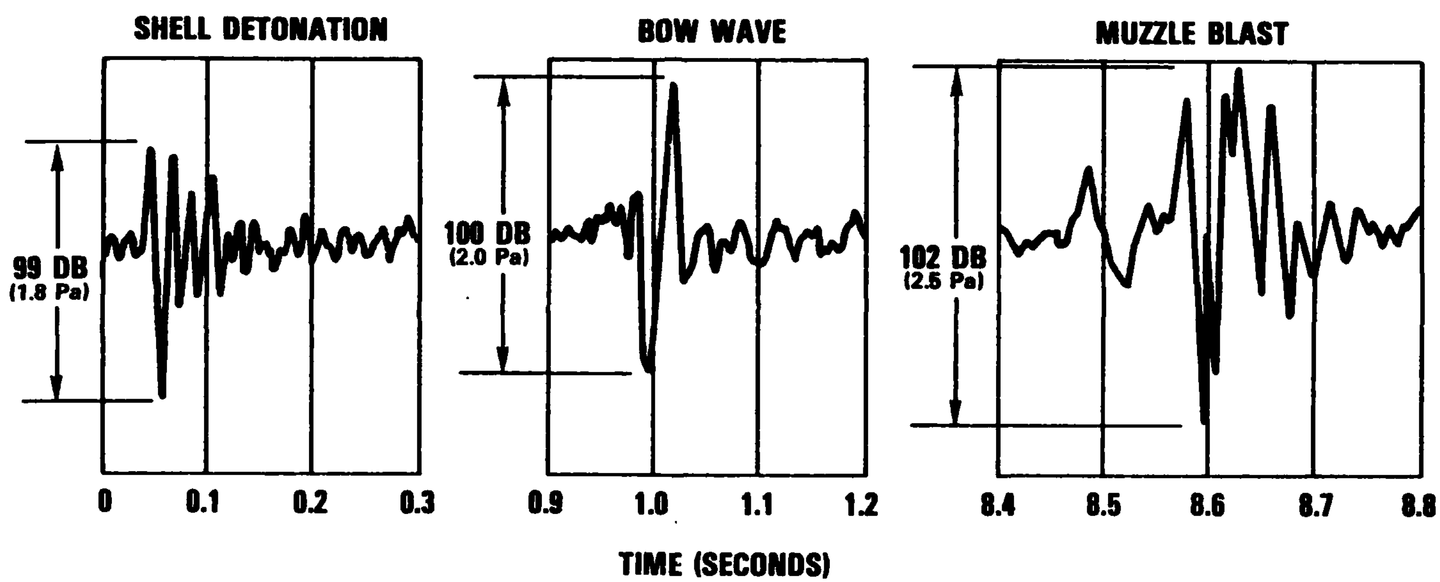
Figure 3-4 shows the complex long range signatures generated by naval gunfire. The shell bow wave shown in Figure 3-4 is separated in time from the shell detonation, but generally the bow wave arrives during the shell detonation signal and is not directly separable. The amplitude of the muzzle blast and its arrival time with respect to the shell detonation pulse varies with the position of the ship, number of guns fired, type of fire (single or multi-gun salvo), and the propellant charge. Generally the amplitude of the muzzle blast was greater than that of the shell detonation, and its predominant oscillations were lower in frequency.

Sample digitized gunfire records are shown in Figure 3-5. The energy of the shell detonation was usually concentrated in frequencies below 100 Hz, while the energy in the muzzle blast is generally found below 30 Hz.

The ground motion resulting from naval gunfire is less severe than that from Mk 82 bombs. Therefore it does not appear that ground motion from naval gunfire contributes significantly to possible damage in the communities near the Bloodsworth Island target range.

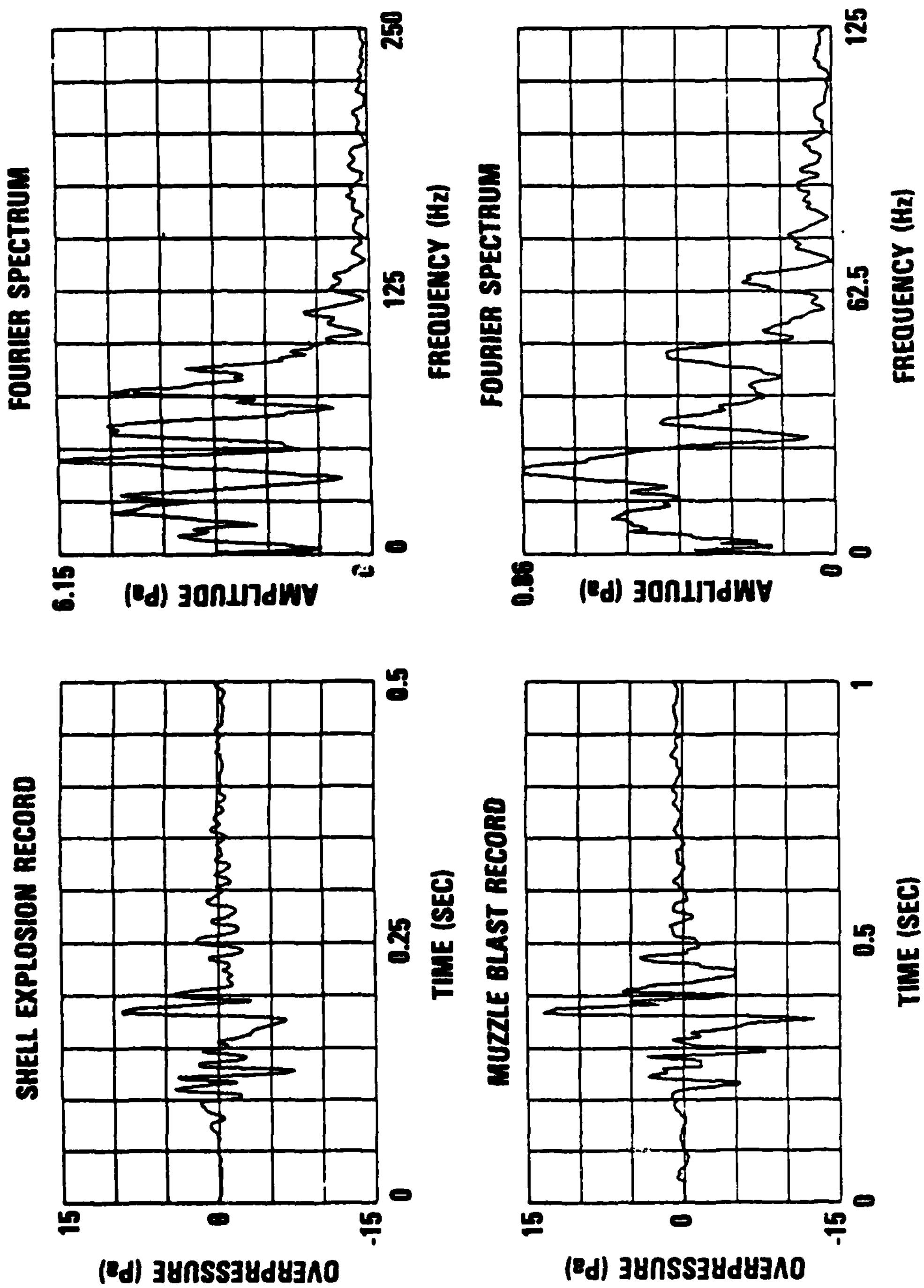
COMPLAINTS DURING INVESTIGATION

A subjective measure of the airblast overpressure levels is the number and severity of complaints which occur during an exercise. Table 3-1 lists the informal complaints reported to the field measurements team during the investigation. One can conclude from these observations that, during heavy focusing, complaints and damage claims may be received for sound pressure levels from Mk 82 bombs in the 125 dB to 135 dB (36 Pa to 110 Pa) range. Although the reported damage was minor and limited in area, the measured sound pressure



DEAL ISLAND STATION RECORDING

FIGURE 3-4 TYPICAL ANALOG RECORDS OF 5"/54 NAVAL GUNFIRE



DEAL ISLAND STATION RECORDING

FIGURE 3-5 TYPICAL DIGITIZED RECORDS OF 5"/38 NAVAL GUNFIRE

TABLE 3-1 INFORMAL COMPLAINTS DURING INVESTIGATION

19 September 1978 MK 82 AIR DROPS - STRONG FOCUS PREDICTED

LOCATIONS	NATURE	SOUND PRESSURE LEVEL	
		Predicted*	Measured
1. WENONA (Near Deal Island)	NOISE	135 dB (110 Pa)	133 dB (90 Pa) DEAL ISLAND
2. CRISFIELD	SHOOK WINDOWS	124 dB (32 Pa)	124 dB (32 Pa) CRISFIELD
3. FAIRMOUNT (Near Kingston)	BROKE WINDOW	123 dB (28 Pa)	122 dB (25 Pa) KINGSTON
4. MARION STATION (Near Kingston)	CRACKED PLASTER	123 dB (28 Pa)	122 dB (25 Pa) KINGSTON

22 September 1978 MK 82 AIR DROPS - STRONG FOCUS PREDICTED

LOCATIONS	NATURE	SOUND PRESSURE LEVEL	
		Predicted**	Measured
1. CHANCE (Near Deal Island)	PICTURE OFF WALL	127 dB (45 Pa)	135 dB (110 Pa) DEAL ISLAND
2. CHANCE (Near Deal Island)	VASE OFF CUPBOARD	127 dB (45 Pa)	135 dB (110 Pa) DEAL ISLAND
3. DEAL ISLAND	CANNED GROCERIES OFF SHELF	127 dB (45 Pa)	135 dB (110 Pa) DEAL ISLAND
4. DEAL ISLAND	BROKE WINDOW	127 dB (45 Pa)	135 dB (110 Pa) DEAL ISLAND

*NSWC Prediction Method (see Chapter 5). Weather conditions 4 hours earlier predicted levels 1 or 2 dB higher.

**NSWC Prediction Method (see Chapter 5). Weather conditions 4 hours earlier predicted a level of 138 dB (160 Pa). The 127 dB (45 Pa) level is based on weather data taken at the same time as the measurement, but 34 km away. If the strongest wind had shifted and were blowing directly toward Deal Island, a level of 133 dB (90 Pa) would have been predicted.

levels were considerably below the 134 dB to 140 dB (100 Pa to 200 Pa) threshold levels normally considered acceptable.[10,11]

No known formal damage claims or nuisance complaints were received during the gunfire exercises. It is possible that nuisance complaints were not made because the community residents were aware that these specific exercises were designed to study worst case noise for their eventual benefit. Therefore unless there was property damage, as occurred in the bombdrop exercises, the residents may have decided not to voice any complaints.

Spectral analysis of the overpressure records shows that the blast energy is characteristically concentrated in frequencies below 12 Hz for Mk 82 bombs and below 25 to 50 Hz for 5" gunfire. Typical house structures can follow these frequencies[12] and should therefore respond to the peak overpressure rather than to the impulse of a blast wave. As a result of the informal complaints received during the investigation, a 125 dB (36 Pa) sound pressure level is recommended as a practical damage threshold level for the Bloodsworth Island area.

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[10] "Sonic Boom Experiments at Edwards Air Force Base," Interim Report, NSBEQ-1-67, AD 655310, 28 Jul 1967.

[11] Reed, J. W., "Guidelines for Environmental Impact Statements on Noise (Airblast)," Minutes of the Seventeenth Explosive Safety Seminar, 14-16 Sep 1976.

[12] "The Effects of Sonic Boom and Similar Impulsive Noise on Structures," NTID300.12, 31 Dec 1971.

CHAPTER 4

WEATHER DATA

AMOUNT OF DATA

Upper air weather soundings were scheduled for Deal Island and NATC, Patuxent River at 0600, 1000, 1400, and 1800 EDT on test days, with an additional sounding at 2200 EDT during evening gunnery exercises. Wallops Island had regularly scheduled soundings at 0700 and 1900 EDT daily.

A total of 153 weather soundings were taken during the 16 test days. Deal Island took 57 soundings, of which only 35 had useable wind data. NATC took 67 soundings, and Wallops Island provided 29 soundings. Tabulated data for the 131 useable weather soundings can be found in the data report.[3]

A wide variety of weather conditions were observed during the test period. There were days when heavy focusing occurred and days when quiescent conditions prevailed. Most days had weather conditions varying between the two extremes. These statements are based both on a review of the measured overpressure records and on the comments of the field personnel.

DATA REDUCTION

Blast focusing occurs when the atmosphere acts like a lens to focus sound rays toward some point (caustic) on the ground surface. This condition can come about when the speed of sound at any altitude exceeds the speed of sound at the ground surface. The weather data, therefore, are used to construct sound speed versus altitude profiles to estimate the degree of blast focusing that can occur.

[3]See footnote 3 on page 1-3.

At each significant altitude, the total sound speed in any direction is approximately equal to the temperature dependent sound speed plus the wind velocity component, and is given by the equation:

$$v(z,\theta) = 331 \sqrt{1 + T(z)/273} - WS(z) * \cos (WD(z) - \theta) \qquad (4.1)$$

where

v = Sound speed (m/sec)

z = Altitude (km)

θ = Azimuth angle (°) clockwise from true North as viewed from the explosion source

$T(z)$ = Temperature (° C), at altitude z

$WS(z)$ = Wind speed (m/sec), at altitude z

$WD(z)$ = Wind direction (°) from which wind is blowing, clockwise from true North, at altitude z

The sound speed was calculated at each altitude level at which either a temperature or a wind reading was taken. To eliminate an excessive number of nonessential levels, temperature and wind altitudes were combined and considered equal when their difference was less than one-third the difference of either temperature or wind levels. The temperature, wind speed, and wind direction were assumed to vary linearly between measured levels. A sample set of weather data and the result of combining the data are given in Table 4-1.

The wind speed and direction data represent 1-minute averages during the rise of the weather balloon. This seems to be an appropriate averaging time to detect the significant wind trends. Most NATC wind data were taken using 15 second averaging intervals. In many cases the measured local fluctuations were large and obscured the major trends. When these data were reworked numerically to give effective 1-minute averaging intervals, the desired trends were obtained.

Sound speed versus altitude profiles were calculated and processed for all azimuth angles of interest by the airblast focusing prediction methods discussed in Chapter 5. Sample sound speed versus altitude profiles are shown in Figure 4-1.

TABLE 4-1 SAMPLE WEATHER DATA

NATC STATION, 1000 ASCENT ON 19 SEP 1978

Input Data					Combined Data				
Alt. (m)	Press. (mbars)	Temp. (° C)	Wind Dir. (°Az)	Wind Speed (knots)	Alt. (m)	Press. (mbars)	Temp. (° C)	Wind Dir. (°Az)	Wind Speed (knots)
0	1016	28.0	300.0	7.0	0	1016.0	28.0	300.0	7.0
144	1000	27.0			144	1000.0	27.0	303.2	11.7
351	977	26.5			351	977.0	26.5	304.9	18.6
465			305.3	22.4	465	964.6	26.1	305.3	22.4
664	943	25.5			664	943.0	25.5	312.9	25.3
852			318.6	28.4	852	923.3	24.2	318.6	28.4
1045	903	22.9			1045	903.0	22.9	321.1	29.1
1244			323.7	29.9	1244	882.9	21.2	323.7	29.9
1570	850	18.5			1570	850.0	18.5	325.3	35.7
1648			325.3	35.7					
1972	811	15.2			1972	811.0	15.2	334.2	36.0
2045			334.2	36.0					
2390	772	13.6			2390	772.0	13.6	329.7	35.4
2425			329.7	35.4					
2812			322.3	33.0	2812	734.0	11.6	322.3	33.0
2815	734	11.6							
3208			312.5	29.2	3208	700.0	9.4	312.5	29.2
3211	700	9.4							
3537			304.2	31.5	3537	670.0	6.7	304.2	31.5
3573	670	6.7							
3926			297.3	29.1	3926	642.0	4.0	297.3	29.1
4127	626	2.4			4127	626.0	2.4	297.6	31.3
4373			298.0	34.0	4373	607.0	1.5	298.0	34.0
4376	607	1.5							
4841			309.0	30.0	4841	566.0	-1.8	309.0	30.0
4937	566	-1.8							
5248			325.0	27.0	5248	536.0	-4.3	325.0	27.0
5369	536	-4.3							
5639			337.0	26.0	5639	518.2	-4.9	337.0	26.0
5916	500	-5.6			5916	500.0	-5.6	337.0	26.0

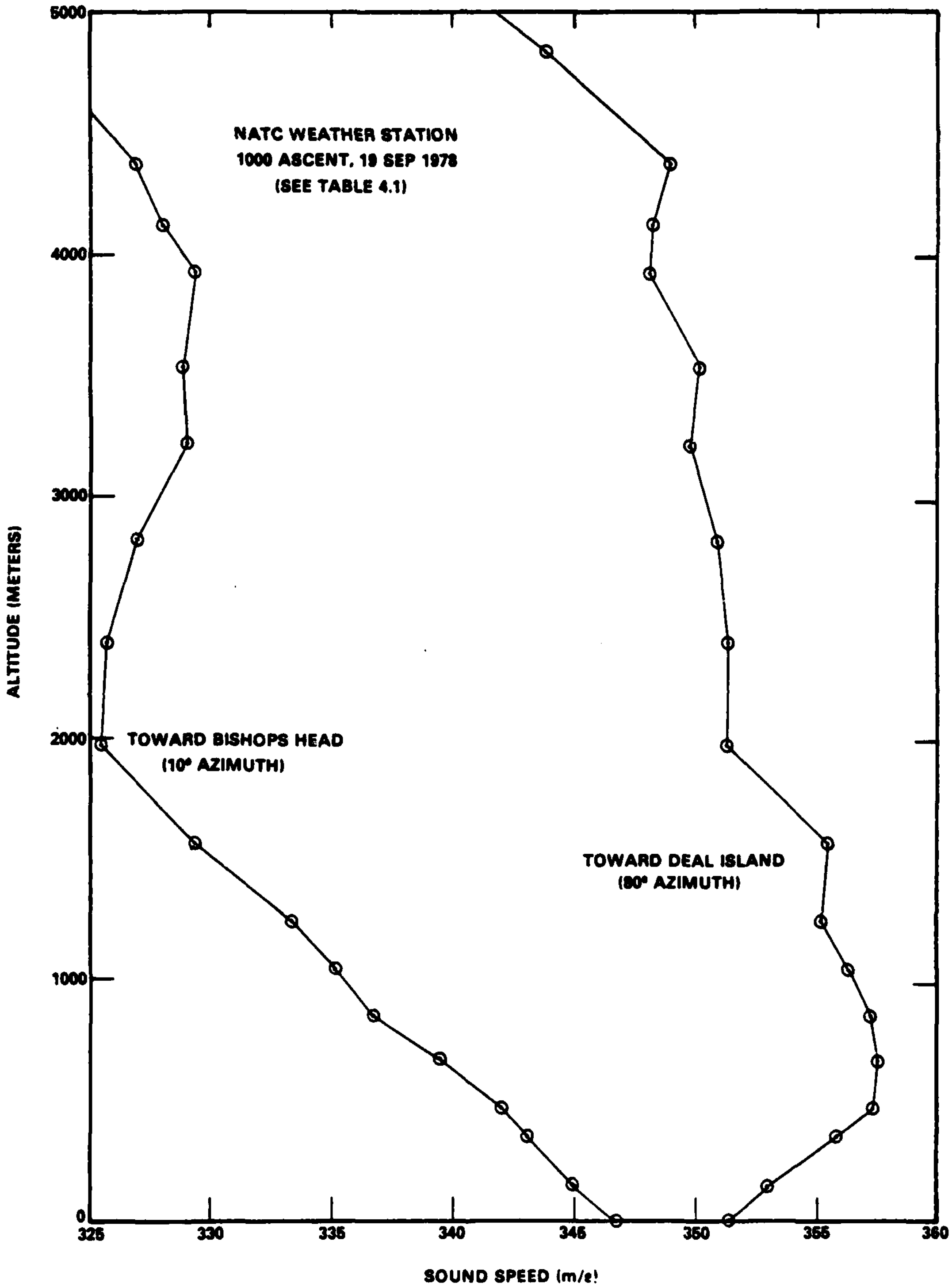

FIGURE 4-1 SAMPLE SOUND SPEED PROFILES

COMPARISON OF WEATHER STATIONS

It was necessary to determine which weather stations could be used to adequately represent the atmospheric conditions in the Bloodsworth Island area. To this end the data from the three weather stations described in Chapter 2 were compared with each other in a number of different ways. These included visual comparisons of selected sound speed versus altitude profiles and the visual comparisons of the distributions of caustics calculated by the SIPS method (see Chapter 5). The results of these comparisons agreed qualitatively with the following procedure.

The most complete and least subjective comparisons of the weather stations were made using the new NSWC method described in Chapter 5. The explosive weight limits for pairs of stations are plotted against each other in Figures 4-2 through 4-4 whenever simultaneous weather data were available. The explosive weight limit is the amount of TNT required on Bloodsworth Island to produce an upper bound sound pressure level at any of a number of specific locations on the Eastern Shore under the given weather conditions. The upper bound sound pressure level chosen for this exercise was 130 dB (63 Pa). If there were perfect correlation between any two weather stations, then all the explosive weight limit points would lie on the central 45° slope line in Figures 4-2 through 4-4. The high and low 45° slope lines represent the standard deviation of the points from the central line.

In Figure 4-2 the points stay close to the central 45° slope line and tend to scatter evenly about it. This suggests that the NATC and the Wallops Island weather data may be expected to give comparable explosive weight limit results within a factor of two* on the average. Note that these stations are approximately 90 km apart and that only early morning and early evening data sets are being compared.

*A factor of 2 in the explosive weight (W) corresponds to a 2.7 dB change in the overpressure level (L). This represents a factor of 1.36 in the overpressure (p) itself. See equation 5.5 and the footnote on page 2-11.

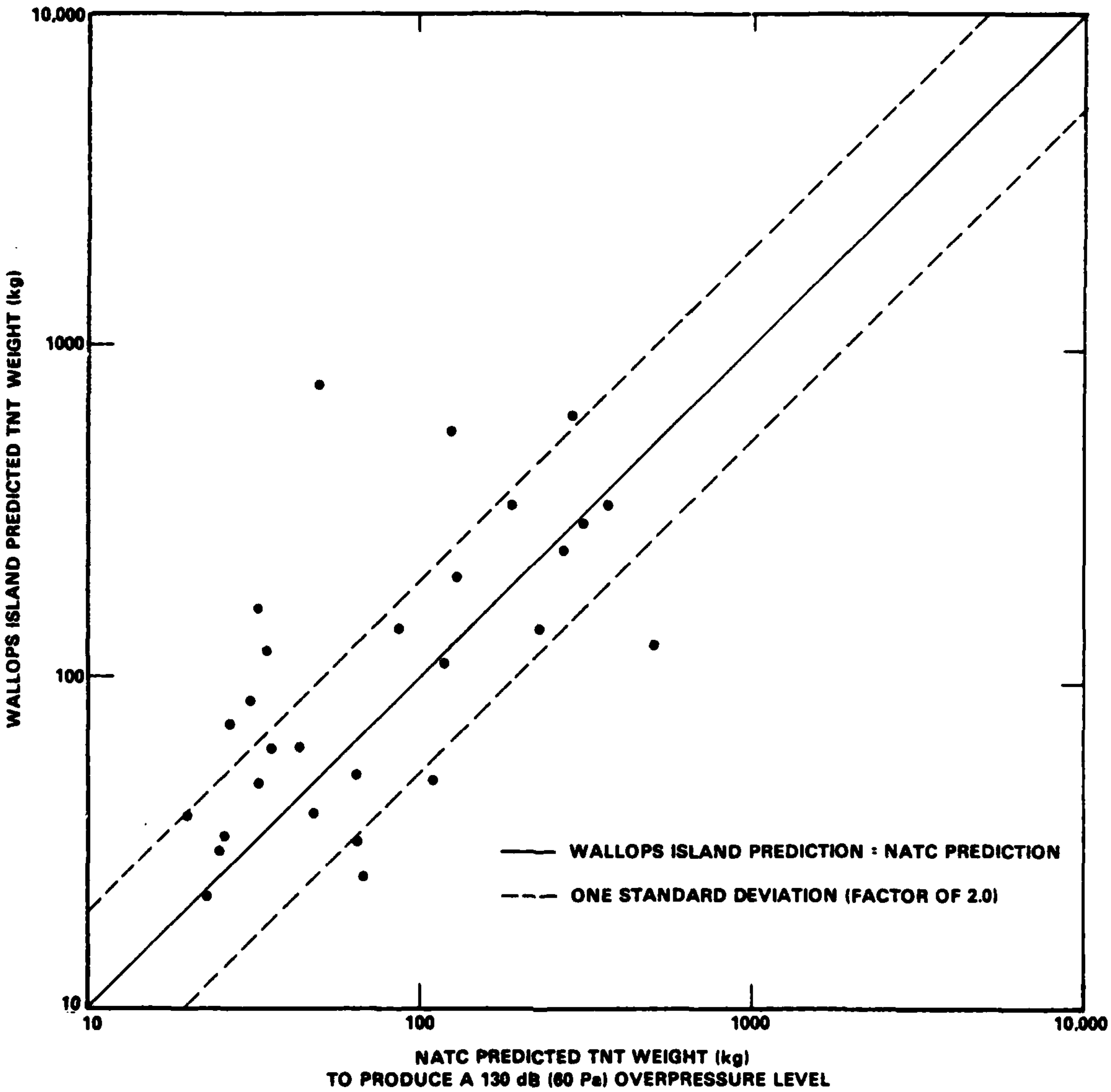

FIGURE 4-2 COMPARISON OF PREDICTIONS BASED ON NATC AND WALLOPS ISLAND WEATHER DATA

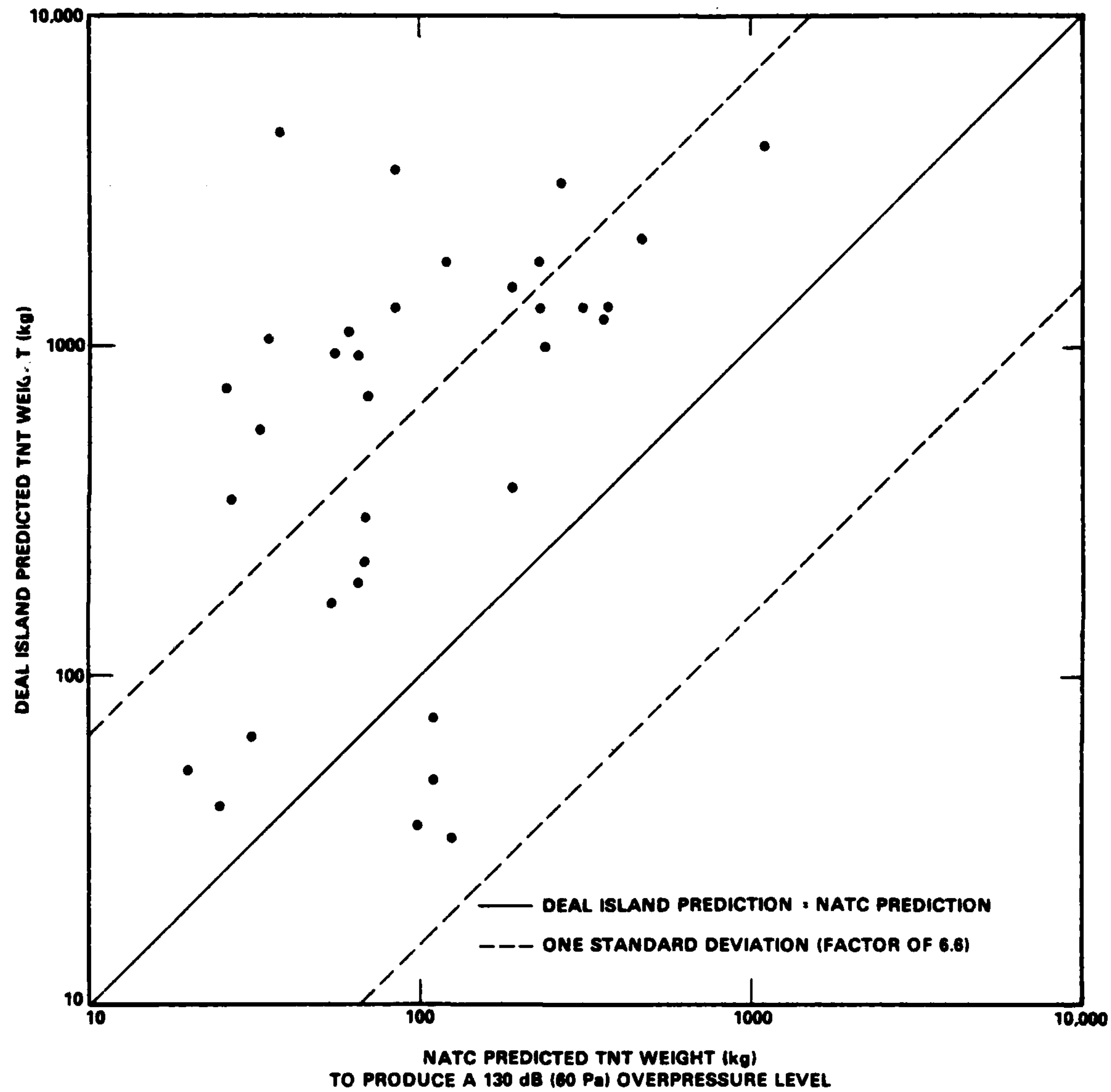

FIGURE 4-3 COMPARISON OF PREDICTIONS BASED ON NATC AND DEAL ISLAND WEATHER DATA

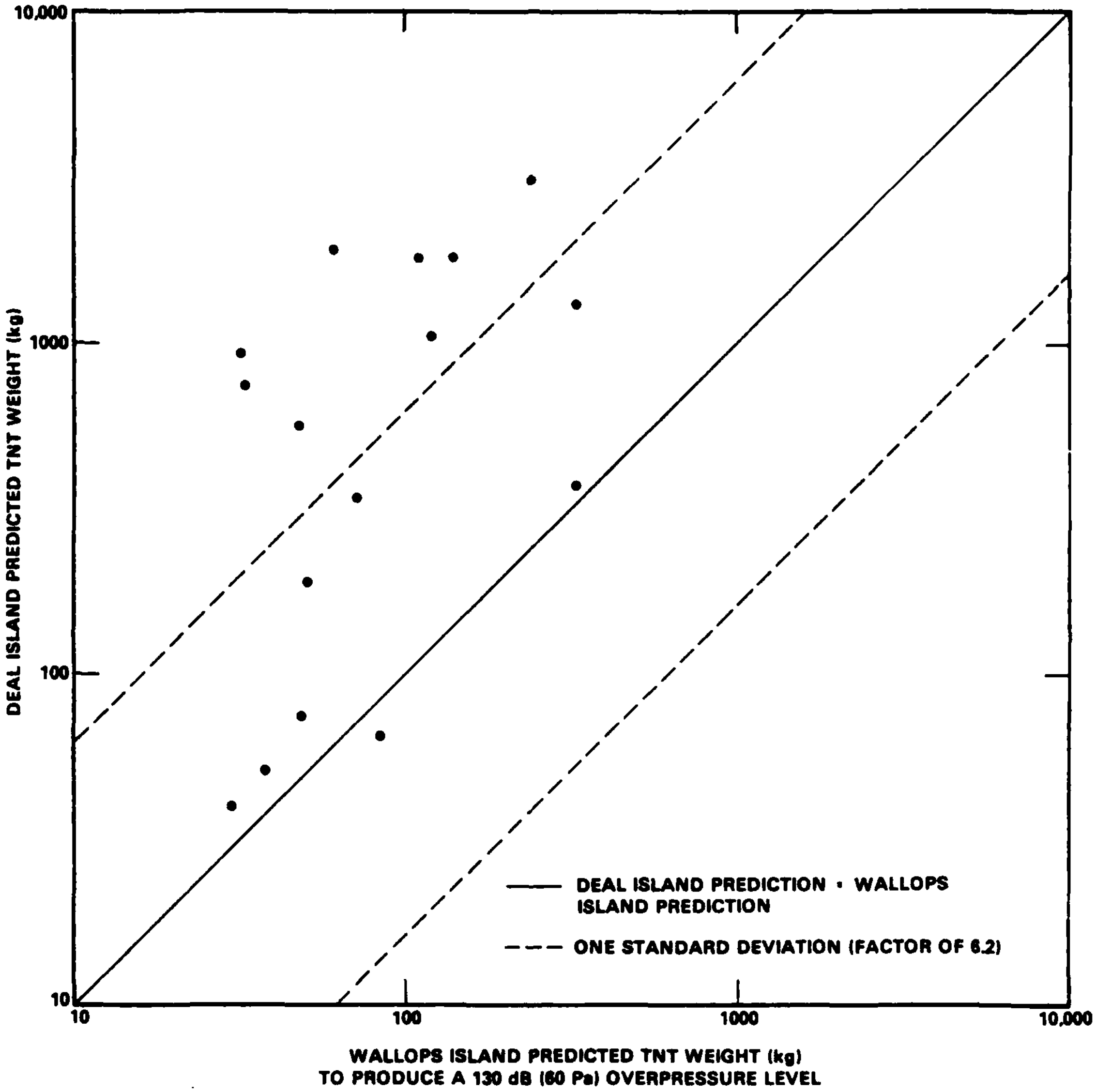

FIGURE 4-4 COMPARISON OF PREDICTIONS BASED ON WALLOPS ISLAND AND DEAL ISLAND WEATHER DATA

No such tendencies can be seen in Figures 4-3 and 4-4. This indicates that the Deal Island weather data are significantly different from those of either NATC or Wallops Island. As noted in Chapter 2, this is most likely the result of Deal Island using the pibal method of visually tracking a balloon to obtain the wind data, rather than using the LORAN-C navigational system as did the other two stations. The Deal Island wind data appears to be excessively smooth when compared to that of the other two stations. A final and decisive factor in judging the Deal Island weather data is that the Deal Island weather data correlated very poorly with the measured overpressure data.

The Deal Island weather data should have represented the atmospheric conditions midway between NATC and Wallops Island, and were expected to best represent the weather in the Bloodsworth Island area. However, as a result of the above considerations the Deal Island weather data were judged to be unreliable and were not considered further. The NATC data were chosen to represent the weather in the Bloodsworth Island area for all subsequent analyses because NATC was the closer of the two remaining stations and because it had the most complete set of weather soundings made throughout the test days.

CHAPTER 5

AIRBLAST MAGNITUDE PREDICTION METHODS

Two ingredients are necessary for airblast magnitude predictions. First, one must obtain or predict the sound speed versus altitude profile which represents the atmospheric conditions for the area of interest at the time of the explosion. This ingredient can be derived from local weather soundings taken shortly before the test. Second, a prediction method must be employed to interpret the sound speed versus altitude profile to determine the expected overpressure levels. The prediction method should be, in order of importance, accurate, fast, and easy to use.

As part of this investigation the Sound Intensity Prediction System (SIPS)[4,5,6] as well as the prediction method used by Fleet Weather Center (FWC), Norfolk, were examined. In addition, information was obtained for prediction methods used at Eglin AFB,[13] Sandia Lab,[14] Ballistics Research Lab (BRL),[15]

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[4]See footnote number 4 on page 2-9.

[5]See footnote number 5 on page 2-9.

[6]See footnote number 6 on page 2-9.

[13]Rasmussen, R. A., CAPT, USAF, "A Prediction Method for Blast Focusing," USAFETAC TN 71-8, Sep 1971.

[14]Thompson, R. J., "Computing Sound Ray Paths in the Presence of Wind," SC-RR-67-53, Feb 1967.

[15]Perkins, B., Jr., Lorrain, P. H., and Townsend, W. H., "Forecasting the Focus of Air Blasts Due to Meteorological Conditions in the Lower Atmosphere," BRL Report No. 1118, Oct 1960.

Lawrence Livermore Lab (LLL),[16] and Holloman AFB.[17] All of these methods are based on the same principles of sound path refraction by the atmosphere, but each implements these principles differently. Most importantly, the focusing criteria and amplitude predictions vary significantly between the methods. The SIPS and FWC methods have been reviewed in detail, while the others have only been superficially examined.

FWC METHOD

In the FWC method, the latest available upper air weather data is obtained from Wallops Island. This data is then smoothed to average out small measured wind fluctuations which are not representative of the weather over the general area. Next, the sound speed versus altitude profile is plotted in a single direction (120° azimuth from true North) representing the direction from Bloodsworth Island toward Wallops Island. Then some simple criteria are applied to determine the degree of focusing to be expected. No estimate is made of the sound pressure levels to be expected. To predict how focusing conditions will change during the day, the weather forecaster at FWC uses his expertise to predict how the sound speed versus altitude profile will change during the day and then reapplies the simple focusing criteria.

FWC Strong Points: The weather forecaster uses his experience and expertise to smooth the weather data and to predict changes expected in the sound speed versus altitude profile throughout the day. The method is easy to use and does not require a computer to perform the calculations. The method is insensitive to the fine details of the sound speed versus altitude profile.

FWC Weak Points: Only one direction is considered; focusing conditions in other directions may go undetected. The sound speed versus altitude profile is

[16]Pfeifer, H. E., Odell, B. N., and Arganbright, V. E., "Noise-Abatement Method for Explosives Testing," American Industrial Hygiene Conference, CONF-790633-1, 1 Jun 1979.

[17]Kahler, J. P., "FOCUS - A Computerized Aid for Making Sound Propagation Forecasts," Holloman AFB, ADTC-TR 79-8, Jan 1979.

constructed only up to about 1500 m, but it is probable that wind shears above 1500 m may cause significant focusing in the neighboring communities. The sound pressure levels are not estimated. The focusing criteria used may be inadequate: these criteria are based on a weather survey reported in 1967. An examination indicated that, through a procedural error, FWC was constructing the sound speed versus altitude profiles incorrectly during the survey. Telephone conversations with FWC personnel substantiated that this procedural error had been faithfully followed through 1978. FWC was notified of this error by telephone as soon as it was discovered in September 1978. Subsequent conversations with FWC personnel revealed that this error has been rectified in practice.

The above discussion describes the FWC method in use at the time of the NSWC field tests in September-October 1978. Since May 1979 FWC has been using a prediction method based on interim recommendations which were made.[1,2] The form of the interim FWC method is similar to the procedure recommended in Chapter 7 of this report.

SIPS METHOD

The SIPS method requires the latest available local upper air weather data. Using a large computer, it calculates 80 or more ray paths in each of 20 directions of interest to find regions where focusing occurs. The location and maximum expected overpressure levels for each caustic are printed out. The overpressure levels are estimated simply by adding 15 dB (amplification factor of 5.6) to the average expected overpressure from the explosion. Quiet directions in which all rays are refracted away from the ground are also detected and printed out.

SIPS Strong Points: All important directions are considered. Caustics are located so that it can be determined whether focusing occurs in populated or in isolated areas. Sound pressure levels are estimated. The ray path calculations

[1]See footnote 1 on page 1-3.

[2]See footnote 2 on page 1-3.

account for reflections from water surfaces and can account for interference from hills and mountains. Quiet directions are detected.

SIPS Weak Points: Frequent weather soundings are required since the computer program cannot predict changes in the sound speed versus altitude profile. The computer is very sensitive to small measured fluctuations in the sound speed profile; each data point will exert its full influence on each ray path being calculated which may not be representative for the general area. These problems can, of course, be overcome by having a weather forecaster smooth and predict changes in the profile, but it may generally be difficult to do this in three-dimensional space for a computer that will look at 20 different directions. A fairly large computer is required for fast computing times; computing times are excessive for minicomputers. The estimated sound pressure levels at the caustics are worst-case values and tend to greatly overpredict the measured levels. No sound pressure enhancement is calculated for any region which does not contain a caustic. Single positive gradients in the sound speed versus altitude profile near ground level, which could produce substantial sound concentrations, are not recognized by SIPS because of its strict application of the ray tracing equations. Thus, sound pressure enhancement produced by this single positive gradient will go undetected.

OTHER METHODS

In an effort to find the "best" prediction model, cursory examinations were made of the Elgin AFB,[13] Sandia Lab,[14] and BRL[15] airblast focusing prediction methods. All of these methods lie midway between the simple but coarse FWC method and the complex but overly sensitive SIPS method. For the present application, the slight improvement in the results for these methods was judged not worth the increase in complexity over the FWC method. In particular, overpressure levels were not predicted. Therefore, these three methods were not considered further.

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[13]See footnote 13 on page 5-1.

[14]See footnote 14 on page 5-1.

[15]See footnote 15 on page 5-1.

The LLL method[16] came to the authors' attention after the new NSWC method, discussed below, was formulated. Despite significant procedural differences, these two methods exhibit some common features: a simple evaluation of the sound speed versus altitude profile is made, overpressure levels can be predicted, and an explosive weight limit can be determined. The two methods give similar results for one of the two examples in reference 16, but disagree for the second with LLL being less conservative. More study and comparisons would be desirable but the LLL method will not be considered further in this report.

The Holloman AFB[17] method came to the authors' attention during the draft stage of this report. The calculations are basically similar to those of the SIPS method except for the following difference. SIPS predicts the overpressure level at a focal point by adding a constant 15 dB (amplification factor of 5.6) to the average expected overpressure level. Holloman AFB, however, calculates an overpressure amplification factor which depends on the convergence of ray paths at the focal point. These amplification factors normally vary between 2.2 (7 dB) and 8.3 (18 dB). This represents an improvement over the SIPS method. However, the Holloman AFB method is also very sensitive to the details of the sound speed versus altitude profile. Whether or not it detects single positive gradients at the ground surface is not known at this time.

OVERPRESSURE AND WEATHER CORRELATIONS

WEATHER PARAMETER. Blast focusing occurs when the atmosphere acts like a lens to focus sound rays toward some point (caustic) on the ground surface. According to ray tracing theory[15,18] this condition can come about when the speed of sound at any altitude exceeds the speed of sound at the ground surface. The weather data are therefore used to construct sound speed versus altitude profile to estimate the degree of blast focusing that can occur.

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[16]See footnote 16 on page 5-2.

[17]See footnote 17 on page 5-2.

[15]See footnote 15 on page 5-1.

[18]Cox, E. F., "Far Transmission of Air Blast Waves," Phys Fluids 1, 95-101, Mar-Apr 1958.

At any altitude the total sound speed in any direction is approximately equal to the temperature-dependent sound speed of the air plus the wind velocity component and is given by the equation:

$$v = 331 \sqrt{1 + T/273} - WS \cos (WD - \theta) \qquad (5.1)$$

where

v = Total sound speed in the θ direction (m/s)

θ = Azimuth angle (°), clockwise from true North as viewed from the explosion source

T = Temperature (° C)

WS = Wind speed (m/s)

WD = Wind direction from which wind is blowing (°), clockwise from true North

Direct application of ray tracing techniques were disappointing and inadequate. Many attempts were made to discover a useful relationship between the sound speed profiles and the measured overpressure levels. The correlations tended to become worse as more details of the sound speed profile were included. Finally, a promising correlation was noticed when only the maximum sound speed difference and its altitude were combined. The parameter which eventually evolved to represent the weather conditions is related to η_{max}=arctan $(\Delta v/\Delta z)$ in Figure 5-1 and is given by the equation:

$$\beta = \arctan \left(3 \cdot \frac{\Delta v}{c_o} \cdot \frac{R}{\Delta z} \right) \qquad (5.2)$$

where

β = Weather parameter (°) for a given azimuthal direction

R = Distance (km) to point of overpressure measurement

c_o = Sound speed (m/s) at ground level

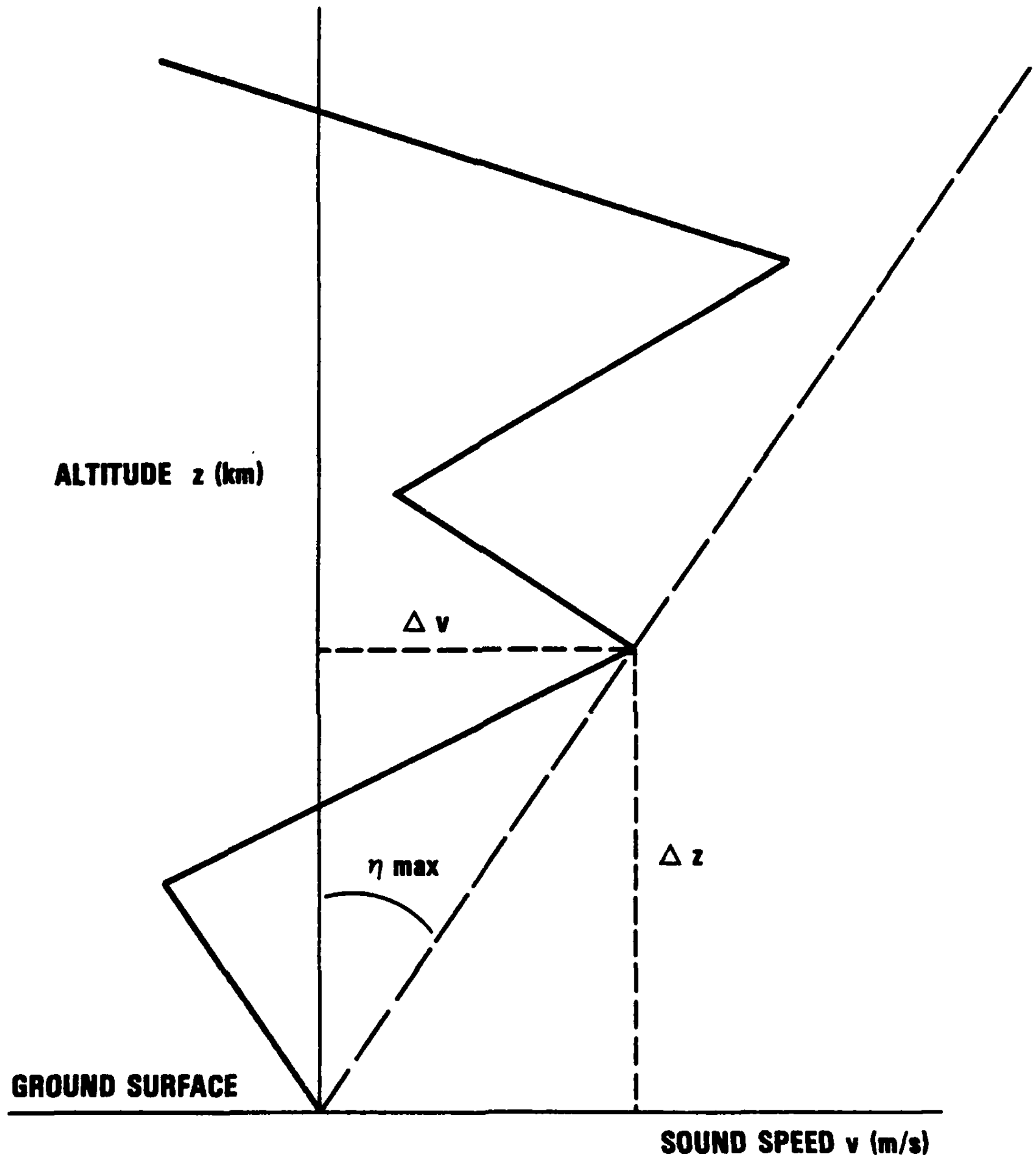

FIGURE 5-1 SOUND SPEED PROFILE DEFINING TERMS IN EQUATION 5.2 ᵢᵣᵣ β

Δv = Sound speed difference (m/s) related to η_{max} in Figure 5-1

Δz = Height (km) for Δv above ground surface. If the ratio $R/\Delta z$ is greater than 75, it is reset to equal 75 for this calculation.

Note that the weather parameter β depends primarily on the single most important feature in the sound speed profile: the velocity difference which would have the maximum effect in standard ray tracing calculations. The usual ray tracing calculations are unreliable because they are extremely sensitive to the detailed shape of the sound speed profile. Normal wind fluctuations can significantly alter the details of a sound speed profile within minutes after it is measured. A strong wind blowing at some altitude, however, can be expected to continue blowing for a considerable time and over a significant area. Therefore, if a sound speed profile is expected to represent the weather conditions over a large area for a period of time, only the major trends in the profile should be relied on in the first place.

The "R" factor in Equation 5.2 effectively scales the sound speed profile for the distance of interest. The "75" limit on the $R/\Delta z$ ratio was rather arbitrarily imposed to prevent gentle breezes near the ground surface from triggering erroneous severe focusing warnings.

AIRBLAST PARAMETER. The airblast parameter L_{pk} for an event is one-half the peak-to-peak overpressure level difference for the measured flat instantaneous overpressure versus time record. Half peak-to-peak is used because the measurements are sufficiently far-field that the peak positive and negative overpressures are approximately equal. In addition, baseline errors are eliminated and the results are more reproducible.

CORRELATIONS. Figure 5-2 shows the surface-detonated Mk 82 bomb peak overpressure level data from Top Point and Crisfield plotted against the weather parameter β. These stations are 25 km from ground zero on two azimuthal directions 45° apart. This comprises the largest set of unscaled data in this test series. A linear trend is noticeable despite the amount of scatter. The upper line in Figure 5-2 was fit to the data as a practical upper bound. It represents the maximum expected peak overpressure level for given weather

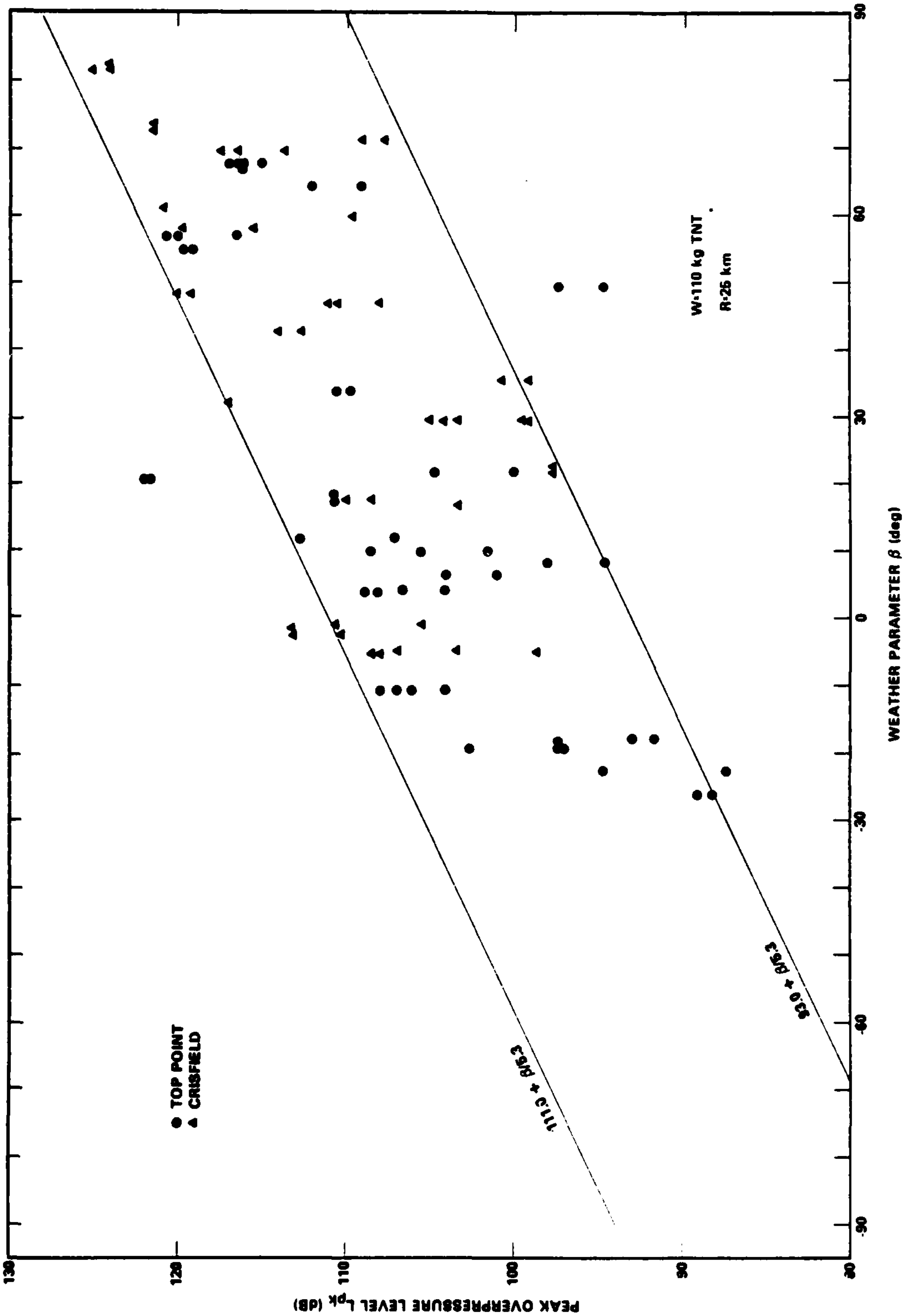

FIGURE 5-2 MK 82 BOMB DATA FROM TOP POINT AND CRISFIELD

conditions. A practical minimum expected peak overpressure level line which bounded the bulk of the data was chosen to be 18 dB below the maximum expected line.

The available peak overpressure level data from the multi-ton shots[19,20,21] listed in Table 5-1 were scaled to Mk 82 bombs at 25 km at sea level (102 kPa). The resulting values in Table 5-2 are plotted in Figure 5-3 along with the Mk 82 data from Figure 5-2 and the scaled Mk 82 data from Deal Island and Kingston. The scaling laws relating a reference level (subscript o) and a level at altitude (subscript z) are:

$$p_o = p_z \left(\frac{PA_o}{PA_z}\right) \quad \text{and } \lambda_o = \lambda_z \left(\frac{PA_z}{PA_o}\right)^{1/3} \tag{5.3}$$

where p is the instantaneous overpressure, PA is the ambient pressure, λ equals $R/W^{1/3}$, R is the distance from the explosion, and W is the TNT equivalent weight of the explosive. Assuming a power decay law of the form $p = \text{const}/\lambda^{\alpha}$, the scaled overpressures become

$$\frac{p_o}{p_z} = \left(\frac{PA_o}{PA_z}\right)^{1-\frac{\alpha}{3}} \times \left(\frac{W_o}{W_z}\right)^{\alpha/3} \times \left(\frac{R_z}{R_o}\right)^{\alpha} \tag{5.4}$$

where a value of 4/3 was used for α. The fact that the scaled multi-ton data for the most part falls within the scatter of the Mk 82 data increases the confidence that a useful overpressure-weather correlation may have been found.

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[19] Reed, J. W., "Project MIDDLE GUST Blast Predictions and Microbarograph Measurements," in Proceedings of the MIXED COMPANY/MIDDLE GUST Results Meeting, 13-15 Mar 1973, Vol. 1, DNA 3151P1, 1 May 1973.

[20] Reed, J. W., "DICE THROW Off-site Blast Predictions and Measurements," in Proceedings of the DICE THROW Symposium, 21-23 Jun 1977, DNA 4377P-2, Jul 1977.

[21] Reed, J. W., "Long Range Predictions and Measurements, MISERS BLUFF, Phase II," in Proceedings of the MISERS BLUFF Phase II Results Symposium, 27-29 Mar 1979, Vol. I, POR 7013-1, 26 Sep 1979.

TABLE 5-1 MULTI-TON SHOTS

MIDDLE GUST B	100 Ton TNT
MIDDLE GUST C	100 Ton TNT
PRE-DICE THROW I	100 Ton TNT
PRE-DICE THROW II	120 Ton ANFO
DICE THROW	600 Ton ANFO
MISERS BLUFF I	120 Ton ANFO
MISERS BLUFF II	720 Ton ANFO

TABLE 5-2 MULTI-TON SHOT DATA

EVENT	STATION LOCATION			SOUND SPEED PROFILE			1/2 PEAK-TO-PEAK OVERPRESSURE LEVEL	
	Station	Range (km)	Azimuth (°)	Δv_{max} (m/s)	Altitude (km)	Weather Parameter β	Measured (dB)	Scaled** (dB)
MIDDLE GUST "B" (90,700 kg)	Crowley	7.25	180	-8.5	2.32	-13.6	140.0	100.6
	Ordway	10.2	120	-0.3	1.71	-1.0	138.2	102.8
	Rocky Ford	26.5	150	-4.7	2.32	-25.9	132.8	108.4
	Limon	118.0*	360	4.6	1.41*	72.1	120.5	113.5
MIDDLE GUST "C" (90,700 kg)	Crowley	7.25	180	-0.8	0.19	-15.3	136.3	97.0
	Ordway	10.2	120	0.7	0.19	18.7	142.4	107.0
	Rocky Ford	26.5*	150	0.2	0.19*	6.0	113.1	88.7
	Limon	118.0	360	-8.8	2.32	-75.6	116.3	109.2
PRE-DICE THROW I (90,700 kg)	Oscuro	31.2*	063	0.1	0.18*	3.7	116.4	93.8
	Carrizozo	52.9*	063	0.1	0.18*	3.7	108.3	91.8
	Tularosa	46.1	140	-7.0	2.32	-50.3	120.7	102.7
	Alamogordo	66.2	140	-7.0	2.32	-60.0	119.6	105.7
PRE-DICE THROW II (90,700 kg)	Oscuro	31.2	063	-10.9	2.93	-45.5	111.5	88.8
	Carrizozo	52.9	063	-10.9	2.93	-59.9	110.0	93.5
	Tularosa	46.1*	140	-0.4	0.18*	-12.9	110.4	92.3
DICE THROW (454,000 kg)	Stallion	19.2	321	0.3	0.32	8.5	127.8	93.4
	Socorro	55.8*	320	0.3	0.32*	10.6	103.9	81.9
	Carrizozo I	60.4*	095	5.9	0.32*	75.7	134.5	113.4
	Carrizozo II	60.4*	095	5.9	0.32*	75.7	134.8	113.7
	Tularosa	81.5*	144	7.2	0.63*	78.2	139.3	121.7
	Alamogordo	102.5*	148	7.0	0.63*	77.9	139.5	124.5

*Ratio $R/\Delta z$ reset to 75
**Scaled to 110 kg at 25 km for $P_{ambient}$ = 102 kPa and c_o = 340 m/s

TABLE 5-2 (Cont.)

EVENT	STATION LOCATION			SOUND SPEED PROFILE			1/2 PEAK-TO-PEAK OVERPRESSURE LEVEL	
	Station	Range (km)	Azimuth (°)	Δv_{max} (m/s)	Altitude (km)	Weather Parameter β	Measured (dB)	Scaled** (dB)
MISERS BLUFF I (90,700 kg)	Admin. Area	4.40	251	-7.6	2.14	-7.6	146.7	100.8
	Planet Ranch	6.80	260	-6.8	2.14	-10.3	141.3	100.4
	Havasu Spring	22.9	280	-3.9	2.14	-19.4	127.6	100.8
	Parker	39.8	253	-7.6	2.14	-50.2	125.4	105.1
	Lake Havasu City	49.2	298	-2.0	2.14	-21.2	121.1	103.2
MISERS BLUFF II (544,000 kg)	Observer Area	2.57	241	-4.2	1.00	- 5.2	164.1	105.0
	Admin. Area	4.52	255	-3.3	1.00	- 7.2	153.3	100.8
	Planet Ranch	6.95	262	-3.0	1.00	-10.0	149.4	101.9
	Havasu Springs	23.1	281	-1.9	1.00	-20.7	132.2	98.6
	Parker	39.6	254	-3.3	1.00	-47.9	116.9	89.5
	Lake Havasu City	49.7	299	0.4	0.73	11.8	117.7	92.9

**Scaled to 110 kg at 25 km for $P_{ambient}$ = 102 kPa and c_o = 340 m/s

Note: The following ambient conditions were used for the scaling calculations:

Event	Pressure (kPa)	Sound Speed (m/s)
MIDDLE GUST "B"	85.41	331
MIDDLE GUST "C"	84.90	343
PRE-DICE THROW I	86.75	348
PRE-DICE THROW II	87.65	343
DICE THROW	85.63	337
MISERS BLUFF I	(98.78)	(353)
MISERS BLUFF II	98.78	353

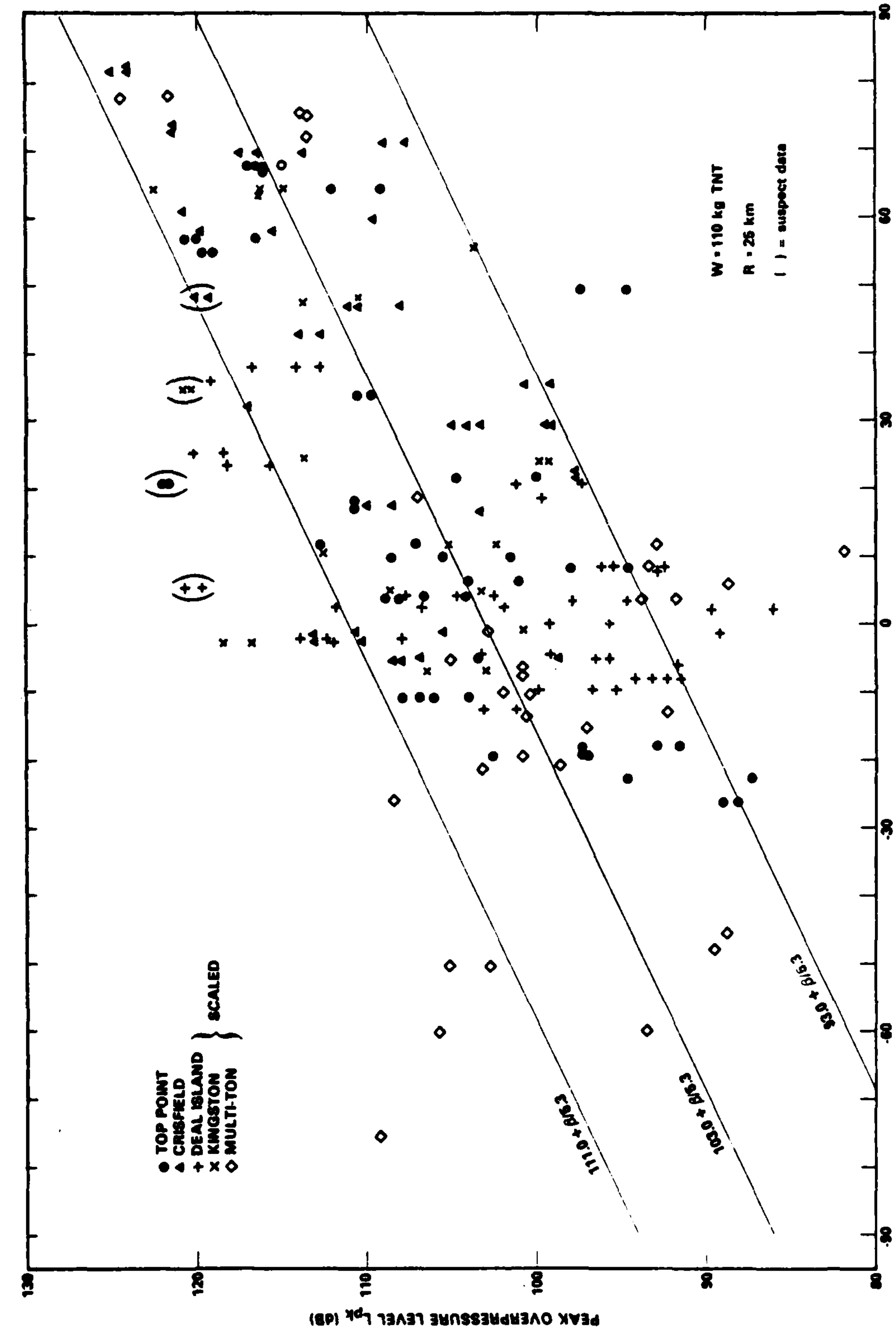

FIGURE 5-3 MK 82 BOMB AND MULTI-TON DATA

The maximum and minimum lines from Figure 5-2 are also drawn on Figure 5-3 and are seen to bracket 80 percent of the plotted points. The four pairs of points in parentheses represent the measurements for two closely spaced events. The fact that these data points are the only related set which are consistently outside of the bracketing lines suggests that the weather data may not have been representative of the actual conditions in the area at the time of the events.

The least squares straight line fit to the data in Figure 5-3 has the equation $L_{pk} = 103.1 + \beta/5.34$ with a standard deviation of 7.6 dB and a correlation coefficient of 0.39. It is interesting to note that the maximum expected peak overpressure level line from Figure 5-2 is almost exactly the one standard deviation line for the data in Figure 5-3. The maximum and minimum lines in Figure 5-3 will henceforth be used to estimate the maximum and minimum peak overpressure levels, respectively, to be expected for weather conditions represented by the parameter β.

The median expected peak overpressure level line is also drawn in Figure 5-3. Figure 5-4 shows a lognormal plot of the differences of the Mk 82 and multi-ton data in Figure 5-3 from the maximum expected peak overpressure level line. From this figure it is seen that the median (50 percent) line lies 8.0 dB below the maximum line. Because of normal weather fluctuations, half of the data in a series of events are expected to lie above the median curve and the other half below. The linearity of the lognormal points indicate that the scatter of the data points about the median line is well represented by a Gaussian (normal) distribution. The average expected peak overpressure level line, 7.9 dB below the maximum line, is essentially equal to the median line.

Figure 5-5 shows the lines of Figure 5-3 scaled from 28 km to 12 km and from 110 kg to 4.1 kg (-3.0 dB). The dots (•) represent the unscaled Deal Island peak overpressure level data from 5" naval gun shells detonating at impact on Bloodsworth Island. The x's represent the Top Point shell explosion data scaled from 28 km to 12 km (+9.7 dB). Each vertical bar connects the maximum, median, and minimum peak overpressure levels from a series of events closely spaced in time. The lines bracket the data and represent the trend quite well. The single disagreeing set of data occurred on a very blustery day;

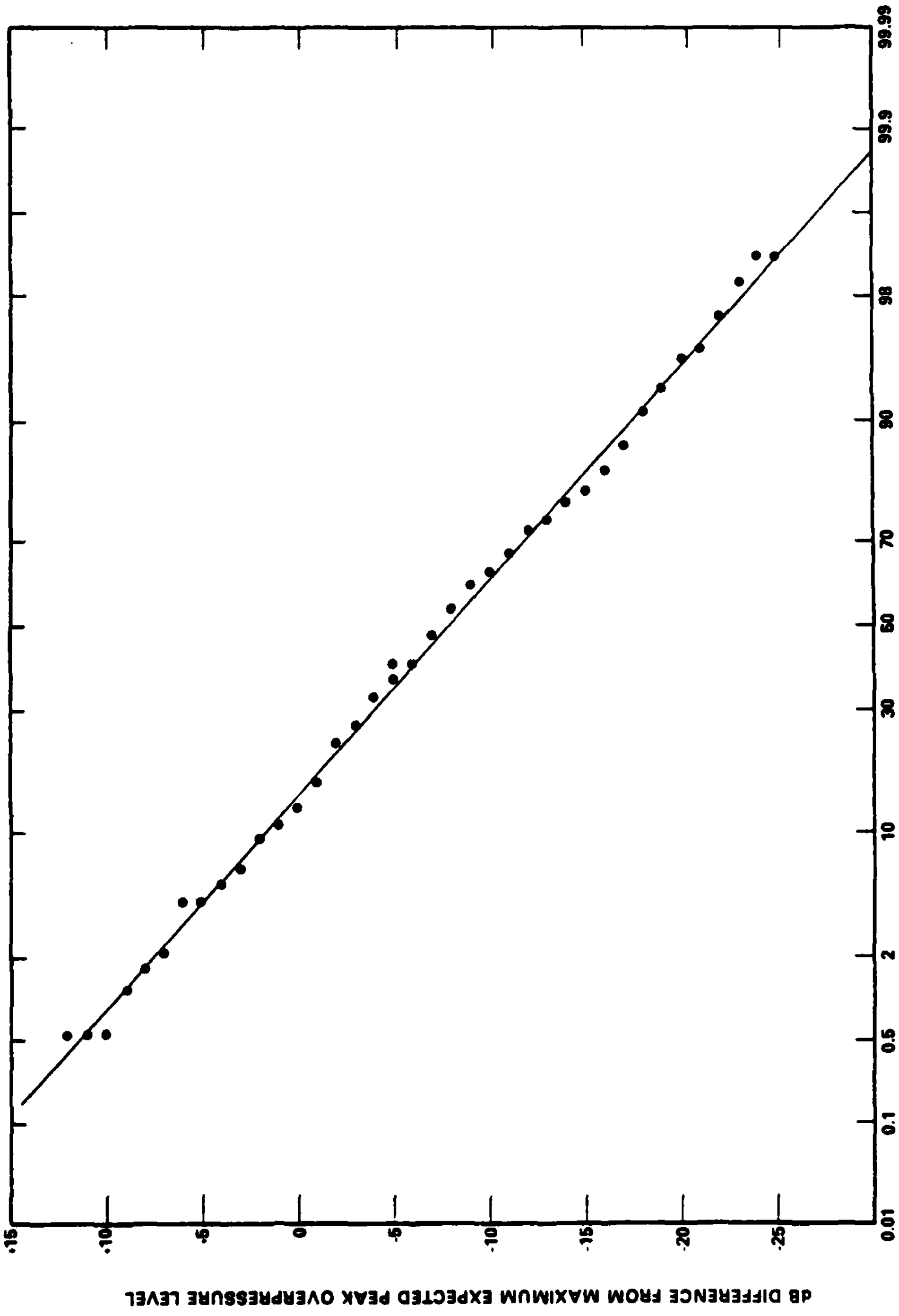

FIGURE 5-4 DISTRIBUTION OF MK 82 BOMB AND MULTI-TON DATA

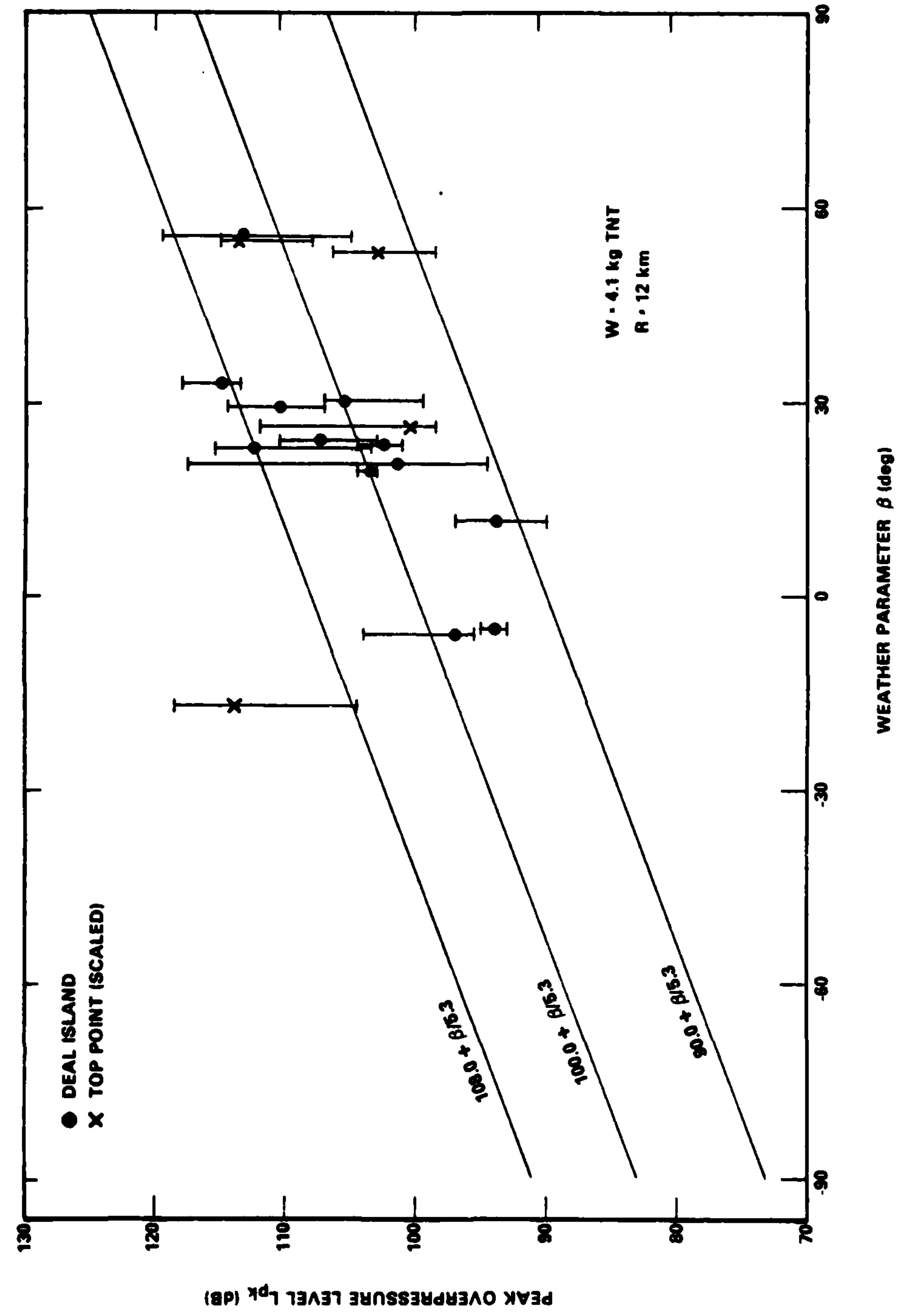

FIGURE 5-5 5" SHELL EXPLOSION DATA FROM DEAL ISLAND AND TOP POINT the actual atmospheric conditions had probably changed drastically from the time the sound speed profile had been measured.

Some difficulty was experienced in determining an acceptable equivalent weight for the muzzle blast of 5"/38 caliber and 5"/54 caliber naval guns. A value can be derived from the Deal Island and Top Point muzzle blast data plotted on Figure 5-6. The dots (•) represent the unscaled Deal Island muzzle blast data measured at a distance of 21 km from a typical ship position. The x's represent the corresponding Top Point data scaled from 37 km to 21 km (+6.5 dB). Each vertical bar connects the maximum, median, and minimum peak overpressure levels from a series of 5" gun firings closely spaced in time. Then a set of lines of the "correct" slope were selected which resulted in a practical upper bound for the muzzle blast data. Note how well they bracket the data and represent the trend. By scaling these lines back to those in Figure 5-3, a value of 30 kg TNT was found to represent the muzzle blast assuming a nominal ship standoff of 21 km from the Deal Island monitoring station. Both Deal Island and Top Point are situated within 10° or 15° from most possible direct lines of fire from the ships. It is known[22] that muzzle blast is a strongly directional phenomenon, but the value of 30 kg TNT can be used as a practical upper bound for the muzzle blast from typical 5" naval gunfire on the Bloodsworth Island range.

SCALING CONSIDERATIONS. Figures 5-3, 5-5, and 5-6 suggest that the overpressure and weather correlation is applicable over a wide range of explosive weights (hundreds of tons TNT to 4.1 kg TNT). However, the distances involved were greater than 9 km. In an effort to see how well the correlation applied much closer to a charge, the following comparison was made.

Figure 5-7 was taken from reference 23 and displays overpressure measurements from 45 kg and 1145 kg charges scaled to 400 m from a 1 kg TNT charge.

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[22]Pater, L. L., "Gun Blast Far Field Peak Overpressure Contours," NSWC TR 79-442, Mar 1981.

[23]Reed, J. W., "Project PROPA-GATOR--Intermediate Range Explosion Airblast Propagation Measurements," SAND 80-1880C, and in Minutes of the 19th DOD Explosive Safety Seminar, 9-11 Sep 1980.

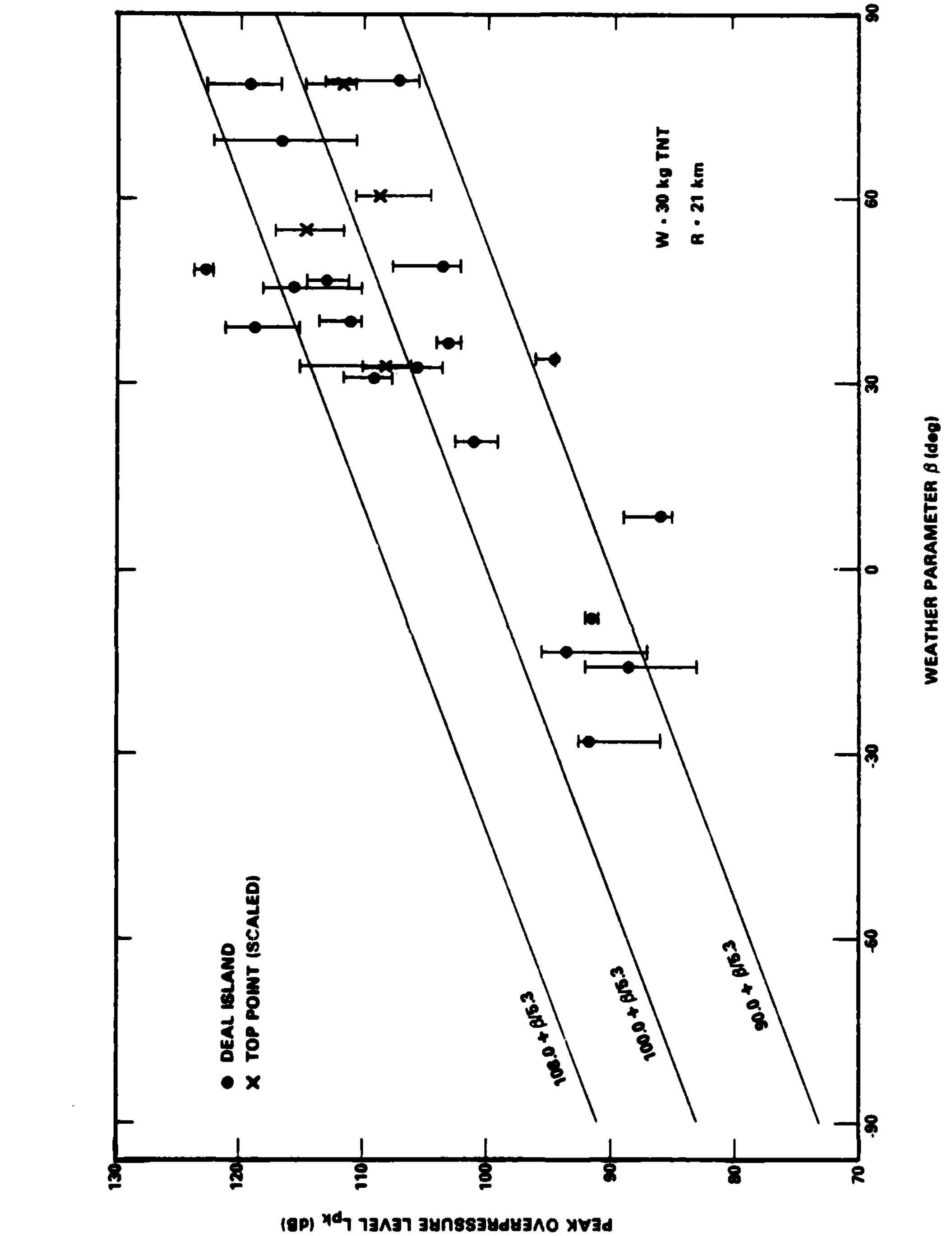

FIGURE 5-6 MUZZLE BLAST DATA FROM DEAL ISLAND AND TOP POINT

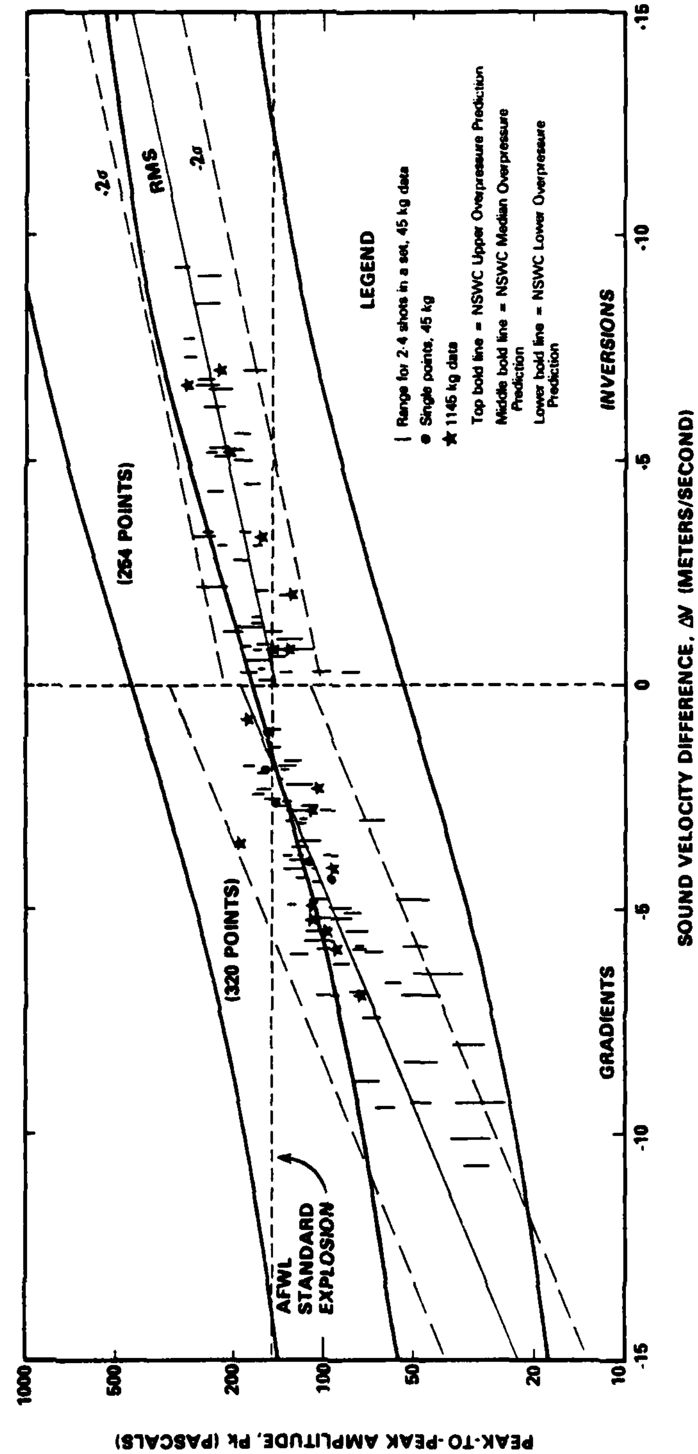

FIGURE 5-7 RECORDED PRESSURE AMPLITUDES VERSUS SOUNDS VELOCITY DIFFERENCES IN THE BOUNDARY LAYER, AT YIELD-SCALED DISTANCE OF 400 m FROM 1 kg TNT

(Taken from Reed, reference 23.)

The abscissa is the maximum measured sound velocity difference in the 152 m high boundary layer at the ground surface. The NSWC weather correlation term is range dependent. A range of 1423 m was used to generate the NSWC curves ($1423\ m\ /\ (45\ kg)^{1/3} = 400\ m/kg^{1/3}$). Note that the NSWC average expected overpressure curve reasonably represents the data. The maximum expected overpressure curve is overly pessimistic. The scatter in the expected overpressure levels should decrease as the range decreases, but this dependence is not accounted for in the NSWC model. For large negative sound velocity differences the data and the NSWC curves seem to be diverging.

The NSWC correlation appears to contain the core of a fairly general prediction method. But further study is needed to determine the applicability of the NSWC correlation outside of the range of data from which it was derived.

FOCAL POINT APPROXIMATION. Many different approaches were tried in the attempt to find a correlation between the weather data and the peak overpressure level data. While working with the BRL ray tracing equations,[15] an approximation was found which greatly simplifies the determination of caustics, i.e., locations on the ground surface at which sound rays are concentrated by the lens effect of the atmosphere. The standard ray tracing methods locate caustics either by finding regions where an unusually large number of ray paths touch the ground[15,18] or by finding locations where the rays' touchdown points decrease in distance from the source and then begin to increase as the rays' initial angles of departure are gradually increased.[4] Both of these methods require that a large number of ray paths be calculated in order to ensure that no caustic is missed. With the new approximation, caustics are calculated in a straightforward manner and only one ray path calculation is required for each possible caustic. This results in a significant savings in computing time, making caustic calculations practical for microcomputers. It is possible to locate regions of reduced airblast propagation as well as regions of enhanced

[15]See footnote 15 on page 5-1.

[18]See footnote 18 on page 5-5.

[4]See footnote 4 on page 2-9.

propagation, whether or not a caustic exists. The effects of single positive gradients at the ground surface can be included.

The approximation is derived and discussed in detail in Appendix A. Equation A.5 is the essential approximation. This enables the caustics to be calculated directly using the sound speed versus altitude profile. The calculated caustic ranges will be equal to or slightly less than the "exact" caustic range. This is conservative. Another approximation, summarized in Equations A.16 and A.17, removes the nonphysical mathematical solutions and certain artificial constraints so that the technique can be extended to all physically possible situations.

However, the approximations mentioned above did not lead to any method which could be used to estimate the overpressure levels at the caustics. Methods using the caustic approximation were pursued for a time but were abandoned when the new NSWC method was formulated. The caustic approximation is included in this report because it is a product of the effort expended in this project and because it might be helpful to others in developing or updating their own methods.

DISCUSSION. Any attempt to correlate the peak overpressure level data with the fine details of the sound speed profiles is destined to fail because of normal wind fluctuations. To make matters worse for this particular investigation, the weather data was taken only once every 4 hours and 34 km away across the Chesapeake Bay from ground zero. In addition the locations of the ships, shell hits, and bomb hits are not precisely known. In spite of all the above, this section demonstrates that a correlation apparently does exist between the peak overpressure levels and the weather data for explosive charge weights ranging from 4.1 kg to 4.5 x 10^5 kg TNT. This correlation must be related to some fundamental large-scale phenomenon which controls the long range airblast propagation. Otherwise any trend would have been masked by all of the above problems. The data scatter certainly prevented the derivation of too elaborate a prediction method, but the one reported below is believed to be realistic and should give useful results, especially for the Bloodsworth Island area.

NSWC PREDICTION METHOD

The correlation discussed in the previous section quantitatively relates the following four parameters: W, the surface-detonated TNT equivalent explosive weight; R, the distance from the explosive to the point of interest; L_{pk}, one-half the peak-to-peak overpressure level difference for the instantaneous overpressure signature at the point of interest; and β, the weather parameter which represents airblast focusing conditions between the explosion source and the point of interest. This means that if any three of these parameters are known, the fourth can be solved for. General instructions are given in Appendix B for programming the NSWC method on any computer. In this section a method will be given to determine L_{pk} when W, R, and β are known.

To determine the weather parameter β, first generate the sound speed versus altitude profile along the azimuth of interest using Equation 5.1. Then for each altitude level, calculate $\tan \eta = \Delta v/\Delta z$ as indicated in Figure 5-1. For altitudes below R/75, where R is the range of interest, calculate $\tan \eta = 75\Delta v/R$. Finally calculate β using Equation 5.2 and the maximum value of $\tan \eta$.

Figures 5-2 and 5-3 show that the maximum expected peak overpressure level $L_{pk} = 111.0 + \beta/5.3$ decibels for W = 110 kg, R = 25 km, and ambient pressure PA_o = 102 kPa. Using Equation 5.4 with $\alpha = 4/3$ to scale these conditions, the maximum expected peak overpressure level L_{pk} in decibels is given by

$$L_{pk} = 111.0 + \beta/5.3 + 20 \log_{10} \left[\left(\frac{PA_o}{102\ \text{kPa}}\right)^{0.556} \left(\frac{W}{110\ \text{kg}}\right)^{0.444} \left(\frac{25\ \text{km}}{R}\right)^{1.333} \right] \quad (5.5a)$$

$$= 107.8 + \beta/5.3 + 20 \log_{10} \left[PA_o^{\ 0.556}\ W^{0.444} / R^{1.333} \right] \quad (5.5b)$$

where L_{pk} = Maximum expected peak instantaneous overpressure level (dB)

β = Weather parameter (°)

PA_o = Ambient pressure (kPa)
W = Explosive weight (kg), TNT equivalent surface detonation
R = Distance from explosion (km)

The median expected peak overpressure level is obtained by subtracting 8.0 dB from Equation 5.5. For the minimum expected peak overpressure level, subtract 18 dB from Equation 5.5. For an airburst, subtract an additional 2.0 dB from Equation 5.5 (surface reflection factor of 1.7).

CHAPTER 6

LOCAL NOISE REGULATIONS

STATE OF MARYLAND NOISE ACT

The local noise ordinances, where they exist, follow the state regulations. The Environmental Noise Act of 1974 of the State of Maryland[24] sets the maximum allowable discrete noise level for residential zoning districts at 60 dBA during daytime hours (0700 - 2200), and at 50 dBA during nighttime hours (2200 - 0700), where A-weighting is understood (see Figure 3-1). In addition, a 55 dBA limit is set for the 24 hour day-night average sound level (L_{dn}) where a 10 dBA penalty is applied to noise occurring during the nighttime hours (2200 - 0700). The definition of L_{dn} is:

$$L_{dn} = 10 \log_{10}\left[\frac{1}{86400}\left(\int_{0700}^{2200} 10^{L_A(t)/10}\,dt + \int_{2200}^{0700} 10^{[L_A(t) + 10]/10}\,dt\right)\right] \qquad (6.1)$$

where time t is in seconds, and $L_A(t)$ is the instantaneous A-weighted overpressure level in decibels defined as

[24]Title 10 - Department of Health and Mental Hygiene, Maryland State Environmental Health Administration. 10.03.45 Rules and Regulations Governing the Control of Noise Pollution in Maryland, as amended 14 Sep 1977.

$$L_A(t) = 10 \log_{10}\left[p_A^2(t)/p_o^2\right] \qquad (6.2)$$

where $p_A(t)$ is the instantaneous A-weighted overpressure and p_o = 20 micropascals.

IMPULSIVE NOISE

The state regulations were derived from the consideration of continuous noise sources. For impulsive noise sources such as blast waves from explosions, where the energy is concentrated in the lower frequencies, the A-weighted contribution to L_{dn} is negligible. The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Research Council, however, recommends in section VII of their report[9] that C-weighted sound exposure levels L_{CE} with a reference time interval of 1 sec be used for the impulsive noise contribution to the day-night average sound level L_{dn}.

Equation 6.1 can be used to derive a formula which relates the C-weighted day-night average sound level L_{Cdn}, the C-weighted sound exposure level L_{CE} for an impulsive event, and the number N of similar events:

$$\begin{aligned} L_{Cdn} &= 10 \log_{10}\left[\frac{N}{86400} \int 10^{L_C(t)/10}\, dt\right] \\ &= 10 \log_{10}\left[\int 10^{L_C(t)/10}\, dt\right] + 10 \log_{10} N - 10 \log_{10} 86400 \\ &= L_{CE} + 10 \log_{10} N - 49.4 \text{ dB} \qquad (6.3) \end{aligned}$$

where

[9]See footnote 9 on page 3-2.

$N \quad = N_d + 10\ N_n$

$N_d \quad$ = Number of events during the day (0700 - 2200)

$N_n \quad$ = Number of events during the night (2200 - 0700)

$L_C \quad$ = Instantaneous C-weighted overpressure level

Relationships were found[3] for the Bloodsworth Island Mk 82 bomb records relating the flat sound exposure level L_E and the C-weighted sound exposure level L_{CE} to the peak flat overpressure level L_{pk}:

$$L_E = L_{pk} - 10\ \text{dB} \tag{6.4}$$

$$L_{CE} = L_{pk} - 23\ \text{dB} \tag{6.5}$$

Equation 6.4 is similar to that found by Young[25] for sonic booms having N-waves of approximately 100 ms duration. Young reported a value of -11.5 dB for the constant term. The NSWC data consists of multiple sinusoidal waves typically of several hundred milliseconds duration (see Figures 3-2 through 3-5). Fifty-four records were analyzed where L_{pk} varied between 105 dB (3.6 Pa) and 132 dB (80 Pa). The NSWC data suggests that the constant, -10 dB, varies slightly with the distance from the source.

Equation 6.5 was derived from 13 records where L_{pk} varied between 101 dB (2.2 Pa) and 132 dB (80 Pa). The constant was found to be -23.3 dB with a standard deviation of 2.2 dB. This value is reasonable, since Young reports that the A-weighted sound exposure level for sonic booms is 33-46 dB (45-200 times) lower than L_{pk}, depending on the value of L_{pk}. There was no indication that the constant, -23 dB, varies as a function of the distance from the source.

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[3]See footnote 3 on page 1-3.

[25]Young, R. W., "Average Sound Level Including Sonic Booms," in <u>Acoustical Society of America Meeting,</u> 6 Nov 1975.

MULTIPLE PULSES

The contribution of a number of similar impulsive events to the day-night average sound level is determined by combining equations 6.3 and 6.5:

$$L_{Cdn} = L_{pk} + 10 \log_{10} N - 72.4 \text{ dB} \tag{6.6}$$

The total day-night average sound level L_{dn} is found by combining the A-weighted background noise level L_{Adn} with the impulsive contribution L_{Cdn} as follows:

$$L_{dn} = 10 \log_{10} \left(10^{L_{Adn}/10} + 10^{L_{Cdn}/10} \right) \tag{6.7}$$

Note that L_{dn} will equal 55 dB when both L_{Adn} and L_{Cdn} equal 52 dB.

The above relationships imply that only one event (N=1) that produces an L_{pk} = 127.4 dB (47 Pa) during the day will result in an L_{dn} = 55 dBA using the CHABA recommendation. Any further activity would then exceed the intent of the State of Maryland noise limitations. At night (2200 - 0700 hours) it would take only one event with L_{pk} = 117.4 dB (15 Pa) to result in an L_{dn} = 55 dBA using the CHABA recommendation and the 10 dBA nighttime penalty.

DISCUSSION

Strictly speaking, the typical Navy exercises described in Chapter 2 should never violate the State of Maryland noise limitations. The energy of the blast waves from typical Navy exercises is contained in the lower frequencies so that the A-weighted contributions are negligible.

The CHABA recommendation is a reasonable criterion, but there is still much controversy among the experts as to how impulsive signals should be processed for L_{dn} calculations. Therefore it is recommended at this time that the damage and nuisance criteria specified in Chapter 7 be adopted for the Bloodsworth

Island area. These criteria are in line with the intent of the Maryland noise regulations and will tend to keep L_{dn} below the 55 dB limit, even using the CHABA recommendation.

CHAPTER 7

RECOMMENDED SHOOT/NO SHOOT DECISION PROCEDURE

The main considerations regarding a shoot/no shoot decision procedure are briefly reviewed below and are followed by a presentation of the recommended decision procedure.

WEATHER SOUNDINGS

Figure 4-2 indicates that the early morning (0600 EST) and early evening (1800 EST) upper air weather soundings from the NATC and Wallops Island stations give comparable results. In Chapter 5 it was shown that the NATC soundings correlated well with the measured overpressure data. Therefore the 0600 and 1800 EST soundings from Wallops Island can be used to represent the early morning and early evening weather conditions in the Bloodsworth Island area.

However, until it can be demonstrated and documented that the changing weather conditions in the Bloodsworth Island area can be adequately predicted throughout the day, it is recommended that additional weather soundings be taken by NATC at least every 4 hours during explosive exercises. The first sounding should be taken at such time that the airblast focusing conditions can be evaluated prior to commencement of the exercise. Wallops Island data will suffice for the early morning and early evening soundings. No sounding should be expected to accurately represent the weather conditions more than 1 or 2 hours before or after the actual sounding. Therefore, on days when rapid changes in weather conditions are expected, such as the passing of a front, weather soundings should be taken at 1 or 2 hour intervals, as needed.

Sound speed versus altitude profiles should be constructed up to at least 3000 m (700 mbar, or 70 kPa) and analyzed for four different directions. Three of these directions are fixed: true North toward Bishops Head; 90° clockwise from true North toward Deal Island; and 135° clockwise from true North toward Crisfield. The fourth direction should be that the maximum wind velocity blowing toward the Eastern Shore communities between true North and 135° clockwise from true North. This fourth direction need not be calculated if it lies within 10° of any of the three fixed directions.

PREDICTION METHOD

The NSWC airblast magnitude prediction method described in Chapter 5 is recommended for the evaluation of blast focusing conditions using the weather data. The new prediction method is the major change to the interim shoot/no shoot procedures.[1,2] The final shoot/no shoot procedure, using the more reliable NSWC prediction method, should keep the overpressure levels from typical Navy exercises below the recommended damage and nuisance levels in the communities surrounding Bloodsworth Island.

The weather parameter (Equation 5.2) is dependent on the distance R of the point of interest from the explosion. For the Bloodsworth Island target range it is recommended that a value of R = 10 km be used between the azimuth angles 350° and 125° clockwise from true North, and that a value of R = 18 km be used between 125° and 180° clockwise from true North.

DAMAGE CRITERIA

The measured ground motion was shown in Chapter 3 to be airblast induced and to be negligible in magnitude. Only the airblast itself was seen to be related to possible damage. Chapter 3 concludes that the peak overpressure level L_{pk} is the principal parameter related to damage and should be held below 125 dB (36 Pa) to eliminate damage claims. The analysis in Chapter 6 indicates that this is also the least restrictive limit which would comply with

[1]See footnote 1 on page 1-3 .

[2]See footnote 2 on page 1-3.

the intent of the State of Maryland noise regulations[24] using the CHABA recommendation[9] for handling impulsive noise events. Let it be restated here that the CHABA recommendation is not required by law and is more restrictive than the actual requirements.

NUISANCE CRITERIA

Whereas it is evident when damage occurs, nuisance or annoyance thresholds are difficult to determine. The "startle" effect, repetition rate, and background noise level strongly influence the perception and tolerance of a signal with a given overpressure level. No obvious nuisance thresholds could be determined from the data obtained in this test series.

The FWC prediction method discussed in Chapter 5 has been used for a significant period of time with fairly good results for 5" naval gunfire. The FWC method evaluates the sound speed profile and categorizes the sound focusing conditions as either NIL, SLIGHT, MODERATE, or HEAVY. The FWC categories can be related to the NSWC weather parameter β as follows:

Category	β (°)
NIL	$\beta < 0$
SLIGHT	$0 < \beta < 31$ (tan 31° = 0.6)
MODERATE	$31 < \beta < 50$ (tan 50° = 1.2)
HEAVY	$50 < \beta$

The categories as defined above are useful and sufficient to characterize the weather conditions for the Bloodsworth Island target range. The recommended courses of action to be taken for the different categories will be somewhat more restrictive than those previously specified by the original FWC method.

[24]See footnote 24 on page 6-1.

[9]See footnote 9 on page 3-2.

RECOMMENDED DECISION PROCEDURE

The weather soundings and analyses should be performed as indicated in the previous sections.

Naval activities at Bloodsworth Island should be restricted to daytime hours (0700 - 2200) as defined by the State of Maryland Noise Act.[24] The additional 10 dBA penalty required for noise occurring during nighttime hours is not incorporated into the procedures recommended below. While gunnery exercises can commence at 0700, the analysis of the 0700 Wallops Island sounding is usually not complete until sometime after 0900. Therefore FWC must be prepared to predict the sound focusing conditions for these early morning activities.

It is recommended that naval activities at Bloodsworth Island be regulated by the following policy. Each activity will be assigned by NAVPHIBSCOL to one of the below categories:

Category A: Ships assigned to qualify and scheduled to deploy within 90 days.

Category B: Ships assigned to qualify and scheduled to deploy within 180 days.

Category C: All other firing ships.

Category D: Bomb drops from aircraft.

The various courses of action available to NAVPHIBSCOL for control of the naval activities are defined as follows:

1 - Continue firing.

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[24]See footnote 24 on page 6-1.

2 - Check firing. Contact FWC to determine if weather will improve. Commence firing after FWC has indicated an improvement in focusing conditions and the course of action can be changed to number 1 above.

3 - Do not open fire. Await FWC weather update.

Before any operation begins on Bloodsworth Island, the Navy activity must contact NAVPHIBSCOL to obtain sound focus conditions and a course-of-action number. NAVPHIBSCOL will obtain the focusing conditions from FWC. The courses of action to be taken BEFORE complaints are received from Eastern Shore residents are as follows:

Sound Focus Condition:	NIL	SLIGHT	MODERATE	HEAVY
Category A:	1	1	2	3
Category B:	1	1	2	3
Category C:	1	2	3	3
Category D:	1	2	3	3

The courses of action to be taken AFTER complaints are received from Eastern Shore residents are as follows:

Sound Focus Condition:	NIL	SLIGHT	MODERATE	HEAVY
Category A:	1	2	3	3
Category B:	1	2	3	3
Category C:	2	2	3	3
Category D:	2	2	3	3

When airdrop or gunfire exercises are in progress on Bloodsworth Island, NAVPHIBSCOL must inform the conducting Navy activity of any change in the course-of-action numbe due either to worsening sound focusing conditions provided by FWC or to the reception of complaints.

IMPACT OF RECOMMENDED PROCEDURE

This operations policy is very similar to the interim procedures[1,2] currently in force and will require no additional effort on the part of FWC and NAVPHIBSCOL for implementation. The major improvements involve the verification of the nuisance and damage criteria, and the incorporation of the new NSWC airblast magnitude prediction method. An important change, however, is the recommendation that range activities cease at 2200 hours instead of the current limit of 2300 hours.

The downtime for naval exercises on Bloodsworth Island can be estimated in the following manner. Table 7-1 gives a summary of the measured sound levels for the 16 days of exercises which were monitored. It indicates the periods during the exercises when the maximum sound levels at all monitoring stations were below the indicated levels. If the 134-140 dB (100-200 Pa) range, which is the documented threshold of window breakage,[10,11] had been taken as the shoot/no shoot criterion, then Table 7-1 indicates that exercises could be conducted at any time irrespective of focusing conditions. However, minor damage and nuisance complaints were received for sound levels as low as 124 dB (32 Pa) during the test series. The objective of the recommended procedures is to significantly reduce the number of complaints by holding the maximum expected sound levels below the 125 dB (36 Pa) level. Based on the 16 days of exercises monitored, Table 7-1 indicates that the downtime during a naval exercise might be as high as 38 percent.

[1]See footnote 1 on page 1-3.

[2]See footnote 2 on page 1-3.

[10]See footnote 10 on page 3-10.

[11]See footnote 11 on page 3-10.

TABLE 7-1 DAILY SOUND LEVELS DURING TESTS

Date	Time	Exercise	Sound Level Below 115 dB (11 Pa)	120 dB (20 Pa)	125 dB (36 Pa)	130 dB (63 Pa)	135 dB (112 Pa)	140 dB (200 Pa)
9/13	AM	Bomb	√	√	√	√	√	√
	PM	Bomb	√	√	√	√	√	√
9/14	AM	Bomb	√	√	√	√	√	√
	PM	Bomb	√	√	√	√	√	√
9/16	—	NGF	x	x	x	√	√	√
9/17	—	NGF	x	√	√	√	√	√
9/18	—	NGF	x	x	x	x	√	√
9/19*	AM	Bomb	x	x	x	x	√	√
	PM	Bomb	x	x	x	x	√	√
9/20	AM	Bomb	x	√	√	√	√	√
	PM	Bomb	x	√	√	√	√	√
9/21	AM	Bomb	x	x	√	√	√	√
	PM	Bomb	x	x	x	x	√	√
9/22*	AM	Bomb	x	x	x	x	x	√
	PM	Bomb	x	√	√	√	√	√
9/30	—	NGF	x	√	√	√	√	√
10/1	—	NGF	x	√	√	√	√	√
10/2	AM	Bomb	√	√	√	√	√	√
	PM	Bomb	x	x	√	√	√	√
10/3	AM	Bomb	x	x	x	x	√	√
	PM	Bomb	√	√	√	√	√	√
10/4	—	NGF	x	x	x	√	√	√
10/5	—	NGF	x	x	x	√	√	√
10/6	—	NGF	x	x	√	√	√	√
	Possible Downtime		75%	50%	38%	25%	4%	0%

*Complaints Received

√ ..... levels were below stated value
x ..... levels were equal to or above stated value

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APPENDIX A

AN APPROXIMATE METHOD FOR DETERMINING CAUSTIC RANGES

This appendix describes an approximation which greatly simplifies the determination of caustics (locations on the ground surface at which sound rays are concentrated by the lens effect of the atmosphere). The standard ray tracing methods[A-1,A-2,A-3] require that a large number of ray paths be calculated in order to ensure that no caustic is missed. With the new approximation, caustics are calculated in a straightforward manner and only one ray path calculation is required for each possible caustic.

The sound speed versus altitude profile must first be constructed using Equation 5.1 of the text. Figure A-1 shows the nomenclature convention used in this appendix: altitude interval "i" extends from z_i to z_{i+1}, with interval "1" beginning on the ground surface. The slope K_i is

$$K_i = \frac{v_{i+1} - v_i}{z_{i+1} - z_i} \qquad (A.1)$$

In ray tracing theory, a sound ray is considered to be travelling in a particular direction as it leaves the source. Snell's law is assumed to hold over the entire ray path:

[A-1] Cox, E. F., "Far Transmission of Air Blast Waves," Phys. Fluids 1, 95-101, Mar-Apr 1958

[A-2] Perkins, B., Jr., Lorrain, P. H., and Townsend, W. H., "Forecasting the Focus of Air Blasts due to Meteorological Conditions in the Lower Atmosphere," BRL Report No. 1118, Oct 1960.

[A-3] Pollet, D. A., "Sound Intensity Prediction System for the Island of Kahoolawe; Program Maintenance Manual," NSWC/DL TR-3786, Mar 1978.

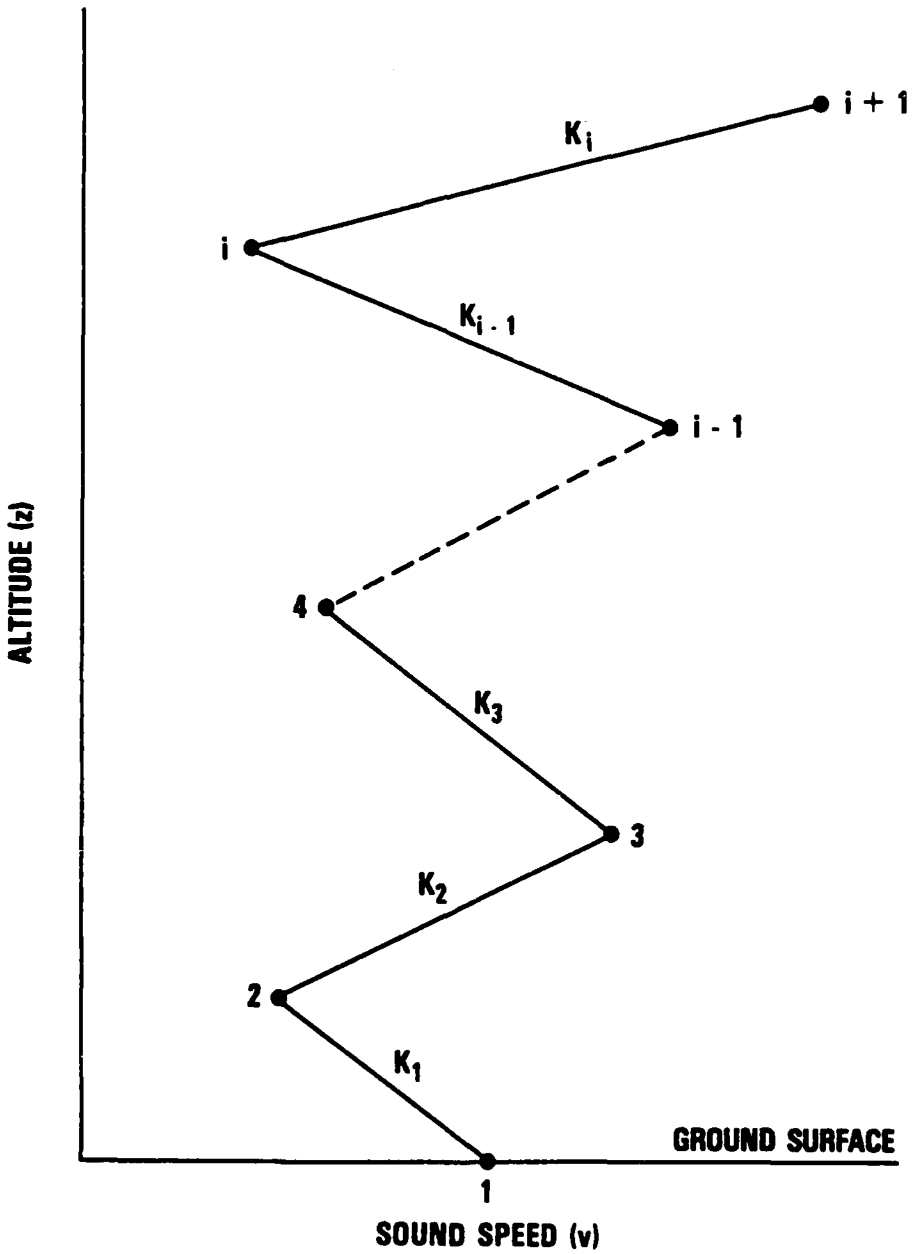

FIGURE A-1 SOUND SPEED PROFILE INDEXING CONVENTION

$$\frac{\cos\theta}{v} = \text{constant} = \frac{1}{v_{max}} \qquad \text{(A.2)}$$

where θ is the angle between the ray path direction and the horizontal, v is the sound speed at the current altitude of the sound ray, and v_{max} is the sound speed at the altitude where the ray turns over ($\cos\theta = 1$) and is determined by the initial angle and sound speed. Because of Equation A.2, the path of a sound ray is uniquely specified by the sound speed profile once the initial angle θ is selected.

The range R of a ray path is the distance from the source to that point at which the ray touches the ground. In this appendix the source and the touch-down point are assumed to be at the same altitude. It can be shown[A-2,A-3] that the range for a ray passing through N complete altitude intervals and turning over in interval N + 1 ($K_{N+1} > 0$) is:

$$R_{N+1} = \sum_{i=1}^{N} \frac{2\,v_i}{K_i \cos\theta_i} (\sin\theta_i - \sin\theta_{i+1}) + \frac{2\,v_{N+1}}{K_{N+1}} \tan\theta_{N+1} \qquad \text{(A.3)}$$

Using Equation A.2 and noting that

$$\sin\theta_i = \sqrt{1 - \cos^2\theta_i} = \sqrt{1 - v_i^2 / v_{max}^2} \quad ;$$

Equation A.3 can be rewritten:

[A-2] See footnote A-2 on page A-1.

[A-3] See footnote A-3 on page A-1.

$$R_{N+1} = \sum_{i=1}^{N} \frac{2\,v_{max}}{K_i} \left(\sqrt{1 - v_i^2/v_{max}^2} - \sqrt{1 - v_{i+1}^2/v_{max}^2} \right)$$

$$+ \frac{2}{K_{N+1}} \sqrt{v_{max}^2 - v_{N+1}^2} \qquad \text{(A.4)}$$

The simplifying approximation is made at this point. (In order to avoid showing a large amount of algebra, only the directions for the operations to be performed will be given.) Since v_i is always less than v_{max} in the first N intervals, the two terms in the parentheses in Equation A.4 can be expanded in Taylor series. Collect terms according to descending powers of v_{max}. A factor of $(v_i^2 - v_{i+1}^2)/v_{max}^2$ can now be taken out of each term. The remainder for each term is a summation of the products of various powers of v_i and v_{i+1}. Now make the approximation

$$v_i \sim v_{i+1} \sim \bar{v} \qquad \text{(A.5)}$$

where $\bar{v}$ is the average sound speed in the first N altitude intervals:

$$\bar{v} = \sum_{i=1}^{N} (z_{i+1} - z_i)(v_i + v_{i+1})/2(z_{N+1} - z_1) \qquad \text{(A.6)}$$

When this approximation is made, the remainder terms are seen to be the expansion of $-1/2\sqrt{1 - \bar{v}^2/v_{max}^2}$ so that the parentheses term in Equation A.4 is simply $(v_{i+1}^2 - v_i^2)/2\,v_{max}\sqrt{v_{max}^2 - \bar{v}^2}$.

Equation A.4 then becomes

$$R_{N+1} = \sum_{i=1}^{N} \frac{(v_{i+1}^2 - v_i^2)}{K_i \sqrt{v_{max}^2 - \bar{v}^2}} + \frac{2}{K_{N+1}} \sqrt{v_{max}^2 - v_{N+1}^2} \tag{A.7}$$

Using Equations A.1 and A.6, Equation A.7 eventually becomes

$$R_{N+1} = \frac{2\,(z_{N+1} - z_1)\,\bar{v}}{\sqrt{v_{max}^2 - \bar{v}^2}} + \frac{2}{K_{N+1}} \sqrt{v_{max}^2 - v_{N+1}^2} \tag{A.8}$$

There can be situations where the range R first decreases and then increases as the initial angle of departure θ gradually increases. A caustic exists where the range reverses direction, that is, at a value of R such that

$$\frac{dR}{d\theta} = \frac{dR}{d\cos\theta} = \frac{dR}{d\,v_{max}} = 0 \tag{A.9}$$

where use has been made of Equation A.2. When Equation A.9 is applied to Equation A.8, the condition for a caustic becomes:

$$0 = \frac{(z_{N+1} - z_1)\,\bar{v}}{(v_{max}^2 - \bar{v}^2)^{3/2}} - \frac{1}{K_{N+1} \sqrt{v_{max}^2 - v_{N+1}^2}} \tag{A.10}$$

where v_{max} is the unknown quantity to be solved for. The focal point is determined when the v_{max} specified by Equation A.10 is substituted into Equation A.8.

Equation A.10 can be transformed into a cubic equation for v_{max} by squaring the two terms on opposite sides of the equal sign. This means that only half of the three cubic solutions will be physically meaningful. It can be shown that if

$$x = \frac{(v_{max}^2 - \bar{v}^2)}{K_{N+1}(z_{N+1} - z_1)\,\bar{v}} \quad \text{and} \quad \cos\phi = \frac{\sqrt{27}}{2}\,\frac{(\bar{v}^2 - v_{N+1}^2)}{K_{N+1}(z_{N+1} - z_1)\bar{v}} \tag{A.11}$$

then the cubic equation is:

$$0 = x^3 - x - \frac{2}{\sqrt{27}}\cos\phi \tag{A.12}$$

This equation is in the desired form for standard cubic solution techniques.[A-4] The physical solutions are:

$$x = \frac{1}{\sqrt{3}}\left(\cos\phi + \sqrt{\cos^2\phi - 1}\right)^{1/3} + \frac{1}{\sqrt{3}}\left(\cos\phi - \sqrt{\cos^2\phi - 1}\right)^{1/3} \quad , \text{ for } \cos\phi > 1 \tag{A.13}$$

$$x = \frac{2}{\sqrt{3}}\cos(\phi/3) \quad , \text{ for } |\cos\phi| \leq 1 \tag{A.14}$$

There is no real solution for $\cos\phi < -1$. This is a nonphysical restriction since caustics can exist for $\cos\phi < -1$. This problem will be addressed again below. When a cubic solution exists, the caustic range is given by:

$$R_{Caustic} = 4\sqrt{\frac{(z_{N+1} - z_1)\,\bar{v}}{K_{N+1}}}\left(\frac{1 + x^2}{2\sqrt{x}}\right) \tag{A.15}$$

This value for the caustic range was obtained with the assumption that there was no upper bound on the altitude interval N + 1. Therefore, the existence of the calculated caustic range must be checked by performing a standard ray path

[A-4]Beyer, W. H., Ed., CRC Handbook of Mathematical Sciences, 5th Edition, CRC Press, Inc., 1978.

calculation using the initial angle of departure θ specified by $v_{max} = v_{N+2}$. If the range for this ray is greater than or equal to the calculated caustic range, then this focal point does physically exist; otherwise not. This checking procedure implies that the caustic calculation need be made only for those situations where v_{N+2} is greater than all sound speeds at lower altitudes. This means that any sound speed profile needs to be evaluated only once from the ground up, with the average velocity $\bar{v}$ being continuously updated and a caustic range calculation made only when a new maximum velocity is found.

The caustic range given by Equation A.15 is always less than or equal to the caustic range obtained by an exact ray path search. Comparisons for a number of simple profiles showed that the approximate caustic ranges were generally within a few percent of the "exact" caustic ranges. The relative errors tended to be less for the shorter caustic ranges.

It was mentioned earlier that when $\cos\phi < -1$ in Equation A.11, there was no real cubic solution even when physical caustics did exist. To obtain solutions in this region, use the following set of equations:

$$W = \frac{(\bar{v}^2 - v_{N+1}^2)}{K_{N+1}\,(z_{N+1} - z_1)\bar{v}} = \frac{2}{\sqrt{27}}\cos\phi \tag{A.16}$$

$$R_{Caustic} = 4\sqrt{\frac{(z_{N+1} - z_1)\,\bar{v}}{K_{N+1}}}\,(1 + W)^{1/4} \tag{A.17}$$

This set is related to a derivation in which the average sound speed $\bar{v}$ was originally defined slightly differently than in Equation A.6 so that the equation corresponding to Equation A.12 was quadratic instead of cubic. The quadratic formulation is somewhat less accurate than the cubic formulation, especially for large caustic ranges. Figure A-2 compares these two formulations. It is recommended that the cubic calculation be used for $\cos\phi > 0$, and the quadratic calculation for $\cos\phi \leq 0$.

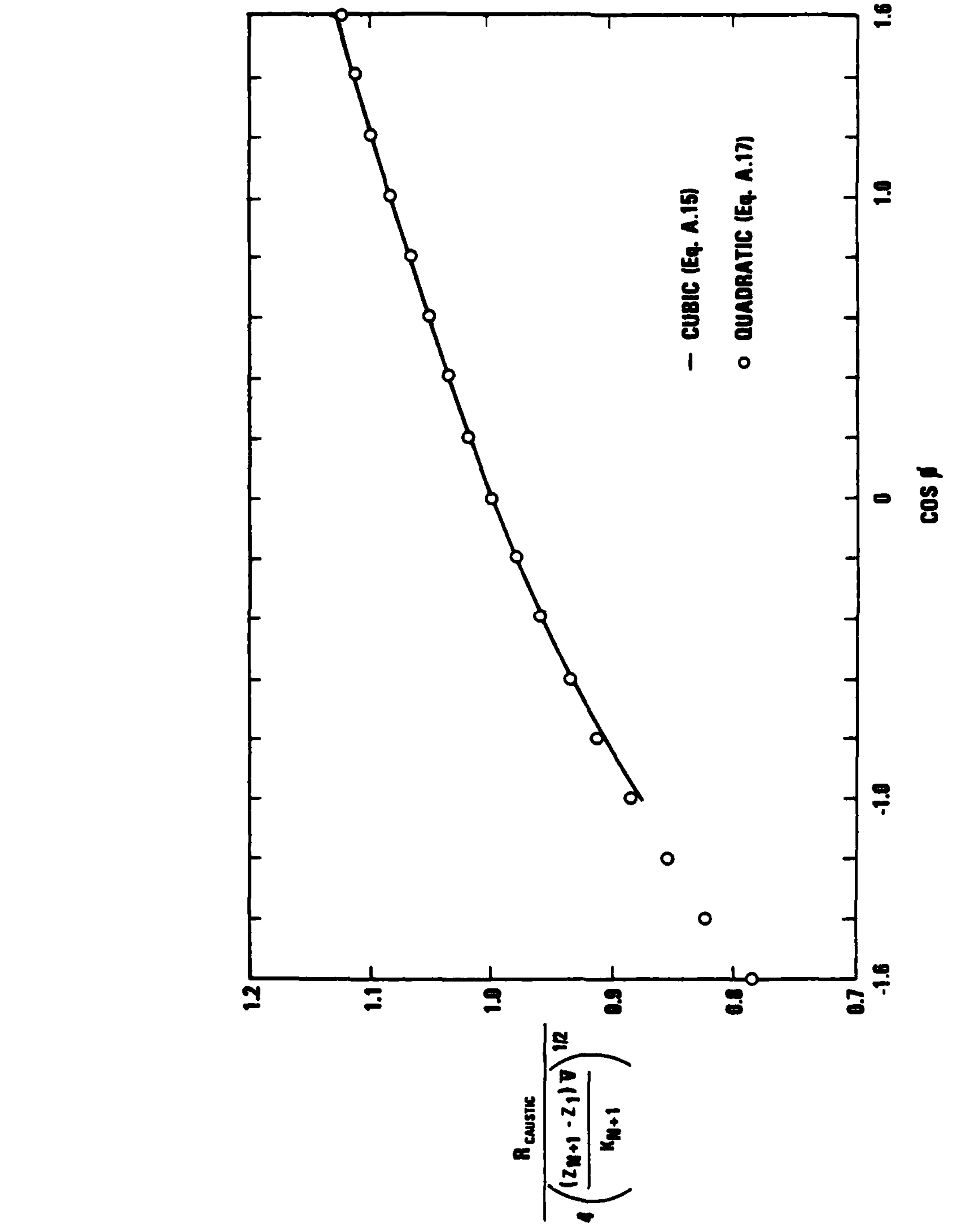

FIGURE A-2 COMPARISON OF CUBIC AND QUADRATIC FOCAL POINT PREDICTION FORMULAS

APPENDIX B

GENERAL INSTRUCTIONS FOR PROGRAMMING THE NSWC LONG RANGE AIRBLAST OVERPRESSURE PREDICTION METHOD

The NSWC airblast magnitude prediction method was developed in an effort to reduce the impact of naval explosive exercises (both airdrops and naval gunfire) on the communities surrounding the Bloodsworth Island target range in the Chesapeake Bay. This method uses measured or forecast upper air meteorological data to predict the airblast levels to be expected in the neighboring communities from explosions of any size. The method is applicable to both positive and negative sound velocity gradients and should be adaptable to other explosive operations.

This appendix outlines the general procedures to be followed when programming the NSWC method for any computer system. An adequate computer/calculator should have at least 50 storage registers and sufficient program memory for the required operations. The method is currently programmed for the TI-59 and the HP-41C hand-held calculators.

The programming notation used below is related to the BASIC programming language and should be obvious to an experienced programmer. The recommended program flow has the following order:

1. WEATHER DATA INPUT

The following upper air meteorological data is needed for each significant altitude level or pressure level. This data should represent the typical weather conditions over the entire area between the explosion source and the locations for which the airblast overpressure predictions are to be made. Unless significant weather changes occur, e.g., the morning temperature inversion disappears or a front moves through, the most recent upper air meteorological data available from a nearby weather station may usually be sufficiently accurate for this purpose. Use any convenient units for input.

N = total number of altitude or pressure levels, including the ground surface level.

I = the index number for a given altitude or pressure level. I = 1 represents the ground surface level.

FOR I = 1 to N (data input loop)

Z(I) = Altitude for level I, or

P(I) = Absolute pressure for level I.

Note: Either Z(I) or P(I) can be entered. Do not enter both.

Note: The highest level should be at a height above the surface equal to one tenth the greatest range of interest.

Note: If Z(I) values are entered, the ambient pressure at the ground surface $P_o \rightarrow P(1)$ must be entered at some point.

T(I) = Temperature at level I.

S(I) = Wind speed at level I.

D(I) = Wind direction at level I.

NEXT I (end of data input loop)

It would be a good idea for documentation purposes to print out the data values that were read in.

2. WEATHER DATA CONVERSION

The weather data must be converted, if necessary, to the units required for the airblast overpressure prediction calculations.

FOR I = 1 to N (data conversion loop)

T(I)→T(I) in units of degrees Celsius

S(I)→S(I) in units of meters/second

D(I)→D(I) in units of degrees azimuth clockwise from true North, the direction from which the wind is blowing.

(if Z(I) was read in:)

Z(I)→Z(I) in units of kilometers

GO TO end of loop (NEXT I)

(if P(I) was read in, use the following approximation derived from the hydrostatic equation $dP = -\rho g dz$)

IF I = 1, THEN 0→Z(I) and GO TO end of loop (NEXT I).

$$0.01464 * [T(I) + T(I-1) + 546.3] * \log_e \left[\frac{P(I-1)}{P(I)}\right]$$

+ Z(I-1)→Z(I) The units are kilometers.

NEXT I (end of data conversion loop)

The short loop below resets the altitude values Z(I) relative to the surface level. Reset the surface level last.

FOR I = 2 to N (Z loop)

Z(I) - Z(1)→Z(I)

NEXT I (end of Z loop)

0→Z(1)

Convert at least the ambient ground surface level pressure P(1) outside the above loops. All pressure P(I) could be converted at the beginning of the data conversion loop if desired, but only P(1) will be used below.

P(1)→P(1) in units of <u>kilopascals</u>.

Note: 1000 millibars = 100 kilopascals.

Now that the weather data has been read in and converted, the versatility of the NSWC method requires that a choice be made. Either (a) an explosive weight can be specified and calculations made for the expected airblast overpressure at a particular location or at a number of locations; or (b) a maximum airblast overpressure can be specified for a particular location and calculations made for the maximum allowable explosive weight which could be used at the target site under the given weather conditions. Other choices could also be made as discussed in the NSWC PREDICTION METHOD section in Chapter 5. In the development below, only choice (a) will be considered.

3. EXPLOSIVE WEIGHT INPUT

The maximum TNT blast equivalent weight W which will be detonated simultaneously on the surface at the target site must now be entered.

input: W = explosive weight (any units)

convert: W→W in units of <u>kilograms TNT</u>

4. LOCATION INPUT

Now some more choices must be made. Either (a) a number of locations can be actively entered each time the program is run; or (b) a number of important locations can be programmed into the code and automatically evaluated each time the code is run; or (c) a combination of the above choices can be made. In the programming below, only choice (a) will be considered.

input: R = Range or distance of desired location from explosion source (any units)

A = Azimuth angle of location as viewed from the explosion source

AD-A122 292 NOISE ABATEMENT INVESTIGATION FOR THE BLOODSWORTH ISLAND TARGET RANGE: DE..(U) NAVAL SURFACE WEAPONS CENTER SILVER SPRING MD R A LORENZ 02 NOV 81 2/2

UNCLASSIFIED NSWC/TR-81-431 SBI-AD-F500 098 F/G 13/2 NL

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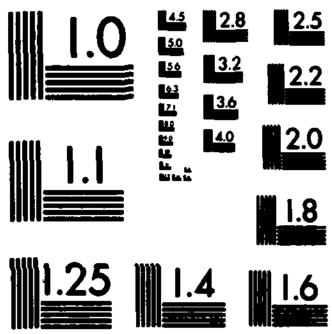
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

convert: R→R in units of <u>kilometers</u>

A→A in units of <u>degrees azimuth clockwise from true North</u> as viewed from the explosion source.

5. WEATHER PARAMETER

The parameter <u>B</u> which represents the airblast focusing power of the input weather conditions is calculated as follows:

initialize: -1000→B (Any large negative value will do as well.)

$$331 \sqrt{1 + T(1)/273} \rightarrow C0$$

$$C0 - S(1)*\cos(D(1) - A) \rightarrow V0$$

FOR I = <u>2</u> to N (weather parameter loop)

$$331 \sqrt{1 + T(I)/273} - S(I)*\cos(D(I) - A) - V0 \rightarrow V$$

(<u>V</u> is the combined sound speed and wind speed for level <u>I</u> less that for ground level in the <u>A</u> direction from the explosion source.)

IF R/Z(I) < 75 THEN 3*R*V/[Z(I)*C0]→B1

IF R/Z(I) ≥ 75 THEN 225*V/C0→B1

IF B1 > B, THEN B1→B

NEXT I (end of weather parameter loop)

convert: arctan (B)→B in units of <u>degrees</u>

(The arctan function must give values between +90 degrees and -90 degrees.)

Now the maximum focusing power parameter <u>B</u> for the given weather conditions at distance <u>R</u> in the direction <u>A</u> has been determined.

6. MAXIMUM EXPECTED OVERPRESSURE LEVEL

The maximum expected peak flat overpressure level $\underline{L}$ can now be calculated for range $\underline{R}$ in the azimuthal direction $\underline{A}$. The units of $\underline{L}$ are decibels (dB) which are defined as:

$$dB = 20 \log_{10} (\Delta P/20 \text{ micropascals})$$

where ΔP is one-half the peak-to-peak overpressure difference in the unweighted overpressure-time signature of the blast wave. For the long range overpressure signatures that are of concern for this method, the peak positive and negative overpressures have approximately the same magnitudes. Therefore ΔP in the above equation is representative of the peak flat positive overpressure value.

$$111.0 + B/5.3 + 20 \log_{10} \left[\left(\frac{P(1)}{102 \text{ kPa}}\right)^{0.556} * \left(\frac{W}{110 \text{ kg}}\right)^{0.444} * \left(\frac{25 \text{ km}}{R}\right)^{1.333} \right] \rightarrow L$$

The units of $\underline{L}$ are decibels. Note that of the four parameters (W, R, B, and L) in the above equation, any three can be specified and the fourth solved for.

7. INTERPRETATION OF L

The maximum expected peak flat overpressure level $\underline{L}$ is to be calculated and evaluated for each location specified in Step 4. The value of $\underline{L}$ can be interpreted according to the following table.

L (dB)	Expected Conditions
> 125	Minor damage (e.g., broken windows, cracked plaster)
> 116	Complaints to be expected
> 112	Complaints are probable
> 108	Complaints once in a while (a 4 dB difference means that the peak pressure of the larger shock is 1.6 times greater than that of the smaller shock.)
< 108	No complaints expected

The mean expected overpressure level is approximately 8.0 dB below L. The minimum expected overpressure level is approximately 18.0 dB below L.

The 125 dB minor damage threshold was observed during the Mk 82 bomb (110 kg TNT) data acquisition program at Bloodsworth Island. The 116 dB and 112 dB complaint thresholds are somewhat more speculative, but are related to long-established 5" naval gunfire control procedures for the Bloodsworth Island target range. It is recommended that the complaint threshold values be refined for a given target range by correlating the predicted L values with actual complaints.

8. LOCATION LOOP

Repeat the above procedures, beginning at Step 4, for each location of interest.

MISCELLANEOUS COMMENTS

TERRAIN EFFECTS. The NSWC airblast prediction method was developed using measurements of surface bursts where the airblast propagated over several kilometers of water and then over flat land. The effect of natural barriers such as mountains or forests is not known. If focusing is caused by high altitude weather conditions, no screening should be expected. The effect of channeling through mountains is also unknown.

It is believed that the NSWC prediction method gives a practical upper bound estimate for the long range overpressure levels to be expected from a given surface explosion under the specified weather conditions, whether barriers are present or not.

MUZZLE BLAST. It was found in Chapter 5 that an equivalent weight of 30 kg TNT at the ship position worked well to correlate the weather parameter B with the overpressure levels measured for the muzzle blast from 5" naval gunfire, for both 5"/38 and 5"/54 caliber shells.

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