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GENERAL MOTORS CORPORATION

TECHNICAL REPORT ON

PACIFIC 'SOFAR' VELOCITY CALIBRATION EXPERIMENT

Sponsored By The
Advanced Research Projects Agency
Project VELA UNIFORM

Submitted to
Office of Naval Research
Field Projects Branch
Washington, D. C.
Under Contract Nonr-429[illegible]
ARPA Order No. 218

GM DEFENSE RESEARCH LABORATORIES
SANTA BARBARA, CALIFORNIA

SEA OPERATIONS [illegible]

Copy No _____

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GM DEFENSE RESEARCH LABORATORIES

SANTA BARBARA, CALIFORNIA

SEA OPERATIONS DEPARTMENT

TR65-28

JUNE 1965

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NOTE: THIS REPORT INCLUDES A CLASSIFIED SUPPLEMENT WITH THE GM DRL CLASSIFIED DOCUMENT SERIAL NUMBER SBL-65-0527-S.

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I. SUMMARY AND CONCLUSIONS

1.1 THE EXPERIMENT

During the summer of 1964 a SOFAR velocity measurement experiment was conducted by GM Defense Research Laboratories between Hawaii and the California coast and between Hawaii and certain islands in the North Central Pacific. Signals also were received and utilized for velocity computation from an independent, concurrent experiment in the Aleutians. GM DRL developed and used a deployable acoustic monitoring buoy station to record signals. Additional fixed acoustic installations were used on the coast of California and on the islands of Eniwetok and Midway. The charges for the GM DRL Oahu shots were M-3 demolition blocks, equivalent to a few pounds of TNT. These were electrically fired at the approximate depth of the SOFAR axis from USS ARIKARA (ATF 98). In the Aleutians, shots equivalent to about one ton of TNT were fired at shallow depth by the RV SEA SCOPE, and 248-lb depth charges to be located acoustically were dropped by a Navy patrol aircraft.

1.2 THE OBJECTIVES

The principal objective of the experiment was to measure the average SOFAR velocity between widely spaced termini and to determine the fluctuations in this measurement. A secondary objective was to determine whether, over a period of five days, coherent temporal variations could be observed and, if so, to correlate them with possible causes. A knowledge of the SOFAR velocity and its fluctuations is required for acoustical source-location systems. (T phase sources are now being located acoustically, and potential systems to locate the sources of nuclear events by means of their underwater acoustic signals are the subject of current research). In a program for computing acoustical source locations, the mean acoustic propagation velocity is an important parameter; also important are the fluctuations of the acoustic propagation velocity. These fluctuations, which are a measure of the uncertainty in our knowledge of the propagation velocity, largely determine the obtainable precision in the location of source events.

1.3 RESULTS

The average propagation velocity, computed and observed for various paths, together with fluctuations, are indicated below:

Source Location	Receiver Location	Propagation Velocity (meters per second)			
		Computed	Number of Observations	Observed	Standard Deviation
Oahu	San Miguel Is. Calif. coast (buoy station)	1480.87	50	1479.27	0.85
Aleutian Trench	Same	1472.87	7	1468.55	0.51
Oahu	Midway	1482.09	22	1480.66	0.31
Oahu	Eniwetok	1472.87	20	1482.69	0.51

The predominant part of the standard deviations quoted above, particularly in the first two paths, must be attributed to experimental effects and not to the fluctuations of the properties of the medium. It was not possible to correlate the observed fluctuations in average propagation velocity with any geophysical effects; nor was it possible over a five day period to determine unambiguously any trends in the average propagation velocity. Hence, these fluctuations must be considered random and attributed to the statistical nature of the generation, propagation, and measurement process.

A source location program was developed and applied in a real problem of locating the sources of signals from the 248-lb, air-dropped Aleutian charges. An rms ensemble residual of about 4 km was observed; the mean contradiction between GM DRL acoustic positioning and the navigational information from the aircraft was 11.9 km.

1.4 CONCLUSIONS

If the standard deviations reported above are combined with other data, the minimum uncertainty in range determination may be calculated for various propagation paths:

Paths	Effective Std. Dev. (m/sec)	$\frac{\sigma}{<c>}$	Average Range (km)	Range Uncertainty (km)
Oahu to West Coast	0.775	5.238×10^{-4}	3884	2.03
Aleutians to West Coast	0.955	6.495×10^{-4}	4295	2.79
Oahu to Midway	0.310	2.094×10^{-4}	2151	0.45
Oahu to Eniwetok	0.350	2.361×10^{-4}	4344	0.47

II. INTRODUCTION

2.1 STATEMENT OF PROBLEM

The detection, classification, and location of underground or underwater nuclear explosions must utilize a portion of the energy of the detonation, generally after the energy has been propagated long distances (from the source of the blast to the location of the detection devices). Most systems for these purposes are seismic, i.e., they measure energy that has traveled through the earth's lithological material. Recently, however, there has been an increase in attention to underwater acoustical methods of detection. For land-based blasts these methods depend on the T phase, a low-frequency, underwater acoustic signal seismically generated.(1, 2, 3)* For in-water blasts the acoustical energy is generated directly by the blast mechanism and propagated long distances. One distinctive characteristic of the in-water blast is that it sometimes produces a pronounced, closely-spaced line structure that is not seen in T phases. Source localization depends on the stability of the ocean as a long-range propagation medium. The two principal objectives of this experiment were (1) to obtain a measurement of the average propagation velocity in the Northeast Pacific over various long path lengths based on a statistically significant number of readings and (2) a measurement of the stability of this velocity over a period of several days.

2.2 STATEMENT OF WORK

The contract statement of work provided for the following:

" (5) conduct field experiments related to the generation, propagation, and detection of T phase signals,

(6) at designated stations the Contractor will monitor the 1964 VELA UNIFORM Aleutian Shot Series . . . . . . ,

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* Raised numbers in parentheses refer to list of references on page 51.

(7) provide technical personnel at the stations for the purpose of making the recordings; and

(8) reduce the data to tubular form; and

(9) perform special analysis on selected signals; and

(10) provide a copy or the original on magnetic tape of the recordings taken."

2.3 CONCEPT OF THE EXPERIMENT

The SOFAR calibration experiment was an attempt to measure properties of the ocean. Shots were to be detonated from a firing vessel near Oahu and received at stations along the California coast and in the North Central Pacific. To remove the masking effect of experimental error it was necessary to impose very precise control on both the generation and reception of the acoustic signals – that is, a precise knowledge of both the time and location of the sound sources was demanded. Since a statistically significant sample size was sought, about 100 shots were planned. Economy and the required precise timing of the shots prompted the use of Navy M-3 demolition blocks (Composition C), electrically detonated and timed. For the firing system it was necessary to design and construct an electrical firing box with special timing terminals and to procure special seismic blasting caps, pressure rated for 1200 psi. The requirement for precise knowledge of the shot position meant that the firing vessel had to have a sophisticated navigation control system – this was Hydrodist, an electronic distance-measuring system, comprised of two shipboard units and two shore stations located accurately with respect to triangulation points.

A self-recording acoustic buoy system was developed and used in the experiment. This system, consisting of a submerged shallow buoy suspending a deep hydrophone on its mooring line at the SOFAR axis, recorded signals for about two weeks. The system served two purposes: (1) it backed up and supplemented data from the fixed stations, and (2) it tested the concept of a deployable recording buoy which could be implanted in strategically important but inhospitable geographic areas.

2.4 CHRONOLOGY

The significant events in the conduct of this experiment are listed chronologically below (all dates 1964).

4/20	Commenced ordering hardware for field experiment
5/18	Commenced work as per task statement
6/22	Conducted site reconnaissance
6/26	Liaison established with: COMSERVPAC, CO ARIKARA, US ARMY HAWAII, University of Hawaii, NAD OAHU, Eaves & Meredith
7/1	Design firm on buoy and explosive source systems
7/8	Pressure tested buoy (MS 15-64)
7/14	Arrangements completed with OU/CWSF for manning site
7/20	Conducted first major system sea tests (MS 16-64)
7/22	Tested buoy installation, ship positioning with Hydrodist, explosive rigging and firing (recovery of buoy unsuccessful)
7/23	Recovered buoy using support vessel to assist SWAN
7/26 8/7	Naval Facility reconnaissance
8/10 8/11	Conducted shallow water release tests (MS 19-64)
8/17	Coordinated arrangements with NEL
8/19	Group A NavFac field party on station
8/21	First NavFac contingent recalled temporarily
8/25	Hawaii field party departs for exercise
8/27	Deployed buoy system for recording of firing runs
8/31	ARIKARA at sea
	Group B NavFac field party on station
9/1	GM shots commence
9/2	Alaskan shots commence
9/5	GM shots complete
	ARIKARA returns to port
9/6	Group A NavFac field party returns GM DRL
9/9	Buoy recovered (MS 26-64)
	Hawaii field crew returns
9/21	Alaskan shots complete
9/21	Group B NavFac field party returns

III. ACOUSTICAL SOURCE SYSTEM

3.1 GENERAL

Sources of the timed signals had to be both safe and inexpensive, and information about the position and time of the source signal had to be accurate. Safety was a concern because the decision had been made to use available explosives as sound sources. Expense was important because of the large number of shots to be fired.

Based upon all of these considerations, the sound source system was designed to use electrically-fired standard Navy M-3 demolition blocks. The explosive is Composition C, a stable plastic material capable of taking the 1200 psi of the firing depth.(1) Also capable of withstanding the high ambient pressure were the special seismic blasting caps, manufactured by DuPont and designated "SSS."

3.2 ACCURACY LIMITS

The overall design of the experiment dictated the precise knowledge required of charge location and detonation time. Variations in transit time due to uncertainties in the position of the charge and time of firing were to be kept below the point where they could mask the observable fluctuations in transit time caused by oceanic inhomogenieties. A limit to precision is set by the characteristics of the received signal itself. The time of the SOFAR axis arrival, indicated by an abrupt fall in signal level, is measurable to about 100 ms. If uncertainties in source position and time were each to be held to about 20% of the signal uncertainty, then they should not measurably widen the statistical spread in the results. Hence, source time uncertainty was to be held to 20 ms, and position uncertainty to 100 feet. Both of these were attainable.

The time measurement required a firing circuit that would record at the same time it fired the charge. The position uncertainty requirement led to precise electronic equipment to locate the firing ship. An electronic distance-measurement system known as "Hydrodist" was employed; this navigation system requires two accurately determined land-based stations from which precision distance measurements can be made to the ship. With a specially prepared grid chart, the geographical position of the ship can be determined to uncertainties of less than 10 feet in ranges up to 14 miles from the shore stations.

The charges were suspended on an electric cable with a 50-lb weight at the end to reduce wire angle at the moment of firing; 2,400 feet of cable was streamed. Correction of horizontal and vertical displacement depended on wire angle at the ship; the amount of change was arbitrarily fixed at one-half of the straight geometric correction. This procedure is based on the practice of oceanographers in correcting Nansen bottle cast geometry:

$$\Delta X = 1/2\ L_w \text{ Sin } \theta \qquad \text{horizontal correction}$$

$$\Delta Z = L_w\ (1 - 1/2 \text{ Cos } \theta) \qquad \text{vertical correction}$$

where L_w = length of wire

θ = wire angle at surface, i.e., angle between vertical and tangent to wire.

3.3 FIRING CIRCUIT

The firing box was designed to operate from the ship's 120-vdc system. Safety interlocks of banana-plug jumpers that were part of the firing circuit prevented the firing circuit from closing accidentally. (If a technician keeps an interlock with him while working on the firing circuit, the circuit can be closed only with his knowledge and concurrence.) The firing box also provided a voltage tap on either side of a 1-ohm resistor to measure the firing current. Leads from this point went to one channel of a two-channel Sanborn recorder to indicate the instant of switch closure; the other channel received time marks from radio station WWV. The firing circuit diagram is shown in Figure 1, and the firing box is illustrated in Figure 2.

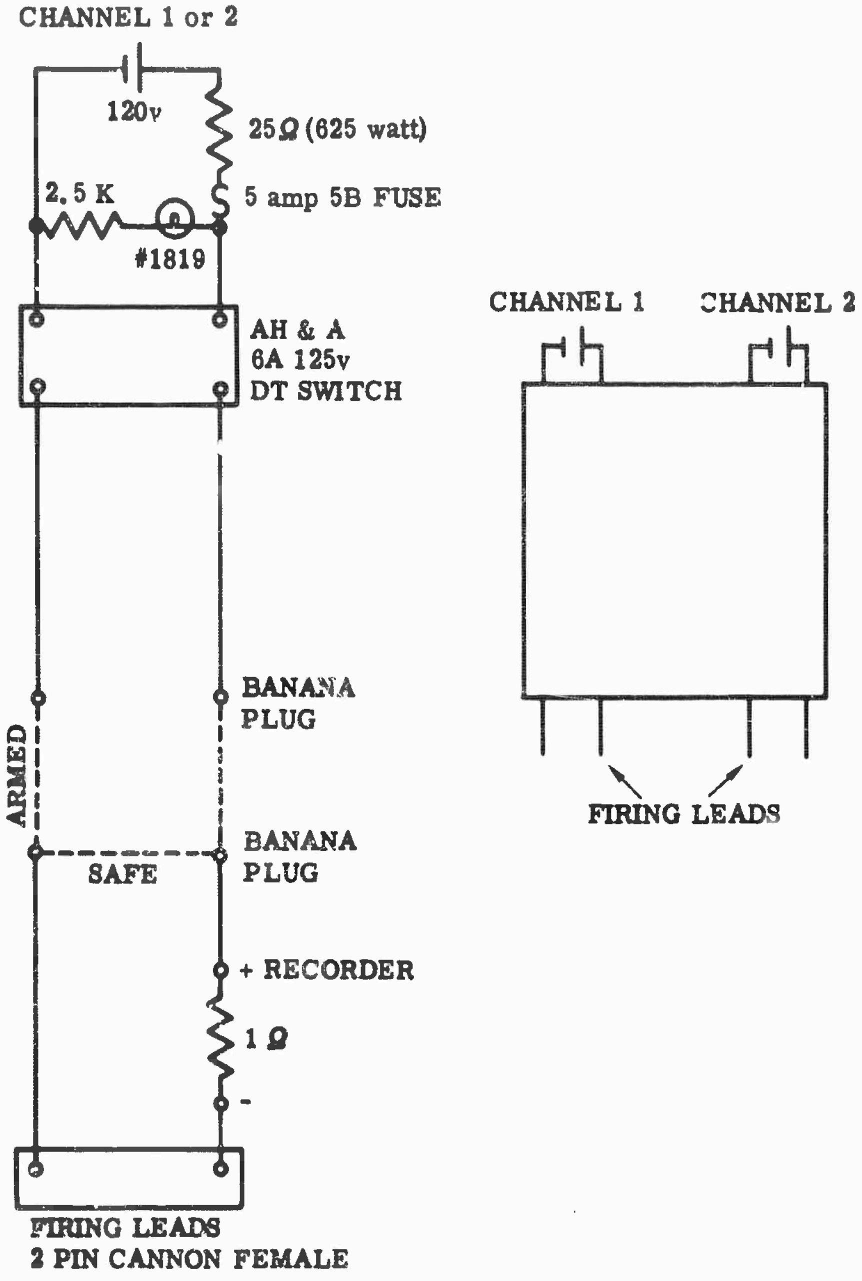

Figure 1 Firing Circuit Diagram

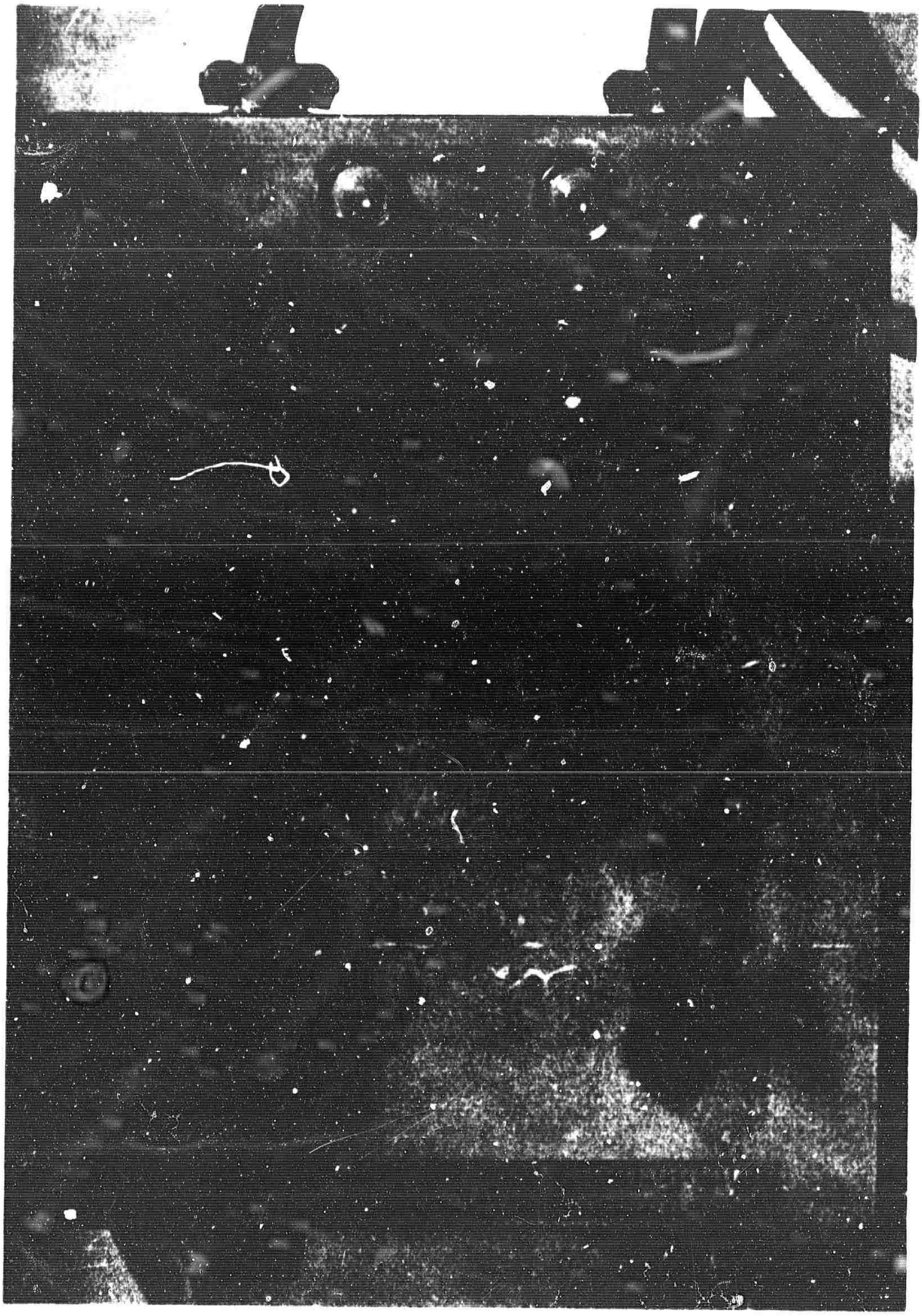

Figure 2 Firing Box

3.4 SOURCE LEVELS

Source levels and spectra, computed from Weston,(4) were

$$P(t) = p_o e^{-t/t_o}$$

$$p_o = 2.16 . 10^4 \left[\frac{W^{1/3}}{R}\right]^{1.13} \text{psi}$$

where W = charge weight in pounds

and R = distance from detonation center in feet

The time constant, t_o is found to be 0.15 ms when calculated for a 5-lb charge, a 10-ft horizontal displacement, and a depth of 2,400 feet.(4) The first bubble-pulse frequency will be 88.6 cps. From Cole,(5) the diameter of the first bubble will be 6.7 feet. In summary, the signal from these charges is very sharp, with rapid decay, a high bubble pulse frequency, and a small bubble. The receiving electronics was designed to be sensitive in the frequency range of the first bubble-pulse frequency.

IV. ACOUSTICAL RECORDING SYSTEM (BUOY)

4.1 MECHANICAL SYSTEM

Figure 3 shows the configuration of the deployed acoustical recording buoy system. The hydrophone is located in the vicinity of the SOFAR axis, and the spherical buoy containing recording instruments and batteries is located about 100 feet below the surface. Buoyancy of the submerged buoy provides tension to keep the system vertical and taut, conditions necessary for minimum horizontal excursion of the hydrophone. The clump anchor connects by means of a 3/8-in., 1 x 19 steel wire rope (IWRC*) to the hydrophone/release assembly, which in turn connects to the submerged buoy via a 3/8-in., 7-conductor, double-helical, armored well-logging cable. The submerged buoy ties to a surface marker through a 1-in. Dacron line containing three electrical conductors, one in each strand. The release mechanism is controlled by a pre-set timer which discharges an explosive nut, dropping the eye-bolt in the lower mooring and freeing the rest of the system to surface under the upward pull of the submerged buoy. The anchor and mooring cable are not recovered. If the timing mechanism fails, or if premature recovery is desired, the explosive nut may be fired from the surface via one of the electrical conductors in the Dacron line. The other two conductors permit monitoring of the hydrophone.

The water depth at the implantment site was about 4,200 feet, and the SOFAR axis was found at about 2,400 feet. These dimensions required 1,800 feet of 1 x 19 mooring cable and 2,300 feet of well-logging cable. The 60-inch-diameter submerged buoy, weighing 386 pounds, produced a net positive buoyancy of about 2,415 pounds when loaded with electronics and batteries. The anchor, consisting of nine discs and a nose cone, weighed about 5,300 pounds in water. Since the submerged buoy supported a suspended weight of 1,210 pounds, a net tension of 1,205 pounds remained in the mooring at the anchor.

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* Independent Wound Rosin Core

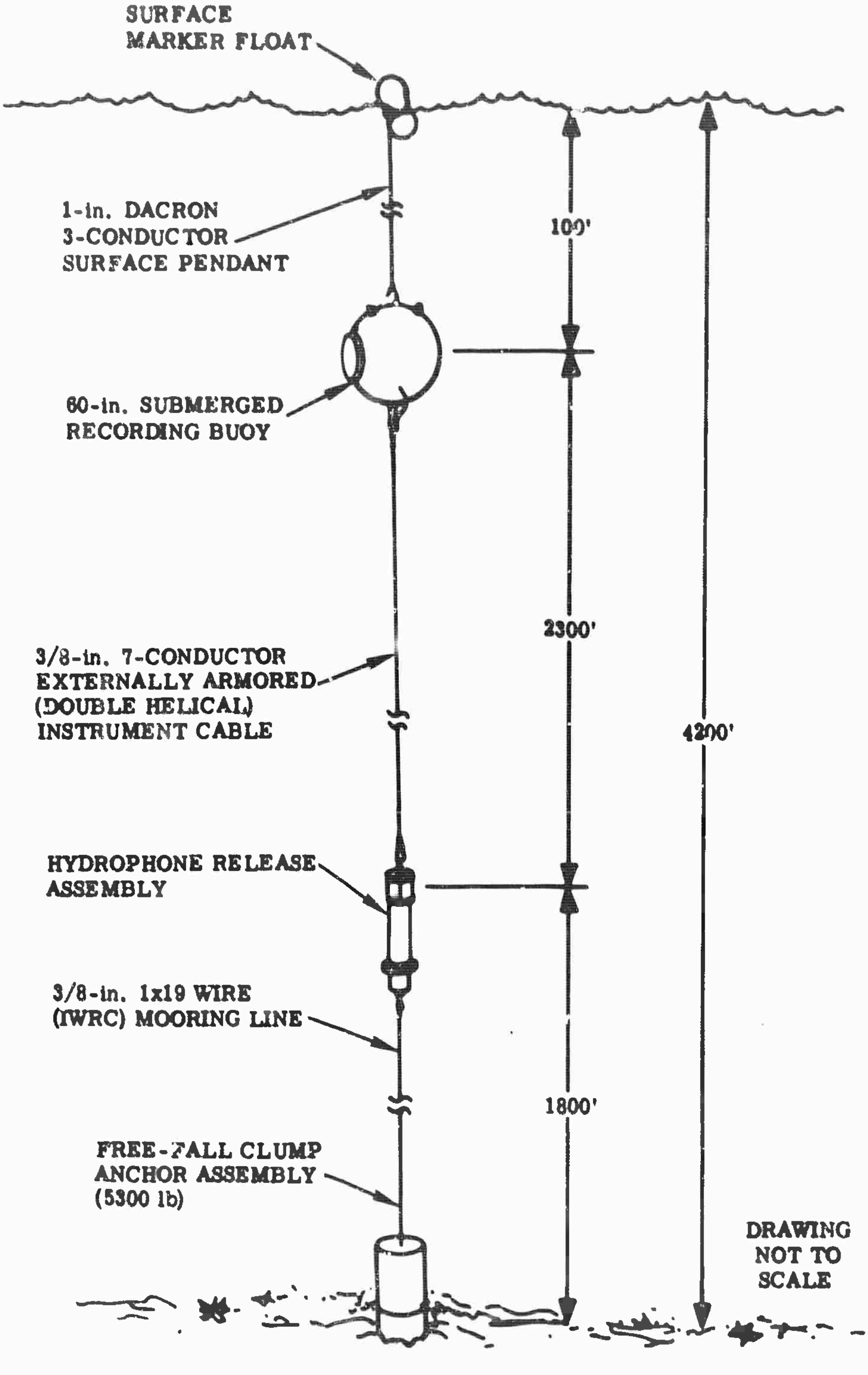


Figure 3 Acoustic Recording Buoy System Deployed

The hydrophone, a $BaTiO_3$ ceramic cylinder resonant at 28 kc with a calculated sensitivity of about -96 dbv per μbar and a capacitance of 0.0182 μf, is shown in Figure 4. The hydrophone/release assembly housing is shown in Figure 5. The spherical buoy, in position to be laid from the afterdeck of SWAN, is shown in Figure 6.

4.2 ELECTRONIC SYSTEM

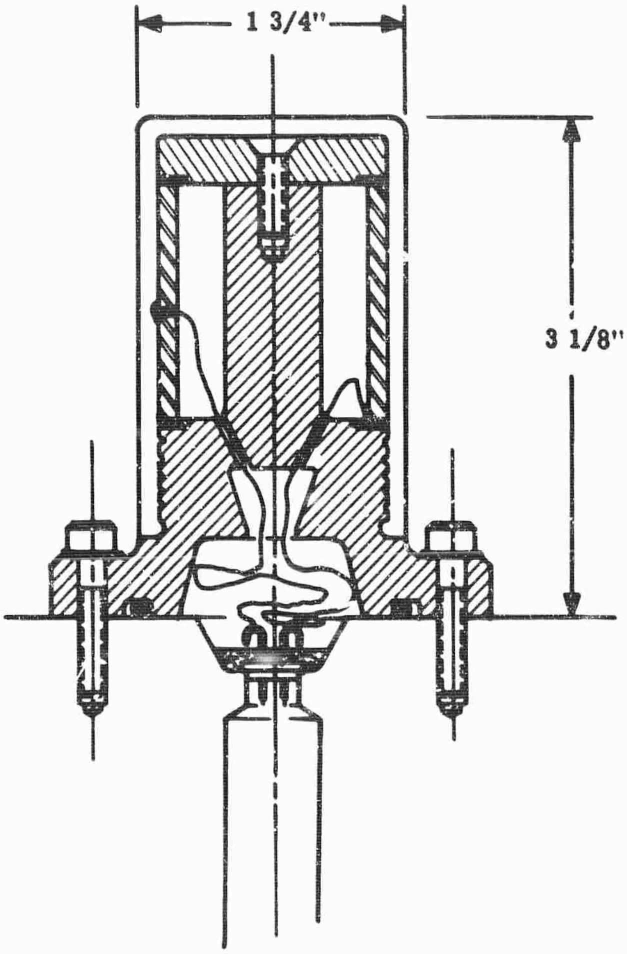
Figure 7 is a block diagram of the electronic system. The hydrophone drives a 40-db preamplifier which in turn drives the cable to the submerged instrument buoy. The frequency band at the output of the preamplifier is designed to lie between 50 cps and 500 cps, the lower cutoff being above the high-level natural T phase noise, and the upper cutoff above expected signal frequencies.

At the submerged buoy the signal from the preamplifier is amplified further, and the detected output drives an optical galvanometer which marks light-sensitive paper carried on the drum of a helical recorder. The recorder advances at the rate of one turn every 15 minutes; at the end of 12 hours, on command from a crystal-controlled timer, the drum re-sets itself and advances its chart paper. Enough paper is carried for 15 days of continuous recording. The crystal-controlled timer also drives a separate optical galvanometer which places minute and hour marks on the record.

Figures 8 and 9 show circuit schematics of the hydrophone preamplifier and the buoy amplifier.

4.3 INSTALLATION AND RECOVERY

Implantment of this single-taut-line buoy system utilizes the free-fall, baled-anchor technique developed at GM DRL. This procedure permits installation in a precise geographic spot, precludes the lengthy handling of heavy, pendulous weights, and may be accomplished smartly in very rough seas.



RESONANT FREQUENCY 28 KC
CALCULATED SENSITIVITY −96 dbv/μb
CAPACITANCE 0.0182 μf
PRESSURE CAPABILITY >2000 psi

Figure 4 Hydrophone Assembly

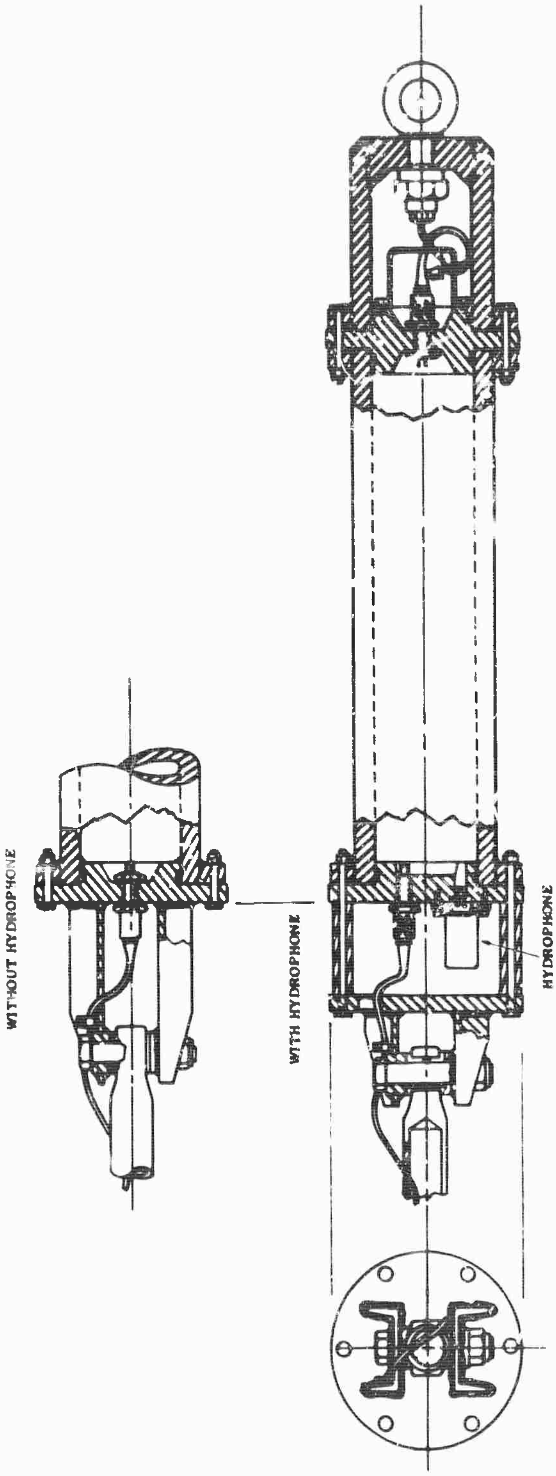


Figure 5 Hydrophone/Release Housing Assembly

Figure 6 Submersible Instrument Buoy Aboard R/V SWAN

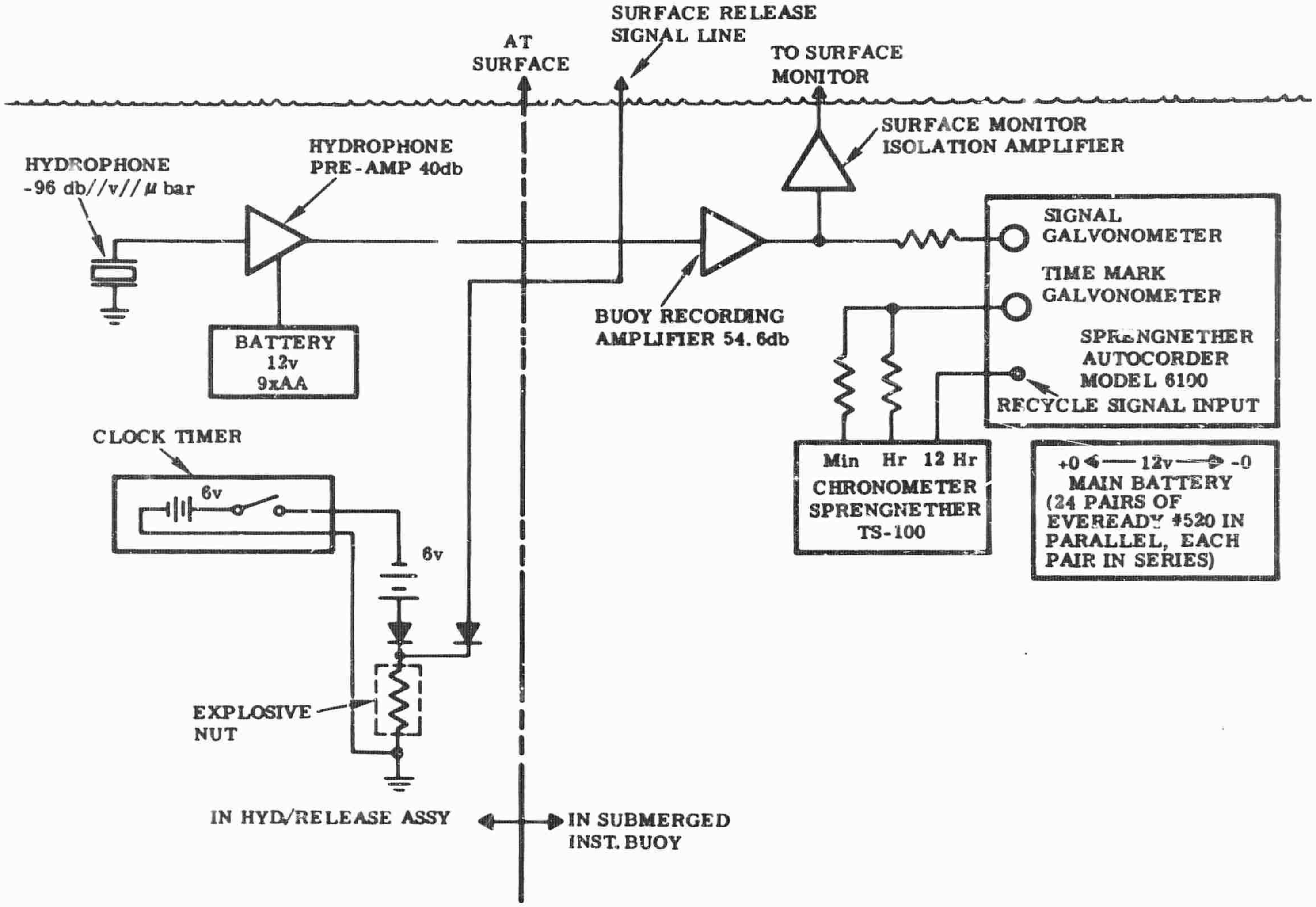


Figure 7 Electronic System Block Diagram

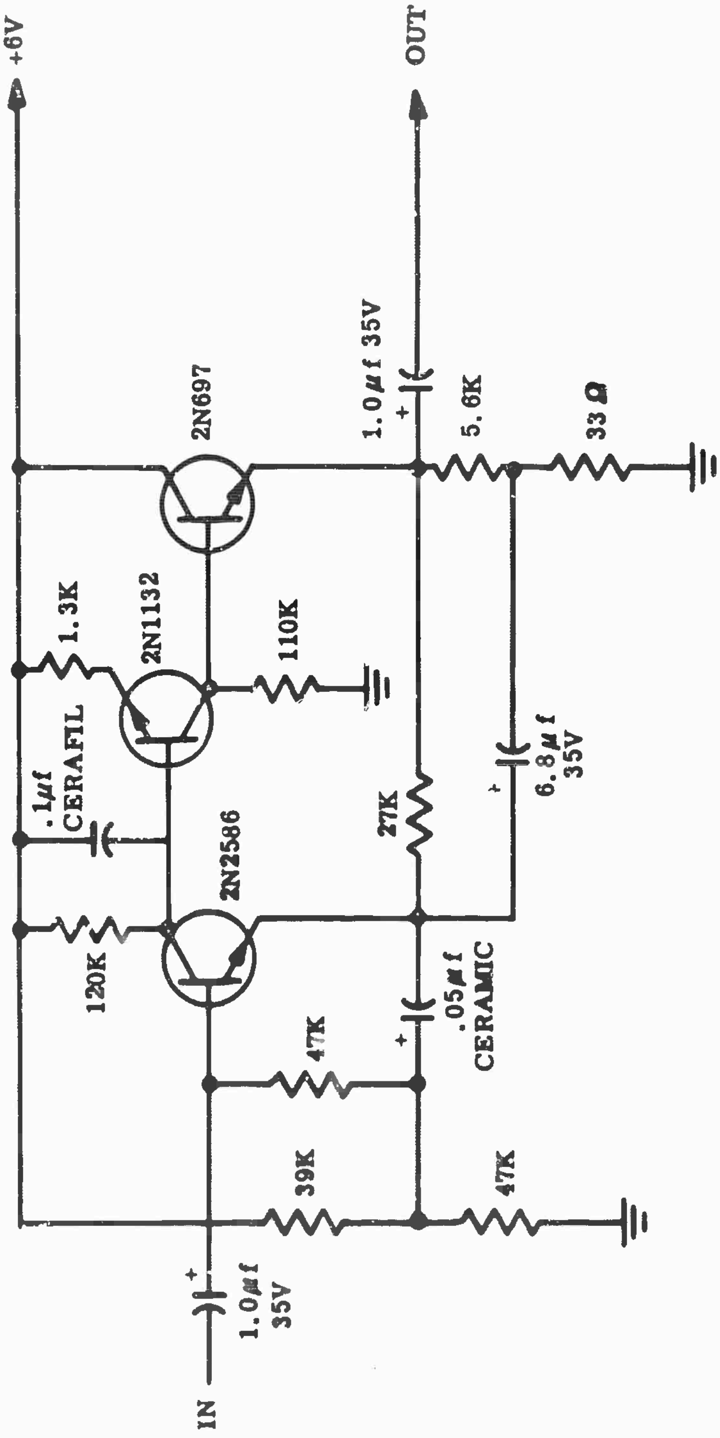
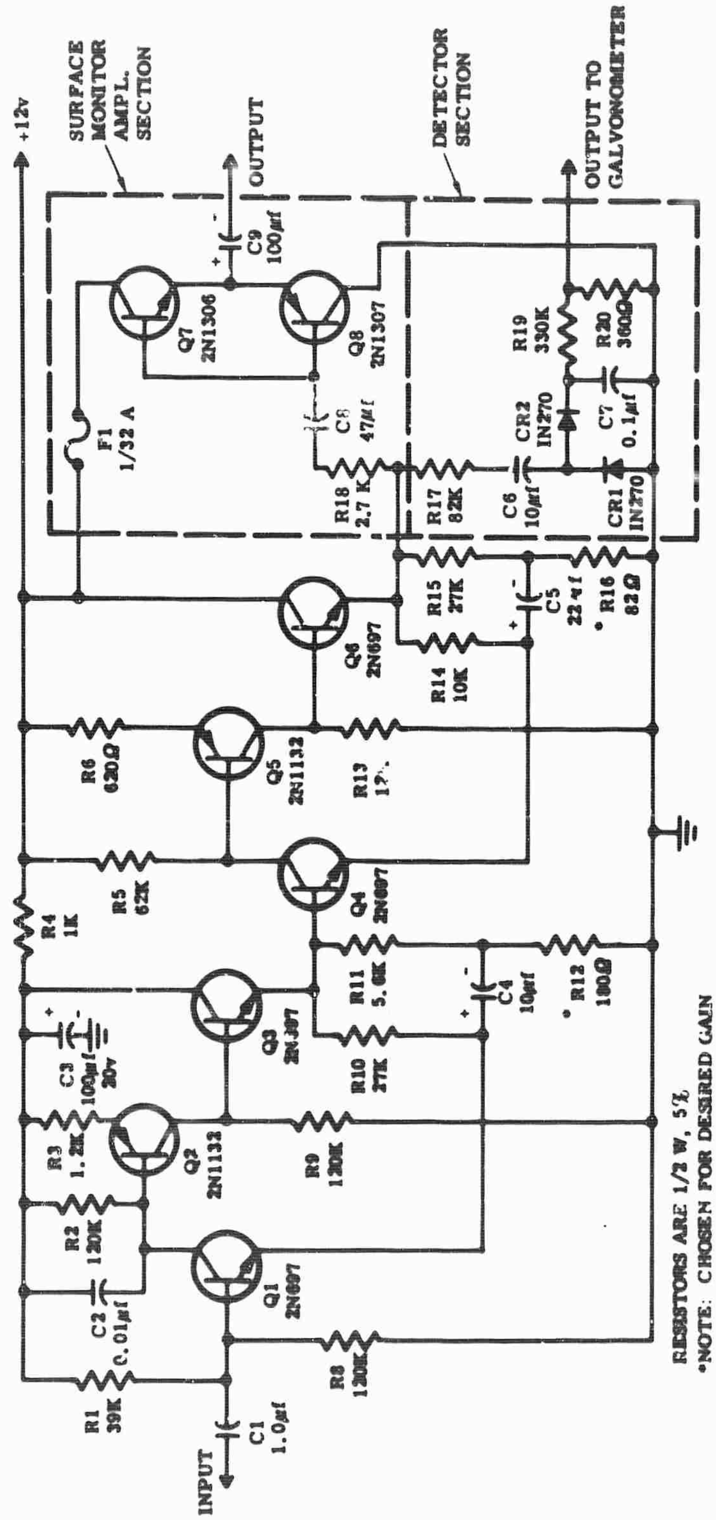


Figure 8 Hydrophone Preamplifier Circuit Schematic



RESISTORS ARE 1/2 W, 5%
*NOTE: CHOSEN FOR DESIRED GAIN

Figure 9 Recording Electronic Circuit Schematic

Figure 10 illustrates the installation sequence. First into the sea goes the safety float which prevents loss of the system in case of trouble during implantment; the float is recovered after a satisfactory installation. Next to be streamed is the Dacron surface pennant which is supported along its length by plastic pneumatic floats. Then the spherical instrument buoy goes over. At this point the buoy is floating; later it will be carried down by the anchor. Then with the ship proceeding at about one knot to keep the buoys separated and tension in the lines, the well-logging cable is streamed until it is payed out. The end of the cable attaches to the upper end of the hydrophone/release assembly, which is lashed to the transom and ready to be released. One end of the 1 x 19 mooring cable attaches to the underside of the hydrophone/release assembly, and the other to the bale on the anchor assembly, which is rigged outboard ready to drop. The mooring line is pre-cut to the known water depth at the installation site. Navigation of the ship at the point of drop must be very precise, especially if the bottom is uneven or steeply sloping. During this installation by the SWAN, the Hydrodist electronic survey instruments aboard ship were used in conjunction with associated instruments at shore stations of known position. When the ship is over the precise geographical point and the sight in the instrument cable is correct, the anchor is dropped. It proceeds straight down, paying out wire as it goes. The hydrophone/release assembly is then cast overboard, thus freeing the entire system from the installing ship. When the mooring wire is out of the bale, the spherical buoy begins to move toward the drop point and then abruptly submerges. Finally, the anchor strikes bottom and the system is configured as shown in Figure 3, except for the safety float which is cast free and recovered. After the hydrophone is monitored for proper output, the surface pennant is taken up and secured to a plastic marker float. The taut-line acoustic monitoring system is now deployed and operating.

The helical recorder and timer are started before the installation, when initial time calibrations are inserted on the record using signals from radio station WWV. After recovery, a terminal time calibration will also be recorded. These time marks permit any long-term drift of the crystal-controlled oscillator to be measured so that timing corrections may be made in the data.

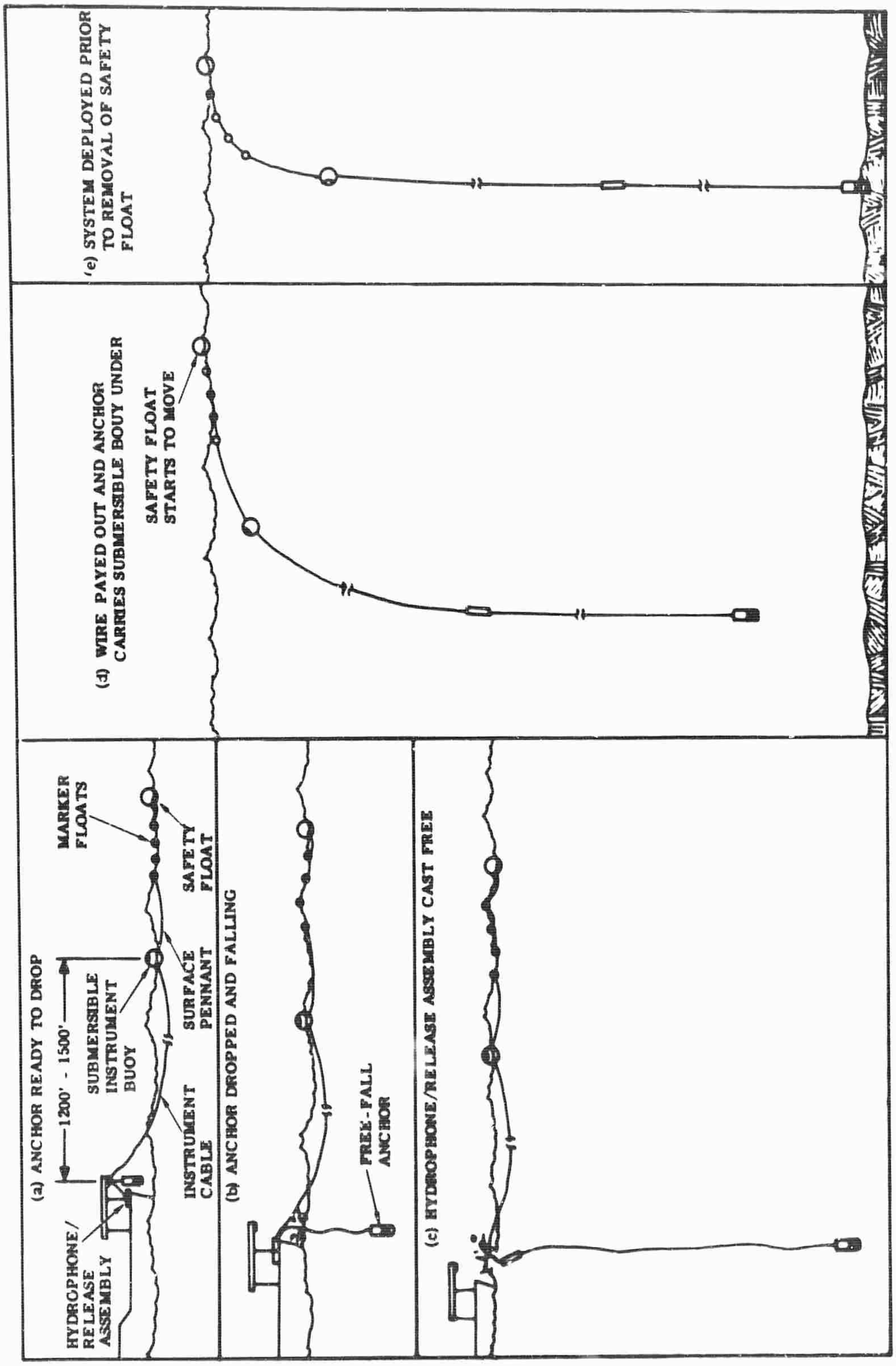


Figure 10 Acoustic Recording Buoy System Installation Sequence

Normal recovery is effected by discharging the explosive nut mentioned in Section 4.1 through the circuitry described in Section 4.2. The actuating signal may come either from a pre-set timer in the hydrophone/release assembly or from a manually thrown switch on the surface. When the explosive nut dischrages, the 1 x 19 mooring cable is released and the system from the hydrophone upward rises under the buoyant pull of the submerged buoy. Since the anchor and mooring are discarded, normal recovery does not involve the handling of large weights.

The two methods of recovery provide redundancy, but during the 1964 SWAN operation both methods failed, forcing recourse to emergency dragging. Recovery was finally effected by fine seamanship abetted by good fortune.

4.4 RECORDS

A reproduction of a portion of the record recovered from the submerged instrument buoy is shown in Figure 11. This record is taken from the period of operation when GM DRL SOFAR shots were being fired hourly, and several of the signals from these shots are shown. This was also a period of low background ambient noise; the signal-to-noise ratio of these shots lies between 30 and 32 db. Duration of these signals ranges between 9 and 10 seconds; their typical sudden termination times the energy which has traveled along the SOFAR axis. Figure 12 shows the signal received from one of the TI Aleutian shots (No. 22). Since the recorder traces the detected output of the amplifier in the buoy within the dynamic range of the electronics, the area under the signal curve is related to the total energy received during the shot. The TI shot signal has a duration of about 19 seconds.

The acoustic monitoring buoy was installed on 27 August 1964 in the following location, about 6 miles south of San Miguel Island off the coast of Southern California:

Lat 33^{O} 46' 15" N
Long 120^{O} 22' 30" W

The buoy was recovered on 9 September 1964.

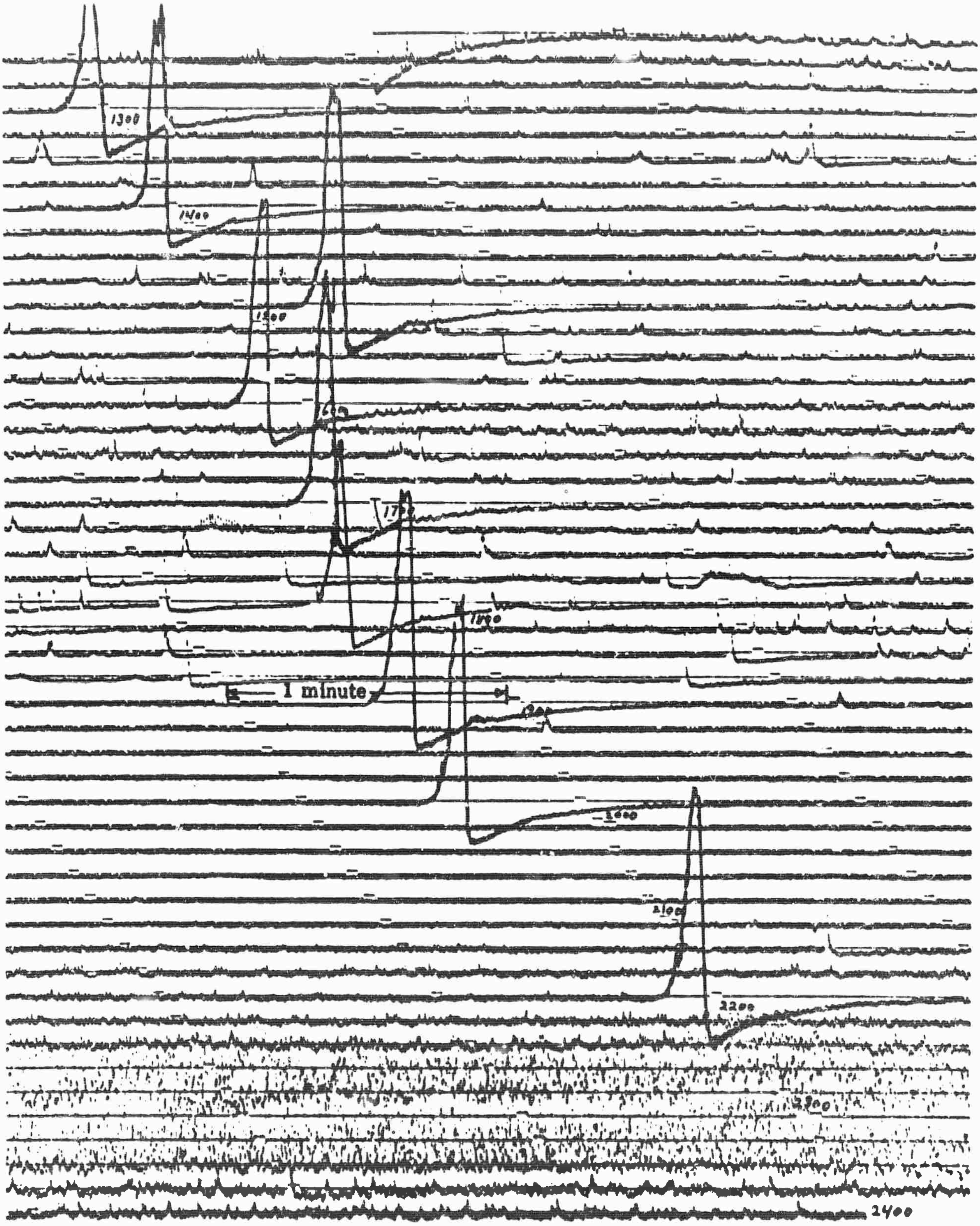


Figure 11 GM DRL SOFAR Signals Received by Acoustic Recording Buoy System

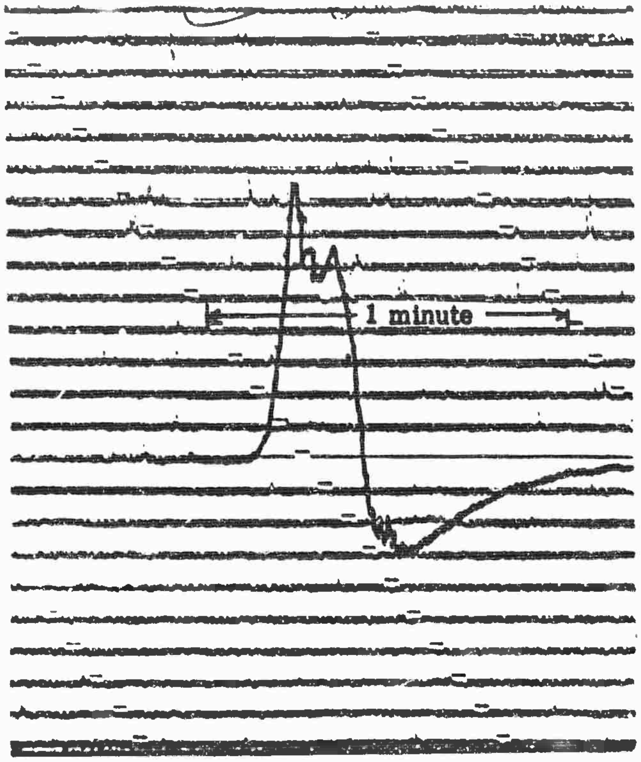


Figure 12 Signal from TI Aleutian 2376-lb Shot as Received by Acoustic Recording Buoy System

V. THE FIELD OPERATION

5.1 PARTICIPATING GROUPS

Two ships and two field parties participated directly in this shot program, and one ship and field party participated indirectly. A navy fleet tug, USS ARIKARA (ATF 98) (Fig. 13) served as firing vessel for the GM DRL Oahu SOFAR shots. Providing tactical support off the California coast, the GM Research Vessel SWAN (Fig. 14), in the course of several operations at sea, tested the charge firing system described in Section 3, and tested, installed, and recovered the acoustic recording buoy described in Section 4. One GM DRL field party coordinated the Hawaiian firing operation, with one section aboard ARIKARA and another operating the shore-based navigation stations. The other GM DRL field party recorded signals received at fixed hydrophone arrays on the West Coast. A third ship and field party, RV SEA SCOPE, a converted navy AM under the control of Texas Instruments, Inc. (TI), although operating in a completely separate and independent program was involved indirectly in the SOFAR calibration experiment. (See Reference 6 for a description of the TI program.) The GM DRL recording field party detected both the small GM Oahu SOFAR shots (5 – 18 lb) and the large TI Aleutian shots (2376 and 248 lb). Personnel of the Tsunami Project, Hawaii Institute of Geophysics, University of Hawaii, also provided data collection services. They tabulated arrival times of the GM DRL Oahu shots at two of the Pacific Missile Impact Location System (MILS) stations and forwarded data together with recorded magnetic tape to GM DRL.

5.2 PREPARATIONS

The success of such an operation requires preparation. Not only was there hardware to be designed, ordered, assembled, and tested, but coordination had to be established among the groups involved and services provided through existing military organizations. The Office of Naval Research provided the basic ship services. Details of schedule and logistics were then worked out directly with

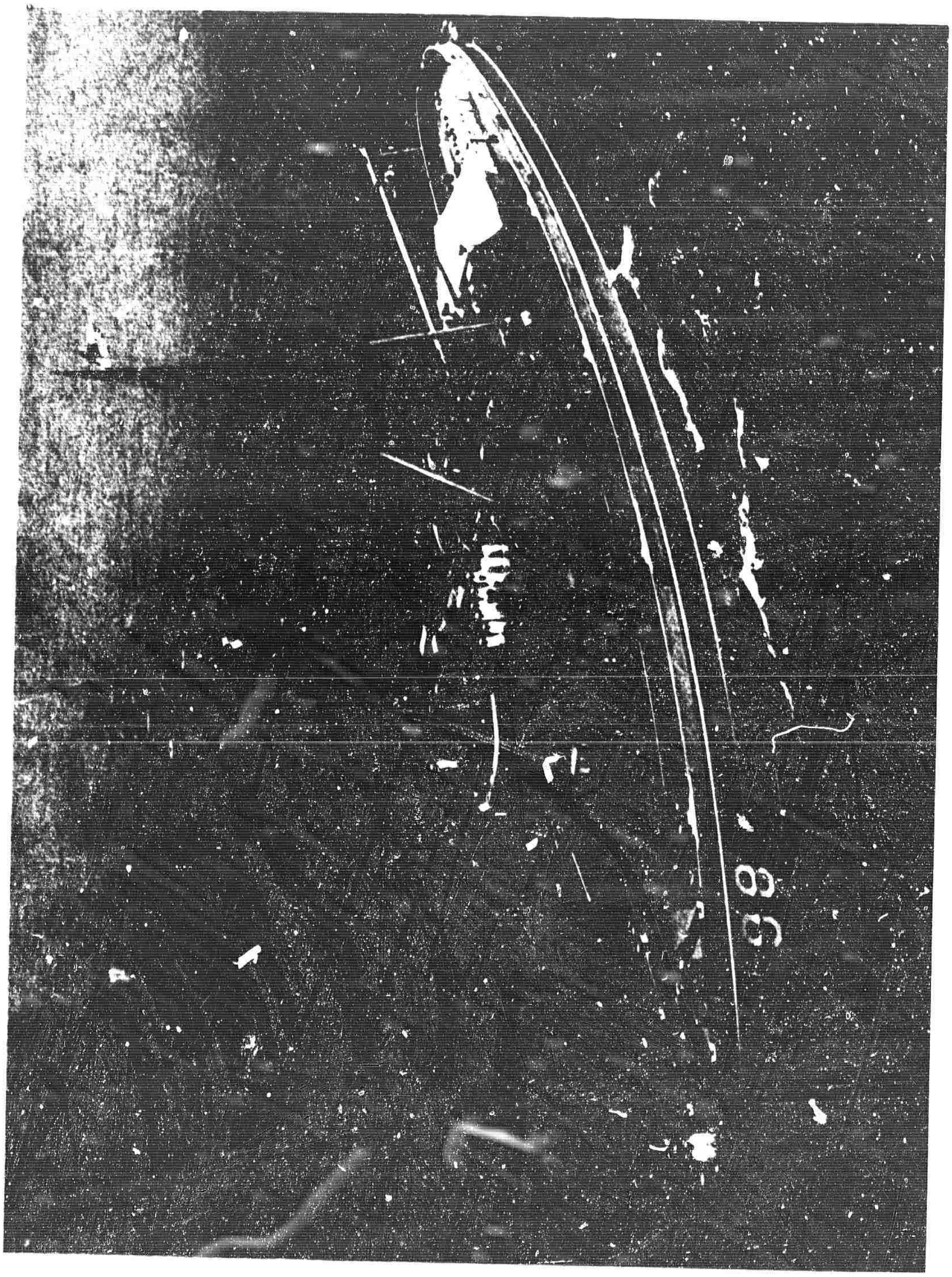


Figure 13 USS ARIKARA (ATF 98)

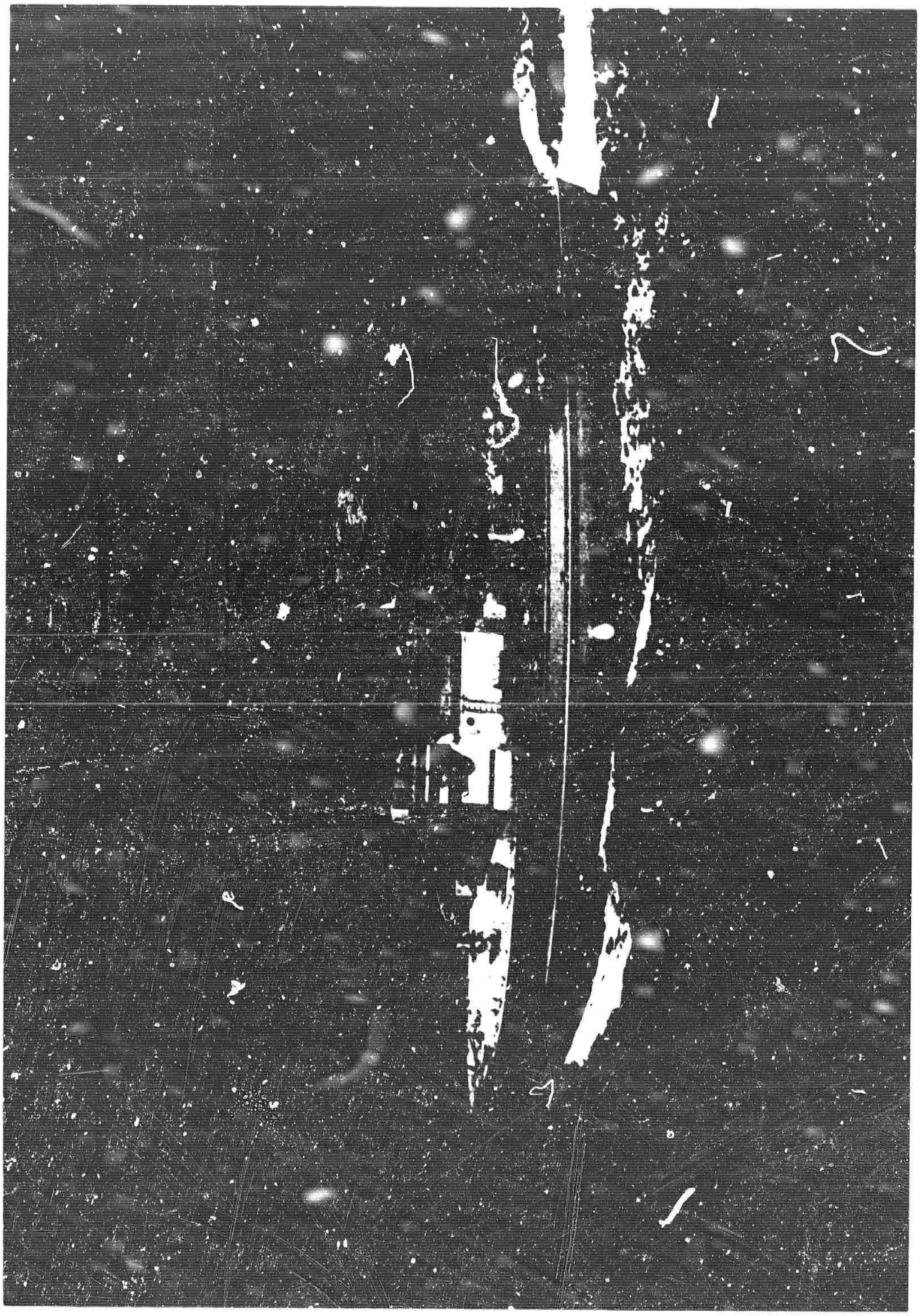


Figure 14 GM DRL Research Vessel SWAN

Commander Service Force, Pacific Fleet, and the Commanding Officer of USS ARIKARA. To establish the shore navigation stations, permission had to be obtained through Headquarters, U ´ Army, Hawaii. The M-3 demolition blocks were provided by the Naval Ammunition Depots, one at Oahu and the other at Seal Beach, Calif., after an official letter request by the Office of Naval Research and telephone contact by GM DRL. Communication arrangements were made and information exchanged with TI and Air Force Cambridge Research Labs (AFCRL), the governmental control agency for the Aleutian shots. Contact was established also with the Navy Electronics Laboratory, San Diego, and their requirements were incorporated into the data recording method.

5.3 SCHEDULE AND PERFORMANCE

The GM Oahu SOFAR shots were to be fired once an hour for five days, which amounts to 120 detonations. Due to difficulties of one kind and another, only half of this number were actually fired. Figure 15 shows the actual firing times of these shots; note that good, around-the-clock coverage was provided with the exception of one hour when a series of misfires thwarted efforts.

The original schedule of the TI Aleutian shots and the actual performance are shown together in Figure 16.

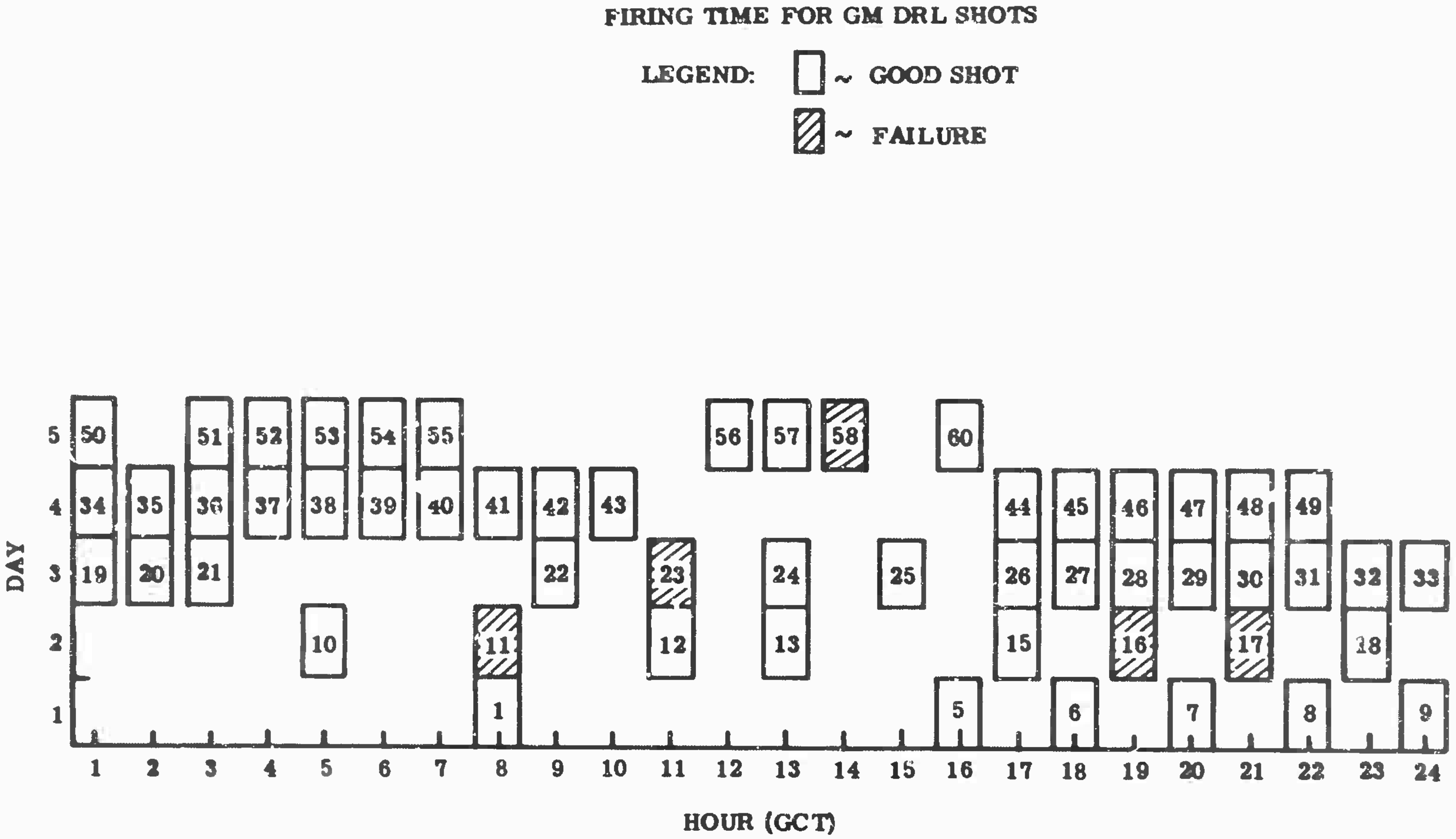


Figure 15 Diurnal Distribution of GM DRL SOFAR Shots

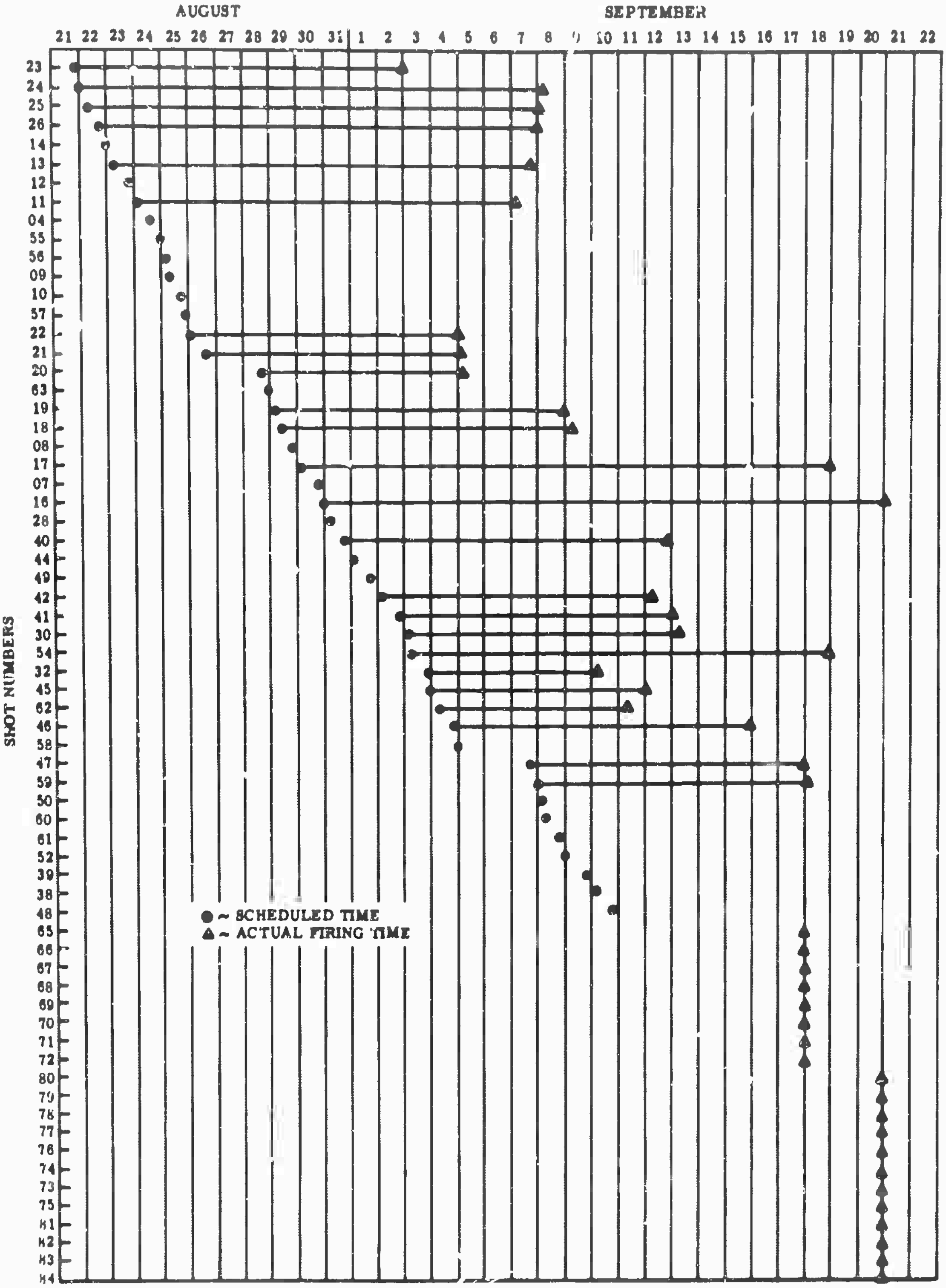


Figure 16 TI Aleutian Shots Scheduled and Actual Firing Times

VI. DATA PROCESSING AND RESULTS

6.1 GENERAL

Appendices I and II contain data summaries of both the source events and recorded signal arrivals. Source data included detonation time and position, charge depth and weight, shot number and qualitative performance. Received-signal data included arrival times at two hydrophones, duration, signal level increase, background level, and amplifier gain. From source and arrival time information at a single receiver, the average propagation velocity was calculated for each shot; from this information at a group of receivers, source locations were computed; and from the information provided by a large number of arrivals, statistics relating to the stability of the SOFAR velocity were derived.

6.2 SOFAR VELOCITY COMPUTATIONS

Computer Program

Reduction of the observed source and received times was accomplished on an IBM 7040 digital computer in two principal stages. The first corresponds to the production of a source log deck. The second used this deck, plus received times, to compute average sound velocity.

Source Log Program

This first program included bringing together several separate logs kept by the charge detonation field party and performing several simple calculations to yield a clear source deck. The principal steps were as follows:

a) Assembling of shot number, date, time, charge weight, and performance from logs

b) Reduction of ship geodetic position from recorded Hydrodist readings to degrees, minutes and nearest second

c) Correction of ship's position to shot position from logs of wire payed out, wire angle, and true bearing. (In an attempt to compensate for wire catenary, the depth and horizontal range of the shot from the ship were calculated using an effective wire vertical angle of one-half the recorded value.)

d) Printing and punching of all these quantities (the resulting source log is presented in Appendix I).

Sound Velocity Program

The second stage step included going from this source log deck and receiver log decks to average sound velocity (listings of the receiver decks are printed in Appendix II). The principal data given for each shot are station and shot numbers, date, arrival times at one to four hydrophones, shot trace amplitude, and system amplitude calibration (a listing of the sound velocity program is given in Appendix III). The principal events are:

a) Input of alpha-numeric constants used by the program

b) Reading and storing of source deck – information is referenced by shot number

c) Conversion of geodetic source positions to geocentric coordinates in radians

d) Reading of geodetic coordinates of centers of two receiving hydrophone arrays (in radians) and conversion to geocentric radians (in this program it was assumed that the first coordinate referred to the received times on channels 1 or 3 on the Sanborn trace, or both, and the second coordinate refers to channels 2 and 4).

e) Reading one receiver card corresponding to a particular shot number

f) Computation of great-circle distance in radians from shot source location to receiver (uses a subroutine entitled GCD). This is converted to a distance in meters using the radius of the earth at the mean of the source and station latitudes (see U.S. Nautical Almanac on International Ellipsoid of reference).

g) Computation of average velocity from this range and the difference between source and received times

h) Taking of time differences in seconds between the times from channels 1 and 2 or 3 and 4. This relates to the shot's apparent bearing.

i) Computation of approximate peak sound pressure level, according to the formula

$$SPL = R + B + A - G_0 - A_0 + M$$

where
R is the rise (in db) of the Sanborn trace
B is the background level or reference in db// 1 volt
A is the current system attenuator setting
G_0 is the system gain at some previous time
A_0 was the attenuator setting when G_0 was measured
M is the hydrophone sensitivity in db// 1 volt/μbar

All the above quantities are read in for each shot, except M, which was assumed to be -80 db// 1 volt/microbar at 100 cps. The sound levels thus computed should not be relied on for absolute values or for relations between stations due to our ignorance of absolute calibration. They are internally consistent, however.

j) Outputting of all calculated data in printed form and punched-card form for statistical analysis

k) Repetition of above steps e – j for each shot at a station

l) Repetition of steps d – [illegible] for each receiving station

The procedure above was repeated for each of the stations, but not for the buoy data. Since only one hydrophone channel was available and the recording medium different, the input format and calculations had slightly different forms from the above.

A listing of the computed sound velocities, time differences, and sound pressure levels is given in Appendix IV for the GM shots received at various stations and for some TI shots received at fixed installations.

6.3 SOFAR VELOCITY SUMMARY

Average sound velocity results, computed for the indicated termini points, are discussed below.

Source	Receiver
GM DRL Oahu	Recording Buoy Station
	Midway MILS Station
	Eniwetok MILS Station
TI Aleutian	Recording Buoy Station

These time series data are plotted in Figures 17 through 20. Mean sound velocities for each pair of termini, together with standard deviations, are listed in Table I which also shows the calculated average sound velocity based on Johnson.(7)

Average expected sound velocity over a total distance D, where the theoretical propagation velocity is known in N piecewise increments and assumed to be constant over the distance interval D_j, is given by

$$<c> = \frac{D}{\sum_{j=1}^{N} \frac{D_j}{C_j}} \qquad (1)$$

where

$$D = \sum_{j=1}^{N} D_j \qquad (2)$$

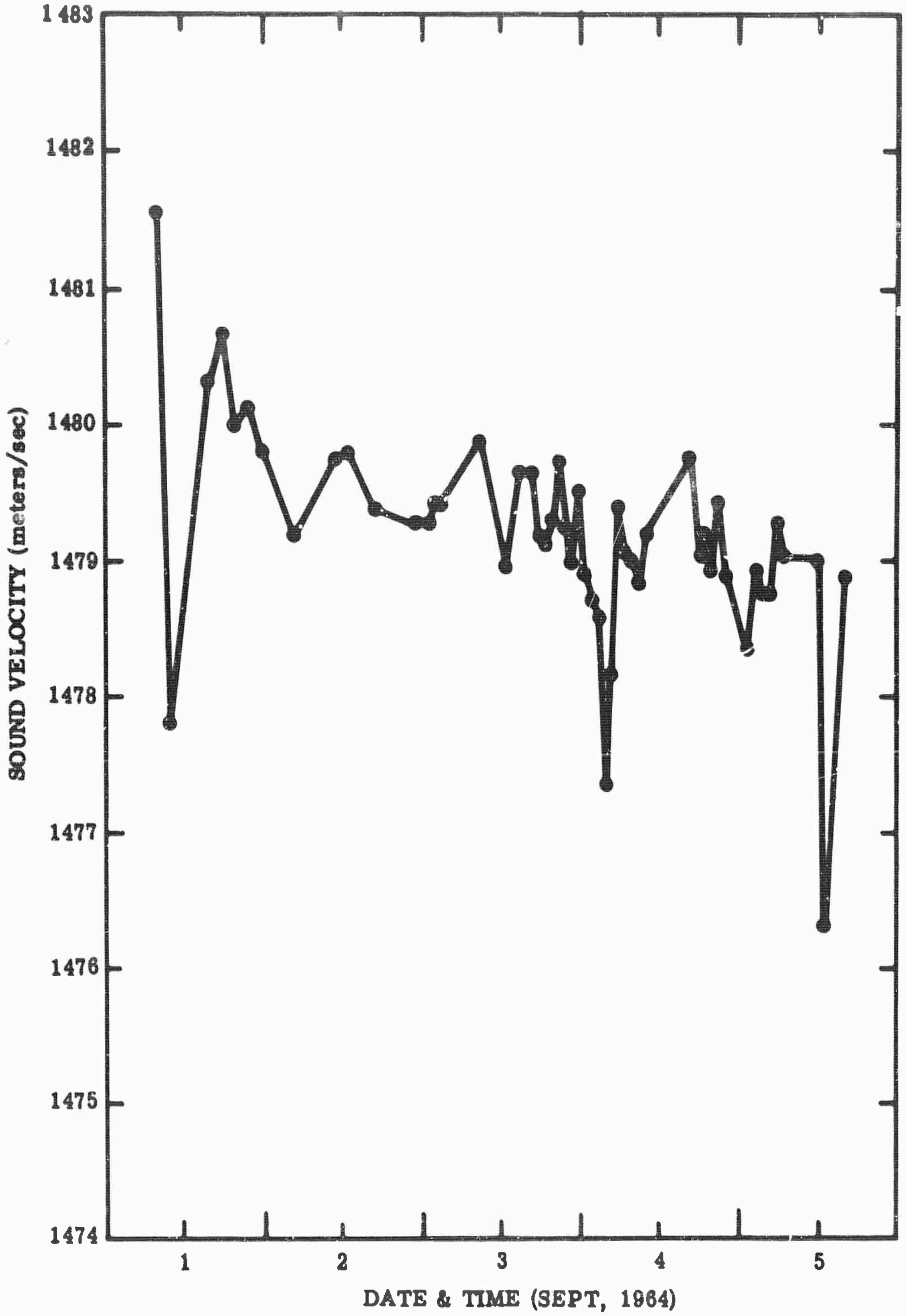


Figure 17 Average Sound Velocity GM DRL Oahu SOFAR Shots Received by Acoustic Recording Buoy Station

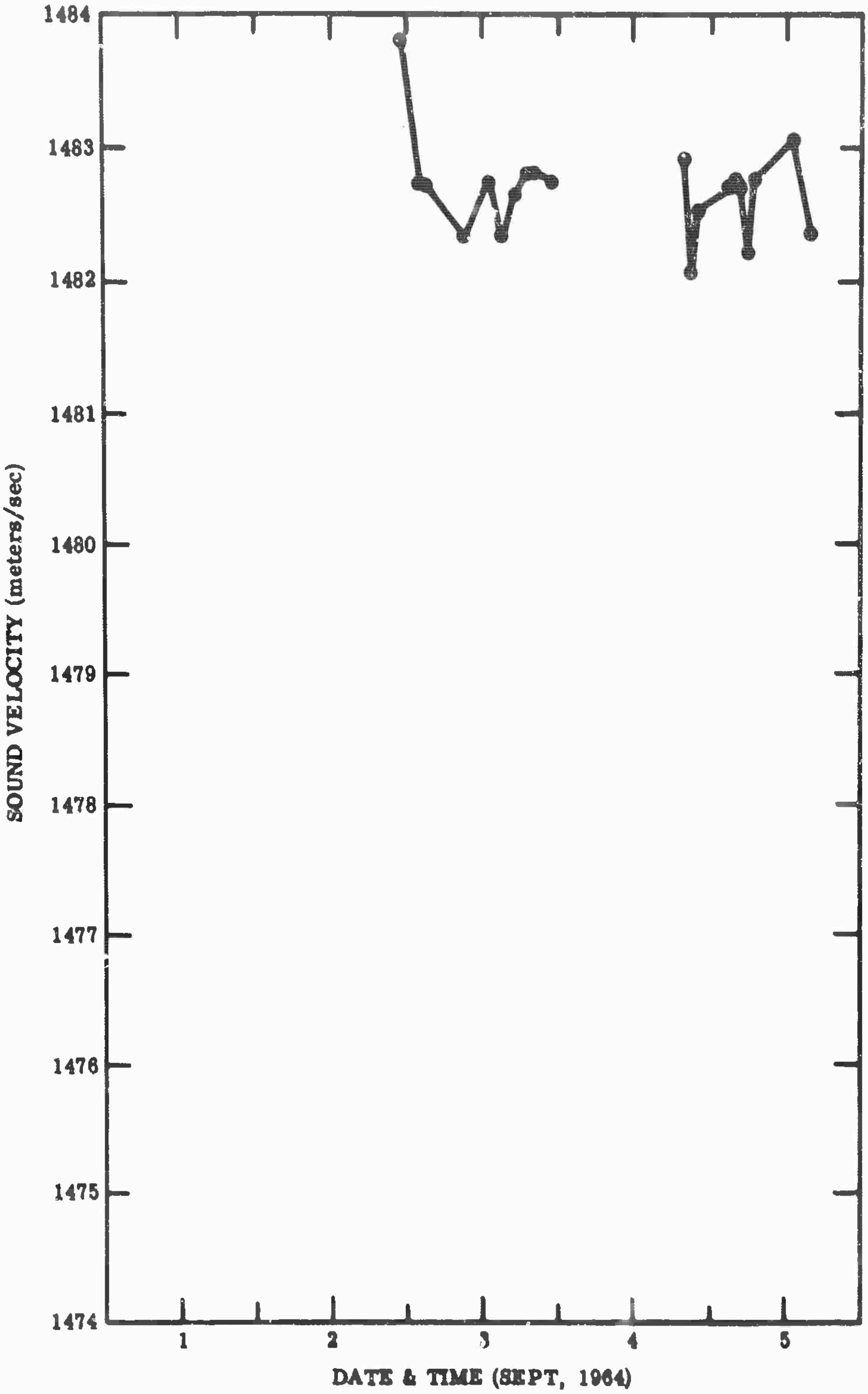


Figure 18 Average Sound Velocity of GM DRL Oahu SOFAR Shots Received by Midway MILS Station

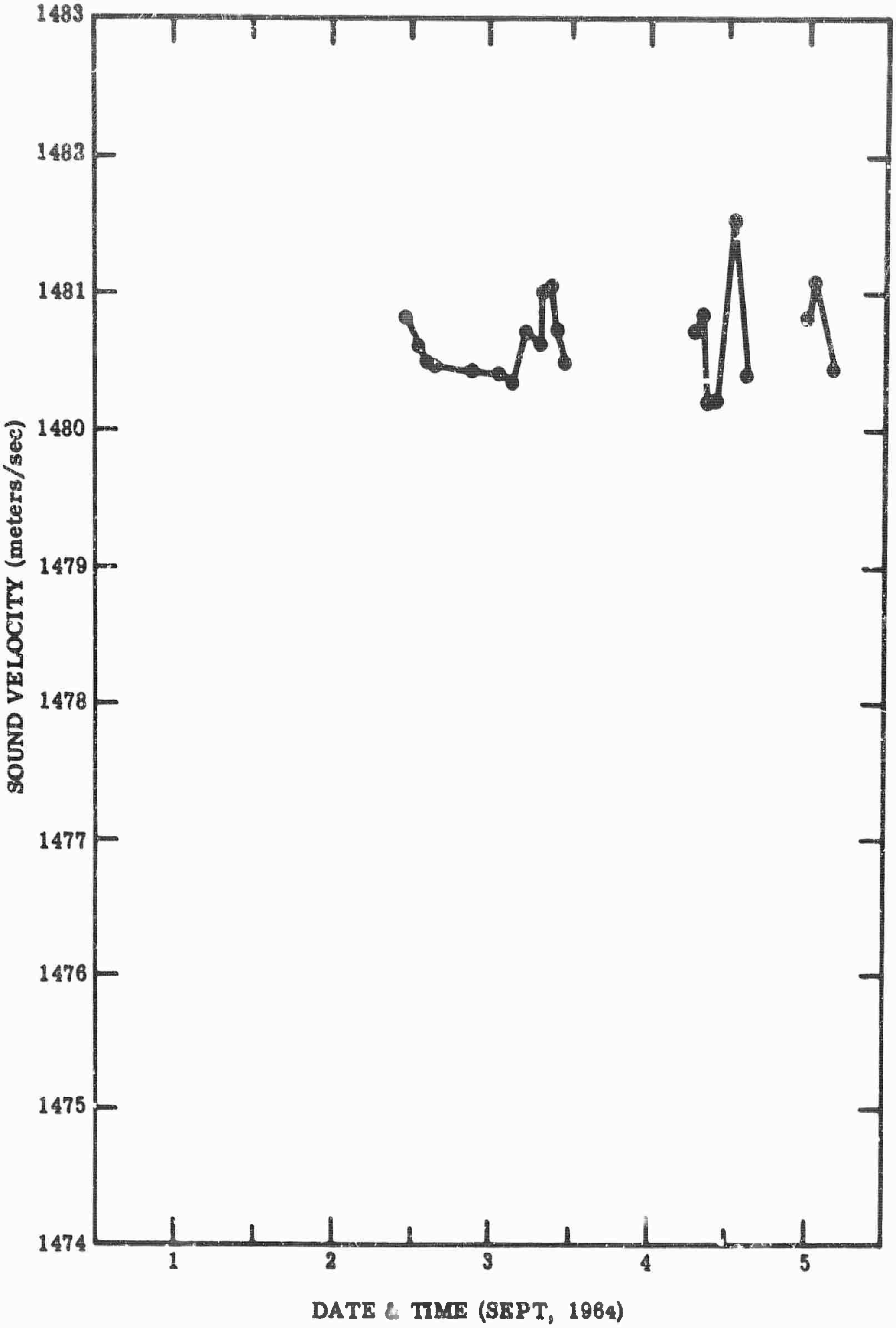


Figure 19 Average Sound Velocity GM DRL Oahu SOFAR Shots Received by Eniwetok MILS Station

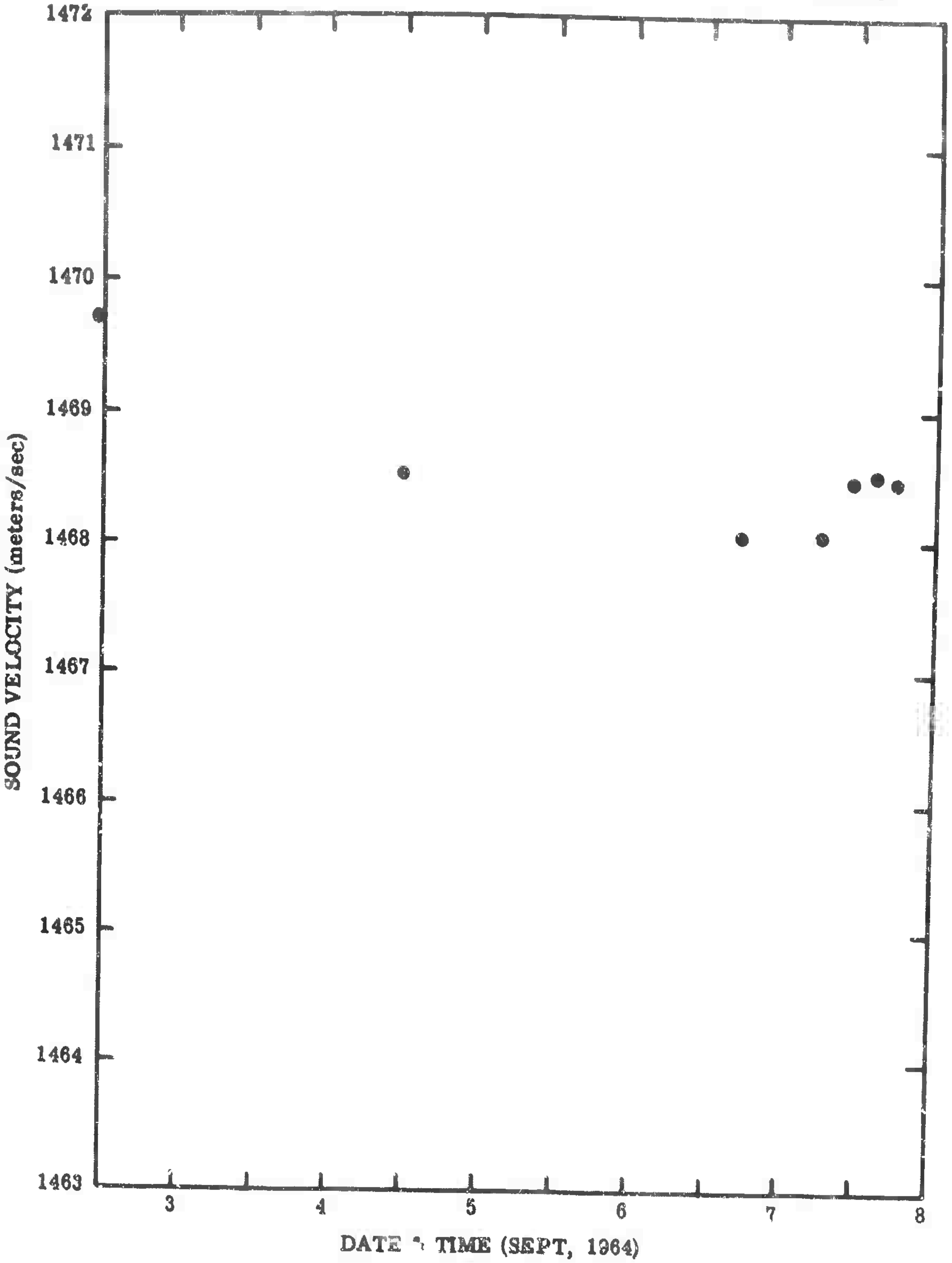


Figure 20 Average Sound Velocity TI Aleutian 2376-lb Shots Received by Acoustic Recording Buoy Station

If the total distance D is divided into N increments of equal length, D_j, in which the SOFAR velocity is approximated by C_i, Equation (1) reduces to

$$\langle c \rangle = \left[N \sum_{i=1}^{N} \frac{1}{C_i} \right]^{-1} \qquad (3)$$

The measured velocity from Oahu to the buoy and other west coast receivers is slightly less than the computed; the decrement is about 1 meter per second. Possible reasons for this effect are many. In the first place, Johnson's chart,(7) which served as the basis of the computation, was in rather small scale for these purposes; hence, the uncertainty of the computed velocity may be 1/2 meter per second, or so. Another hypothesis assumes that the sound actually traveled farther than the strict geodesic calculation would indicate. Variations in path could be in the horizontal plane, due to horizontal velocity gradients or scattering, or in the vertical plane, due to changes in depth of the SOFAR axis. Such an effect might occur if significant internal wave activity were present. To check the horizontal deviation hypothesis, statistical correlations were run at each West Coast installation between the sound velocity and azimuth of arrival. Results were negative, i.e., there was no significant correlation between deviations from the great circle, as received, and the average sound velocity. The effect of vertical variation in SOFAR axis depth seems to be in the right order of magnitude and could account for reductions in apparent sound velocity of the magnitudes observed. The table below indicates the relationship between wavelength and amplitude to produce a velocity decrement of one meter per second and ten meters per second, assuming a sinusoidal path.

Table I

PATH AMPLITUDE AND WAVELENGTH PRODUCING A GIVEN VELOCITY DECREMENT

	Velocity Decrement 1 m/sec	Velocity Decrement 10 m/sec
Amplitude (meters)	Wavelength (meters)	Wavelength (meters)
10	1200	380
25	3000	950
50	6000	1900

Based on the indicated results at the buoy station and others, the net standard deviation at a range of about 2115 nautical miles (3923 km) is about 0.05 km per second. This uncertainty in velocity produces a position uncertainty in the source of about 2.25 kilometers. This statement of uncertainty is one of the main objectives of the experiment. The remainder of the receivers, particularly the MILS station, showed a smaller spread in the data, which would indicate a smaller position uncertainty.

6.4 SOURCE LOCATION

General

During the course of the Aleutian experiment several 248-lb bombs were dropped by Navy P2V patrol planes.

Accurate source locations were required for the TI seismic experiment; accordingly ARPA requested GM DRL(8) to locate the source of these shots acoustically as a check and as a supplement to the navigational information provided by the aircraft. A similar request was sent to the Hawaii Institute of Geophysics, University of Hawaii. The receiving stations in the GM DRL source location computational net were spaced along the west coast of the United States and throughout the North Central Pacific. Approximately six to eight station times were involved in each location computation. Stations used by the University of Hawaii included those in the North Central Pacific but only one on the west coast of the United States mainland.

Source Location Program

Given the arrival time of signals from an acoustic event at three or more known locations on the earth's surface, source time and location are to be determined. Because signal waveforms become distorted during propagation it is difficult to measure arrival times precisely, and errors will appear in the measured data. Furthermore, the average propagation velocity between source and receiver may not be known exactly. Thus, for more than three receiving stations it is quite likely that there is no source location on the earth's surface from which the computed and observed arrivals at all stations match precisely. This situation, as is usual when attempting to match an analytic expression to the real world, required curve fitting with a least squares criterion. The source location and time are chosen to minimize the rms deviation of the set measured arrival times from those predicted from the solution.

Because of the non-linearity of the spherical geometry no exact analytical solution is possible for the minimization problem. Good results may be obtained, however, by linearizing the equations through a perturbation approach, i. e., solving for small corrections to approximate solutions. With sufficient iteration any degree of precision may be attained in finding the optimum point consistent with the data. Note that bad input data may cause this point to be an inaccurate solution. The only claim is that the position is the best that the data supports.

In the following analysis a good first guess for source time and location will be assumed. The actual limitations on this first approximation for convergence will be discussed later.

Basic Equations

The j^{th} station residual is defined as the difference between the observed arrival time T_{0j}, and the computed arrival time T_{cj}.

$$s_j = T_{0j} - T_{cj}(L, \lambda, T_0) \tag{4}$$

where

L = longitude
λ = latitude

The computed arrival time is a function of the source location and time. For a set of n stations the ensemble residual is defined as the rms of the individual station residuals.

$$S = \left[\frac{1}{n} \sum_{j=1}^{n} s_j^{\,2} \right]^{1/2} \tag{5}$$

The source location problem is to find the geographical point and origin time that will minimize the ensemble residual. This is effected through maximizing the negative change in S from the trial point, assuming a planar geometry. The change in S may be expressed:

$$\Delta S = \frac{-1}{nS} \sum_{j=1}^{n} s_j \left(\frac{\partial T_{cj}}{\partial L} \Delta L + \frac{T_{cj}}{\delta \lambda} \Delta\lambda + \frac{\partial T_{cj}}{\partial T_0} \Delta T_0 \right) \qquad (6)$$

Maximizing the series in parentheses will find an approximate solution to the optimum ΔS.

In Figure 21 the initial trial point is (L', λ', T_0') and the new point is (L, λ, T_0). Plane geometry and long distances to receiving stations are assumed. With this assumption, we set

$$\begin{aligned} \Delta Y &= \Delta L \\ \Delta X &= \text{Cos } L \, \Delta\lambda \end{aligned} \qquad (7)$$

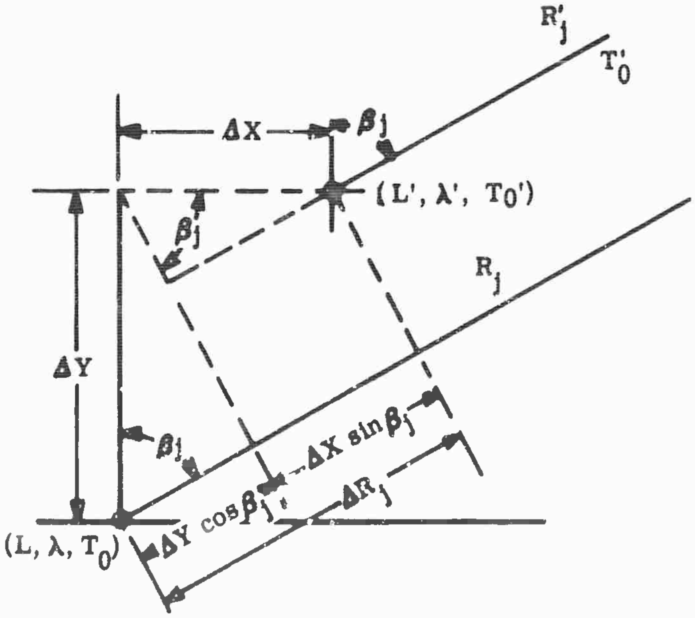


Figure 21 Trial Location Geometry

It can be shown:

$$\frac{\partial T_{cj}}{\partial L} \Delta L = \frac{\Delta Y \text{ Cos } \beta_j}{C} \qquad (8)$$

$$\frac{\partial T_{cj}}{\partial \lambda} \Delta \lambda = \frac{\Delta X \text{ Sin } \beta_j}{C} \qquad (9)$$

$$\frac{\partial T_{cj}}{\partial T_0} \Delta T_0 = \Delta T_0 \qquad (10)$$

The job is thus to find the ΔX, ΔY, and ΔT_0 which will minimize $\sum_j \left[s_j - \Delta s_j\right]^2$ with the set of equations

$$\begin{array}{l} \Delta X \text{ Sin } \beta_1 + \Delta Y \text{ Cos } \beta_1 + C \Delta T_0 = C \Delta s_1 \\ \quad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \\ \Delta X \text{ Sin } \beta_j + \Delta Y \text{ Cos } \beta_j + C \Delta T_0 = C \Delta s_j \\ \quad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \\ \Delta X \text{ Sin } \beta_n + \Delta Y \text{ Cos } \beta_n + C \Delta T_0 = C \Delta s_n \end{array} \qquad (11)$$

If there are but three receivers, there are three equations in the set (11), and an exact solution to $s_j = 0$ is possible, within certain geometric constraints. For four or more receivers a least squares criterion is required. After several iterations ΔX, ΔY, and ΔT_0 approach zero as S approaches its minimum. A solution is considered reached when ΔX and ΔY are both less than 10 meters.

Program Mechanics

Appendix III contains a listing of the GM DRL source location program specially configured to solve for the TI 248-lb shot locations using data largely supplied by and in the format of the University of Hawaii epicenter location program. The principal steps in the program are as follows:

a) Alpha-numeric constants are read in.

b) Hydrophone station location data (in geodetic radians) and sound velocities in m/sec appropriate to each station are read in and filed by number. Latitudes are converted to geocentric radians. (Average sound velocities to the

West Coast stations were measured from the TI 2376-lb shots. MILS station velocities were supplied by the University of Hawaii.)

c) A common starting point for all iteration is read in and converted to radians.

d) A reading of the time of day is taken from the real-time computer clock.

e) Arrival times of one shot at each station that received it are read in, and the corresponding station locations are taken from general storage and placed in working arrays. Arrival times are converted to seconds.

f) The variables L and λ are given the initial values in radians read in at c) above. The variable T_0 is given a starting value 1689 seconds, earlier than the first arrival time read in.

g) The great-circle ranges from the trial point to each station are computed using a subroutine GCD. The subroutine also returns the values of the sine and cosine of the true bearing of each station from the trial point.

h) A sound velocity in radians/sec is computed from the station sound velocity and the average radius of the earth over the path.

i) The station residuals are formed, Equation (4).

j) A subroutine LSTSQ3 is called. This solves the system of Equations (11) using the coefficients computed in g) and h) for the values of ΔX, ΔY, and ΔT to minimize the sum of the squares of the residuals. The subroutine also returns the resulting value of the rms residual, Equation (5).

k) The coordinates L, λ, and T_0 are corrected with ΔX, Cos L, ΔY, and ΔT; λ and L are reduced modulo 2π and to a reasonable latitude respectively.

l) If the corrections ΔX and ΔY are greater than 10 meters the program repeats steps g) – k) until they are both 10 meters or less.

m) When the solution is finished, the locations are reduced to geodetic degrees, minutes, and seconds, and the time to hours, minutes, and seconds. Residuals are converted to meters. A heading, the final values of all residuals, and the source coordinates are printed out. The source coordinates are also punched out on cards.

n) A second clock reading is taken and the total elapsed time is computed and printed out.

o) Steps d) – n) are repeated for all shots.

In the production runs for the TI 248-lb shots, the above calculations were run for 6 – 13 hydrophones at 4 – 5 stations to a solution precision of 10 meters in 7 – 12 iterations. The average time was about 2.5 seconds for a complete solution, including all input-output operations. The results are listed in Appendix VI, together with the results of similar runs from the University of Hawaii (using MILS data only) and the radar fixes on the plane at the times of drop.

Convergence Behavior

The linear set (11) will always have a solution; however, this solution is not necessarily the solution to the geographical problem. Because the earth is spherical and finite, the assumptions leading to (11) are never exactly true. Thus when the ΔX, ΔY, ΔT are added to the trial parameters, the result is still in geographical error (although usually an order of magnitude better), and the problem must be re-solved to get an even better answer. In the working version the iteration is cut off when ΔX and ΔY are both less than 10 meters. The number of iterations necessary to achieve this precision varies according to the accuracy of the first guess. For a first guess within 5 – 10 degrees of the true location, 5 – 7 iterations are adequate to reach the 10-meters precision.

Allowing a first guess of nearly unlimited sloppiness, this technique appears to have a very wide convergence range. The three probable reasons are as follows:

1) The test of a successful iteration is whether it moves the trial point closer or farther away from the actual point. Thus, considerable error (in fact, $\pm 90^{\circ}$) is still tolerable in the direction of movement from the true one.

2) The earth's surface is finite and closed. Thus, while some really wild $\Delta \lambda$ and ΔL can arise (e.g., $+300^{\circ}$, -653°), the trial point is reduced modulo 360° and stays on the surface.

3) The third variable, time, is truly linear. Thus, a really bad first guess is more readily corrected.

The following is an example of the latitude allowable. Received times appropriate to a source time of about 1800 hours and a source location in Hawaii were given to the program. The initial guess was zero hours, zero. Very occasionally, with a really bad first guess, the solution will converge to a local rather than a global minimum. The station residual as a function of position on the earth's surface is very complicated and can have one or more local minima. As an example, the arrival times of TI shot 74 at the MILS and West Coast stations were taken, and for a lattice of points on the earth's surface the best possible source time was calculated and an rms station residual calculated. Iso-residual contours were then interpolated and plotted in (Fig. 22) for a 100-deg square in the Pacific Ocean.

As may be seen, besides the absolute minimum of the real solution, there is one other local minimum near 9°N, 158°W. Viewed in this manner, the program solution becomes one of rolling to the lowest point on the map. The weak minimum did capture several test solutions. There is little danger of mistaking this solution for the true one, however, since the residual has a value of 750 km at this point. In a production version of the program some algorithm should be used to leap out of such false minima. One successful algorithm was to drop one hydrophone from the solution and resolve. This yielded the correct answer in every case tried but was expensive in terms of computer time. Perhaps merely solving the problem over from a different starting point would be best.

The contours in Figure 22 are a very special case corresponding to one particular receiver configuration and one particular actual source location. The contours could change greatly by changing the numbers or locations of hydrophones or by changing the general source location. A study consisting of systematic variations of these parameters might prove valuable for optimizing patterns of receiving stations.

Results of Computations

Source locations for the 248-lb Aleutian shots by three agents and two methods (GM DRL acoustical, University of Hawaii acoustical, and the aircraft navigational) are presented in Appendix VI. A measure of the goodness of fit of a source

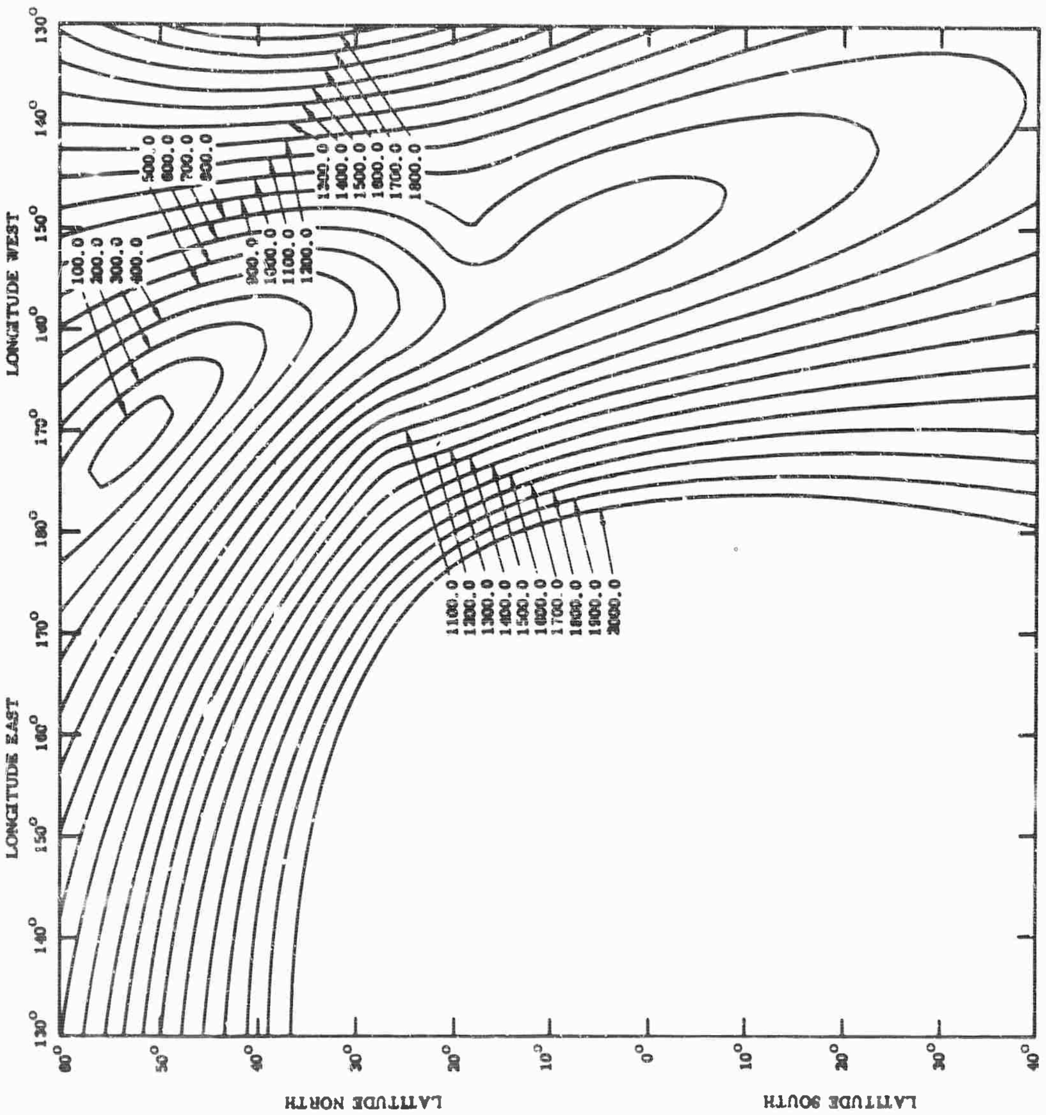


Figure 22 Pacific Ocean Area for Illustrative Source Location Problem

location calculation to the data is the ensemble residual. For the GM DRL computation, the ensemble residual is the rms result of the individual station residuals expressed in meters. The station residual is the distance the station would have to be moved toward or away from the assumed source location to match the computed and actual arrival time. University of Hawaii residuals are in seconds of time. The two are convertible to one another through the nominal sound velocity, 1480 meters per second. Another indicator in a positional calculation where more than one method is used is the geographical distance between locations, determined by separate means. The averages of this "distance contradiction" among the three location computation agents, together with mean ensemble residuals for the entire group of 248-lb shots, are indicated below.

Average Ensemble Residuals		
GM DRL	4026 meters	2.72 seconds
U of H	3049 meters	2.06 seconds
Average Location Contradictions		
GM DRL	Navigation	11.9 kilometers
U of H	Navigation	12.0 kilometers
GM DRL	U of H	7.79 kilometers

Table II

AVERAGE SOUND VELOCITY COMPUTED AND OBSERVED

Source	Receiver	$\overline{V}p$ (m/sec)	$\overline{V}e$ (m/sec)	$\overline{V}e$-$\overline{V}p$	S	N
1	8	1480.66	1482.09	1.43	0.31	22
1	9	--	1483.32	--	--	--
1	10	1482.69	1484.11	1.42	0.35	20
1	11	1479.27	1480.87	1.60	0.85	50
2	11	1468.55	1472.87	4.32	0.51	7

Legend:
$\overline{V}p$ - determined from observed data and GM DRL program
$\overline{V}e$ - estimated from U of H contour plots
S - standard deviation for $\overline{V}p$
N - number of points used to determine $\overline{V}p$

Receiver:
8 - Midway
9 - Wake Island
10 - Eniwetok
11 - GM DRL acoustic monitoring buoy

Source:
1 - GM DRL Oahu shots
2 - TI Aleutian Shots

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APPENDIX I

SOURCE DATA SUMMARY

This appendix includes the listings of the final source logs for the TI 2376-lb Aleutian shots as reported in Reference 9, and the GM DRL Oahu shots used in all calculations of sound velocity. These numbers were assembled from various logs kept at the time of the shots. The reduction is briefly described in Section 6. The column headings are self-explanatory.

SOURCE TIMES AND LOCATIONS TI 2376 LB SHOTS

SHOT	DATE	GCT		LATITUDE			LONGITUDE			DEPTH	CHARGE	WATER
	MO DY YR	HRMN	SEC	DG	MN	SC	DEG	MN	SC	METERS	WT LBS	DEPTH
2 23	9/ 2/64	2311	00.00	51	29	10N	175	52	30W	91.	2376.	3380
2 22	9/ 4/64	2336	59.75	51	22	15N	176	42	22W	91.	2376.	2104
2 21	9/ 5/64	0246	00.06	51	20	10N	177	20	55W	91.	2376.	2122
2 20	9/ 5/64	0354	00.02	51	17	43N	177	49	55W	91.	2376.	1220
2 11	9/ 7/64	0527	00.00	51	03	30N	175	51	30W	91.	2376.	3475
2 13	9/ 7/64	1824	00.02	51	14	45N	174	19	00W	91.	2376.	4505
2 26	9/ 7/64	2305	00.35	51	45	50N	173	35	30W	91.	2376.	2415
2 25	9/ 8/64	0230	59.75	51	41	30N	174	14	30W	91.	2376.	3038
2 24	9/ 8/64	0557	00.17	51	35	55N	175	00	45W	91.	2376.	3075
2 19	9/ 8/64	2341	00.05	51	11	05N	178	27	20W	91.	2376.	2453
2 18	9/ 9/64	0627	00.25	51	02	30N	178	55	50W	91.	2376.	3075
2 32	9/10/64	0522	00.14	51	46	42N	178	33	45W	91.	2376.	1510
2 62	9/11/64	0931	59.92	52	12	00N	178	05	40W	61.	2376.	3185
2 45	9/12/64	0155	59.89	52	08	00N	179	01	20W	61.	2376.	2465
2 42	9/12/64	0545	00.00	51	51	15N	179	35	08W	61.	2376.	1757
2 40	9/12/64	2030	59.92	51	51	50N	178	34	56E	61.	2376.	586
2 41	9/13/64	0201	00.15	51	40	15N	179	28	15W	61.	2376.	1244
2 30	9/13/64	0605	59.97	51	21	55N	179	47	35W	61.	2376.	1538
2 46	9/15/64	1906	00.20	52	20	22N	177	16	25W	91.	2376.	3335
2 47	9/17/64	2206	00.13	52	21	30N	176	42	55W	91.	2376.	3475
2 59	9/18/64	0122	00.21	52	45	13N	176	43	30W	91.	2376.	3550
2 54	9/18/64	1904	00.02	51	28	20N	179	23	10W	91.	2376.	1061
2 17	9/18/64	2256	00.23	51	02	12N	179	44	50W	91.	2376.	3755

SOURCE TIMES AND LOCATIONS GM/DRL SHOTS

SHOT		DATE	GCT		LATITUDE			LONGITUDE			DEPTH	CHARGE	EXPLOSION
		MO DY YR	HRMN	SEC	DG	MN	SC	DEG	MN	SC	METERS	WT LBS	STRENGTH
1	1	9/ 1/64	0801	08.00	21	48	25N	158	10	17W	720.	4.50	GOOD
1	2	9/ 1/64	1000	32.90	21	48	00N	158	10	30W	720.	4.50	GOOD
1	5	9/ 1/64	1600	58.60	21	47	55N	158	13	28W	649.	4.50	GOOD
1	6	9/ 1/64	1800	47.40	21	47	19N	158	11	9W	732.	4.50	GOOD
1	7	9/ 1/64	2003	26.00	21	47	39N	158	10	48W	707.	4.50	GOOD
1	8	9/ 1/64	2201	00.70	21	47	27N	158	10	52W	676.	4.50	GOOD
1	9	9/ 2/64	0002	54.80	21	47	26N	158	11	4W	947.	4.50	GOOD
1	10	9/ 2/64	[illegible]	00.07	21	48	2N	158	10	42W	711.	4.50	GOOD
1	11	9/ 2/64	0500	32.00	21	48	8N	158	10	55W	879.	4.50	DUD
1	12	9/ 2/64	1100	53.70	21	47	56N	158	11	7W	872.	4.50	GOOD
1	13	9/ 2/64	1303	28.20	21	48	4N	158	11	3W	801.	4.50	GOOD
1	15	9/ 2/64	1700	35.00	21	48	11N	158	10	41W	771.	4.50	GOOD
1	16	9/ 2/64	1900	30.00	21	48	2N	158	10	46W	744.	4.50	CAPS
1	17	9/ 2/64	2100	27.70	21	47	40N	158	11	7W	676.	4.50	CAPS
1	18	9/ 2/64	2302	54.78	21	48	5N	158	10	42W	750.	4.50	GOOD
1	19	9/ 3/64	0102	07.50	21	48	5N	158	10	42W	803.	9.00	GOOD
1	20	9/ 3/64	0200	46.00	21	48	6N	158	10	48W	843.	4.50	GOOD
1	21	9/ 3/64	0300	50.00	21	48	8N	158	10	49W	850.	9.00	GOOD
1	22	9/ 3/64	0904	11.40	21	47	57N	158	11	4W	881.	9.00	GOOD
1	23	9/ 3/64	1100	44.70	21	47	48N	158	11	25W	854.	4.50	CAPS
1	24	9/ 3/64	1304	42.70	21	47	58N	158	11	10W	863.	4.50	GOOD
1	25	9/ 3/64	1500	40.70	21	47	35N	158	11	25W	854.	4.50	GOOD
1	26	9/ 3/64	1700	29.39	21	48	2N	158	10	44W	845.	4.50	GOOD
1	27	9/ 3/64	1800	30.40	21	47	0N	158	10	41W	858.	4.50	GOOD
1	28	9/ 3/64	1900	47.20	21	48	7N	158	10	35W	820.	7.75	GOOD
1	29	9/ 3/64	2000	46.29	21	48	7N	158	10	37W	761.	4.50	GOOD
1	30	9/ 3/64	2101	10.00	21	47	0N	158	10	54W	730.	13.50	GOOD
1	31	9/ 3/64	2200	38.60	21	47	59N	158	10	50W	860.	4.50	GOOD
1	32	9/ 3/64	2300	38.40	21	48	3N	158	10	45W	860.	11.25	GOOD
1	33	9/ 4/64	0000	26.60	21	47	0N	158	10	46W	802.	4.50	GOOD
1	34	9/ 4/64	0100	25.40	21	48	1N	158	10	57W	774.	11.25	GOOD
1	35	9/ 4/64	0200	22.45	21	48	7N	158	10	43W	802.	4.50	GOOD
1	36	9/ 4/64	0304	20.50	21	48	15N	158	10	39W	788.	9.00	GOOD
1	37	9/ 4/64	0400	41.20	21	48	16N	158	10	59W	766.	13.50	GOOD
1	38	9/ 4/64	0500	29.80	21	48	2N	158	10	53W	817.	4.50	GOOD
1	39	9/ 4/64	0604	53.40	21	47	22N	158	13	6W	831.	9.00	GOOD
1	40	9/ 4/64	0702	03.20	21	47	53N	158	10	56W	729.	4.50	GOOD
1	41	9/ 4/64	0801	01.20	21	48	1N	158	10	24W	883.	9.00	GOOD
1	42	9/ 4/64	0900	00.60	21	48	10N	158	10	34W	841.	4.50	GOOD
1	43	9/ 4/64	1000	34.80	21	48	4N	158	10	42W	773.	13.50	GOOD
1	44	9/ 4/64	1701	14.40	21	47	44N	158	10	46W	801.	9.00	GOOD
1	45	9/ 4/64	1801	49.60	21	48	8N	158	9	50W	831.	4.50	GOOD
1	46	9/ 4/64	1900	38.60	21	48	4N	158	10	26W	704.	4.50	GOOD
1	47	9/ 4/64	2000	37.40	21	48	10N	158	10	16W	589.	4.50	GOOD
1	48	9/ 4/64	2101	36.00	21	47	37N	158	10	29W	586.	9.00	GOOD
1	49	9/ 4/64	2200	19.80	21	48	6N	158	9	56W	831.	13.50	GOOD
1	50	9/ 5/64	0103	57.20	21	47	57N	158	10	19W	766.	9.00	GOOD
1	51	9/ 5/64	0300	49.30	21	47	28N	158	10	29W	784.	9.00	GOOD
1	52	9/ 5/64	0400	43.10	21	47	38N	158	10	13W	659.	9.00	GOOD
1	53	9/ 5/64	0502	46.80	21	47	49N	158	10	0W	624.	9.00	GOOD
1	54	9/ 5/64	0600	25.60	21	47	49N	158	10	26W	663.	22.00	GOOD
1	55	9/ 5/64	0700	23.65	21	47	31N	158	10	5W	591.	18.00	GOOD
1	56	9/ 5/64	1200	32.00	21	47	43N	158	10	43W	667.	9.00	GOOD
1	57	9/ 5/64	1300	31.20	21	47	55N	158	11	36W	684.	18.00	GOOD
1	58	9/ 5/64	1402	12.0	21	37	52N	158	8	57W	671.	18.00	DUD
1	60	9/ 5/64	1600	48.70	21	47	50N	158	10	59W	615.	18.00	GOOD

APPENDIX IIa
GM BUOY LOG

GM OAHU SHOTS

The following is a log taken from the GM DRL buoy roll chart. The column headings for station, date, and shot number are self-explanatory, as are those for hours and minutes. The fraction of a minute and amplitudes are all measured in hundredths of an inch. The last number is a calibration, the number of hundredths of inches per minute. Thus, the first return arrived at 0845 and $\left(\frac{.68}{2.37}\right)$ x 60 seconds, lasted for $\left(\frac{.32}{2.37}\right)$ x 60 seconds, and had an amplitude of 1.75 inches.

ALEUTIAN TI SHOTS

A reproduction of the receiver log is shown. In contradistinction to the Oahu shot log, the column labeled TIME indicates the nearest time fiduciary mark preceding the onset of the arrival signal. This time is given in hours, minutes and millimeters. The column labeled DUR gives the duration time of the arrival signal in millimeters and SOFARR gives the time elapsed in hundredths of millimeters from the fiduciary mark to the arrival of the axial ray. The conversion factor is 60.5 millimeters per 60 seconds. Thus, for shot 23 the axial ray arrives at 2405 hours plus (60/60.5) (03 + 30.00) seconds, and the duration is (60/60.5) (73) seconds.

ARRIVAL TIMES OF TI ALEUTIAN SHOTS AT GM/DRL BUOY

Stn No	Date mo dy yr	Shot no	Time hr mn mm	Dur mm	SOFARR mm
11	090264	23	240503	73	3000
11	090464	22	243154	76	7150
11	090764	11	062113	76	3200
11	090764	13	191700	74	1900
11	090764	26	235730	64	4650
11	090764	25	032400	64	1600
11	090864	24	065034	72	5250

```
ARRIVAL TIMES GM/DRL OAHU SHOTS AT GM/DRL BUOY

STN    DATE SHOT     TIME   AMPDUR IN/
NO   MODYYRNO      HRMN IN   IN IN MIN
110070901640101   0845068 175032 237
110070901640201   1044185 145025 238
110070901640501   1645054 123029 238
110070901640601   1844238 175030 239
110070901640701   2047154 158031 237
110070901640801   2245054 177033 238
110070902640901   0047034 185034 239
110070902641001   0544056 179026 238
110070902641201   1145029 178028 238
110070902641301   1347165 165031 238
110070902641501   1744193 135025 238
110070902641801   2347034 172030 237
110070903641901   0146085 173036 238
110070903642001   0244237 172027 238
110070903642101   0344253 174034 238
110070903642201   0948098 110023 238
110070903642401   1348229 178027 238
110070903642501   1544218 178033 238
110070903642601   1744430 155026 605
110070903642701   1844179 172030 238
110070903642801   1944243 175038 238
110070903642901   2044238 179032 238
110070903643001   2145095 183034 238
110070903643101   2244532 168026 605
110070903643201   2344210 190040 238
110070904643301   0044162 178035 238
110070904643401   0144160 182036 238
110070904643501   0244148 166030 238
110070904643601   0348141 172033 238
110070904643701   0444234 174034 239
110070904643801   0544183 150025 239
110070904643901   0649040 180032 239
110070904644001   0746071 165029 238
110070904644101   0845061 180029 238
110070904644201   0944060 165028 238
110070904644301   1044194 175030 238
110070904644401   1745110 062015 236
110070904644501   1845250 135028 238
110070904644601   1944208 176030 238
110070904644701   2044205 158030 239
110070904644801   2145198 156030 239
110070904644901   2244134 175034 239
110070905645001   0148050 184034 239
110070905645101   0344255 173023 239
110070905645201   0444230 183026 239
110070905645301   0546244 192032 239
110070905645401   0644157 132021 239
110070905545501   0744150 100025 239
110070905645601   1244186 098025 239
110070905645701   1344205 060019 239
110070905646001   1644254 178034 239
```

APPENDIX IIb

MILS STATION RECEIVED DATA LOG

The following listing shows the recorded date at MILS stations Eniwetok and Midway of the GM DRL Oahu shots.

The column headings are self-explanatory.

ARRIVAL TIMES GM/DRL OAHU SHOTS AT MIDWAY

STN	DATE	SHOT	TIME	DUR	START ARRIVAL SEC				SHOT	RIS BG			
NO	MODYYR	NO	HRMN	SEC	CH1	CH2	CH3	CH4	BRG	DB	DBV	A	GOAO
	9 264	18	12325		1274	377							
	9 364	19	10124		1403	506							
	9 364	20	10223		1188	290							
	9 364	21	10323		1228	331							
	9 364	22	10926		1441	543							
	9 364	24	11327		1153	255							
	9 364	25	11523		1133	237							
	9 364	26	11723		1021	124							
	9 364	28	11923		1201	304							
	9 364	29	12023		1188	291							
	9 364	30	12123		1428	530							
	9 364	31	12223		1112	216							
	9 364	32	12323		1113	216							
	9 464	46	11923		1116	217							
	9 464	47	12023		1104	207							
	9 464	48	12124		1097	197							
	9 464	49	12223		938	041							
	9 564	50	10126		1296	398							
	9 564	51	10323		1229	331							
	9 564	56	11223		1048	151							
	9 564	57	11323		1027	128							
	9 564	60	11623		1215	318							
	9 264	18	12351		420	476	342	044					
	9 364	20	10248		952	1007	873	555					
	9 364	21	10348		992	1050	913	596					
	9 364	22	10952		610	669	536	215					
	9 364	24	11352		914	971	838	517					
	9 364	25	11548		899	957	820	503					
	9 364	26	11748		788	844	706	391					
	9 364	28	11948		965	1023	888	572					
	9 364	29	12048		955	1012	879	556					
	9 364	32	12348		876	935	798	481					
	9 464	47	12048		869	924	792	475					
	9 464	48	12149		868	926	783	475					
	9 464	49	12248		704	758	624	304					
	9 564	51	10348		988	1046	910	591					
	9 564	52	10448		928	984	849	532					
	9 564	53	10550		969	1026	892	571					
	9 564	54	10649		162	218	086						
	9 564	55	10748		735	791	659	339					
	9 564	57	11348		788	846	710	393					
	9 564	60	11648		984	1040	907	587					

APPENDIX III

SOFAR VELOCITY PROGRAM

The following is a listing of the program used to convert source and receiver logs into average sound velocities. The program mechanics are briefly described in Section 6. The coding is done in IBM 7040 Fortran IV, and the program was run on an IBM 7040 computer.

```
C PROGRAM TO COMPUTE AVERAGE SOUND VELOCITY FROM SOURCE AND STATION LOGS
C   MW MCLENNAN  1/16/65
      DIMENSION IMO(100),SDAY(100),SHR(100),SMN(100),SSEC(100),SLAT(100)
     1,SLNG(100),SDEPTH(100),SWT(100),SPER(100),RSC(4),N1(10),N2(60)
     2 ,RCLAT(4),RCLNG(4),RDEPTH(4),LABEL(56)
      REAL N
      READ 2,N1,N2
    2 FORMAT(10A1,35A2/25A2)
      READ 3,N,S,F,W,GOOD
    3 FORMAT (4A1,A4)
      READ 22,LABEL
   22 FORMAT(13A6,A2)
    4 READ 5,ISRC,ISHOT,IMO(ISHOT),SDAY(ISHOT),SHR(ISHOT),SMN(ISHOT),
     1SSEC(ISHOT),SLATDG,SLATMN,SLATSC,SLATNS,SLNGDG,SLNGMN,SLNGSC,
     2 SLNGEW,SDEPTH(ISHOT),SWT(ISHOT),SPER(ISHOT)
    5 FORMAT( I2,2I3,1X,F2.0,4X,2F2.0,F6.2,1X,3F3.0,A1,2X,3F3.0,A1,3X,
     1 F4.0,F7.2,1X,A4)
      IF(ISHOT.EQ.100)GO TO 10
      SLATRD=.174532925E-1*(SLATDG +SLATMN/60. +SLATSC/3600.)
      SLAT(ISHOT)=SLATRD-.33726712E-2*SIN(2.*SLATRD)+.5687E-5*SIN(4.*
     1   SLATRD)
      IF(SLATNS.EQ.S)SLAT(ISHOT)=-SLAT(ISHOT)
      SLNG(ISHOT)=.174532925E-1*(SLNGDG +SLNGMN/60. +SLNGSC/3600.)
      IF(SLNGEW.EQ.W)SLNG(ISHOT)= -SLNG(ISHOT)
      GO TO 4
   10  DO 14 I=1,2
      READ 11,RLAT,RCLNG(I),RDEPTH(I)
   11 FORMAT(2F15.0,F10.0)
      RLAT=RLAT -.33726712E-2*SIN(2.*RLAT) +.5687E-5*SIN(4.*RLAT)
      RCLAT(I)=RLAT
      RCLAT(I+2)=RLAT
      RCLNG(I+2)=RCLNG(I)
   14 RDEPTH(I+2)=RDEPTH(I)
      M=0
   15 READ 12,ISTN,RDAY,ISHOT,JSRC,ISETUP,ICHAN,RHR,RMN,RSCST,DURMIN,
     1 DURSEC,RSC,IAMP,DBRISE,DBBKGD,ATTEN,GZERO,ATZERO
   12 FORMAT(I2,5X,F2.0,2X,I4,I2,I4,I2,5F2.0,4F5.2,4X,I2,2F3.1,F2.0,F3.0
     1 ,F2.0)
```

```
      IF(ISTN.GT.20)GO TO 10
      M=M+1
      FUDGE=0.
      IF(RSCST.GT.RSC(ICHAN))FUDGE=60.
      TIME= 86400.*(RDAY-SDAY(ISHOT)) +3600.*(RHR-SHR(ISHOT))
     1 +60.*( RMN-SMN(ISHOT)) +RSC(ICHAN)-SSEC(ISHOT) +FUDGE
      RLAT=RCLAT(ICHAN)
      RLNG=RCLNG(ICHAN)
      CALL GCD(RLAT,RLNG,SLAT(ISHOT),SLNG(ISHOT),RANGE,EM,EN)

      AVLAT= .5*( RLAT+SLAT(ISHOT))
      RADIUS=6378388.*(.998320047 +.1683494E-2*COS(2.*AVLAT)-.3549E-5*
     1 COS(4.*AVLAT))
      RANGE=RADIUS*RANGE
      CBAR= RANGE/TIME
      RKM=RANGE*.001
      DT=RSC(1)-RSC(2)
      IF(RSC(1).EQ.0..AND.RSC(2).EQ.0.)DT=RSC(3)-RSC(4)
      SPL=DBRISE+DBBKND+ATTEN -GZERO-ATZERO+80.
      IDAY=SDAY(ISHOT)+1.
      IMIN=SMN(ISHOT) +1.
      IHR =SHR(ISHOT) +1.
      IF(MOD(M,40).EQ.1)PRINT 20
   20 FORMAT(1H1)
      IF(MOD(M,40).EQ.1)PRINT 22,LABEL
      PRINT 24,JSRC,ISTN,ISHOT,IMO(ISHOT),    N2(IDAY),N2(IHR),N2(IMIN),
     1RKM,CBAR,SDEPTH(ISHOT),RDEPTH(ICHAN),DT,SPL
      PUNCH 24,JSRC,ISTN,ISHOT,IMO(ISHOT),    N2(IDAY),N2(IHR),N2(IMIN),
     1RKM,CBAR,SDEPTH(ISHOT),RDEPTH(ICHAN),DT,SPL
   24 FORMAT( 4I3,1H/,A2,4H/64 ,2A2,F9.2,F9.2,2F6.0,F7.2,F6.0,14X)
      GO TO 15
      END
```

APPENDIX IV

AVERAGE SOFAR VELOCITY LISTINGS

The following are listings of the output from the sound velocity program described in Section 6 and Appendix III. Average velocities are given for the GM DRL deployable monitoring buoy station for both the Oahu and TI 2378-1b shots. The column headings are self-explanatory (ZSOURCE and ZREC are depths in meters.

AVERAGE SOUND VELOCITIES TI ALEUTIAN SHOTS IN GM/DRL BUOY

SCR No	RC No	Shot No	Date mo dy yr	Source Time	Range km	C Avg m/sec	Z Source m	Z Rec m
2	11	23	090264	2311	4805.93	1469.70	91.	732.
2	11	22	090464	2336	4863.44	1468.54	91.	732.
2	11	11	090764	0527	4803.48	1468.06	91.	732.
2	11	13	090764	1824	4696.37	1468.08	91.	732.
2	11	26	090764	2305	4649.46	1468.49	91.	732.
2	11	25	090864	0230	4693.80	1468.53	91.	732.
2	11	24	090864	0557	4746.58	1468.47	91.	732.

AVERAGE SOUND VELOCITIES GM/DRL OAHU SHOTS TO GM/DRL BUOY

SRC NO	RC NO	SHOT NO	DATE M DY YR	SOURCE TIME	RANGE KM	C AVG M/SEC	ZSOURCE M	ZREC M
1	11	1	9/01/64	0801	3925.04	1481.59	720.	732.
1	11	2	9/01/64	1000	3925.73	1477.82	720.	732.
1	11	5	9/01/64	1600	3930.32	1480.34	649.	732.
1	11	6	9/01/64	1800	3927.31	1480.69	732.	732.
1	11	7	9/01/64	2003	3926.49	1480.03	707.	732.
1	11	8	9/01/64	2201	3926.77	1480.17	676.	732.
1	11	9	9/02/64	0002	3927.09	1479.83	947.	732.
1	11	10	9/02/64	0500	3926.01	1479.21	711.	732.
1	11	12	9/02/64	1100	3926.73	1479.77	872.	732.
1	11	13	9/02/64	1303	3926.51	1479.81	801.	732.
1	11	15	9/02/64	1700	3925.85	1479.41	771.	732.
1	11	18	9/02/64	2302	3925.86	1479.31	750.	732.
1	11	19	9/03/64	0102	3925.96	1479.30	803.	732.
1	11	20	9/03/64	0200	3926.10	1479.46	84[illegible].	732.
1	11	21	9/03/64	0300	3926.10	1479.44	850.	732.
1	11	22	9/03/64	0904	3926.64	1479.90	881.	732.
1	11	24	9/03/64	1304	3926.78	1478.99	863.	732.
1	11	25	9/03/64	1500	3927.49	1479.69	854.	732.
1	11	26	9/03/64	1700	3926.06	1479.66	845.	732.
1	11	27	9/03/64	1800	3926.88	1479.20	858.	732.
1	11	28	9/03/64	1900	3925.76	1479.15	820.	732.
1	11	29	9/03/64	2000	3925.81	1479.32	761.	732.
1	11	30	9/03/64	2101	3927.21	1479.76	730.	732.
1	11	31	9/03/64	2200	3926.25	1479.28	860.	732.
1	11	32	9/03/64	2300	3926.07	1479.00	860.	732.
1	11	33	9/04/64	0000	3927.01	1479.52	802.	732.
1	11	34	9/04/64	0100	3926.40	1478.91	774.	732.
1	11	35	9/04/64	0200	3925.96	1478.75	802.	732.
1	11	36	9/04/64	0304	3925.74	1478.60	788.	732.
1	11	37	9/04/64	0400	3926.24	1477.39	766.	732.
1	11	38	9/04/64	0500	3926.29	1478.19	817.	732.
1	11	39	9/04/64	0604	3930.24	1479.40	831.	732.
1	11	40	9/04/64	0702	3926.49	1479.07	729.	732.
1	11	41	9/04/64	0801	3925.57	1479.01	883.	732.
1	11	42	9/04/64	0900	3925.69	1478.87	841.	732.
1	11	43	9/04/64	1000	3925.98	1479.21	773.	732.
1	11	44	9/04/64	1701	3926.37	1479.79	801.	732.
1	11	45	9/04/64	1801	3924.60	1479.07	831.	732.
1	11	46	9/04/64	1900	3925.57	1479.21	704.	732.
1	11	47	9/04/64	2000	3925.23	1478.95	589.	732.
1	11	48	9/04/64	2101	3926.04	1479.46	586.	732.
1	11	49	9/04/64	2200	3924.78	1478.91	831.	732.
1	11	50	9/05/64	0103	3925.50	1478.33	766.	732.
1	11	51	9/05/64	0300	3926.17	1478.94	784.	732.
1	11	52	9/05/64	0400	3925.52	1478.78	659.	732.
1	11	53	9/05/64	0502	3925.13	1478.70	624.	732.
1	11	54	9/05/64	0600	3925.79	1479.30	663.	732.
1	11	55	9/05/64	0700	3925.52	1479.06	591.	732.
1	11	56	9/05/64	1200	3926.31	1479.01	667.	732.
1	11	60	9/05/64	1600	3926.61	1478.91	615.	732.

APPENDIX V

SOURCE LOCATION PROGRAM

The following is a listing of the GM DRL source location program configured especially for the University of Hawaii MILS data format. The coding is an IBM 7040 Fortran IV, and the program was run on a 7040 with a real-time storage clock. The program is described in greater detail in Section 6.

```
C PROGRAM TO COMPUTE SOURCE LOCATION OF UNDERWATER ACOUSTIC EVENTS
C BY LEAST SQUARES CRITERIA
C MW MCLENNAN JAN 1965
      DIMENSION RLAT(99).RLNG(99).RCAV(99).SINBTA(25).COSBTA(25).TAR(25)
     1.SLAT(25).SLNG(25).SCAV(25).D(25).CHAD(25).IDAY(25).IMO(25)
     2 .NSTN(25).RANGE(25)
      EXTERNAL IBCLK
      REAL N
      GODT(Y)=Y+.33726712E-2*SIN(2.*Y)-.5687E-5*SIN(4.*Y)
      GOCN(Y)=Y-.33726712E-2*SIN(2.*Y)+.5687E-5*SIN(4.*Y)
      ITIME(T)=4096*MOD(INT(T/60.).10) +262144* MOD(INT(T/600.).6)
     1 +16777216*MOD(INT(T/3600.).10) +1073741824* INT(T/36000.)
      RAD(Y)=6378388.*(.998320047+.1683494E-2*COS(2.*Y)-.3549E-5*COS(4.*
     1Y))
      READ 2.N.S.E.W
    2 FORMAT(4A1)
C INPUT STATION DATA
    4 READ 5.ISTN.RLAT(ISTN).RLNG(ISTN).RCAV(ISTN)
    5 FORMAT(I2.F13.8.F15.8.F10.2)
      IF(ISTN.EQ.99)GO TO 10
      RLAT(ISTN)=SIGN(GOCN(ABS(RLAT(ISTN))).RLAT(ISTN))
      GO TO 4
C INPUT TRIAL PARAMETERS
   10 READ 12.YZERO.XZERO
   12 FORMAT(2F10.2)
      XZERO=.0174533*XZERO
      YZERO=.0174533*YZERO
      GOTIME=IABS(IBCLK)
C INPUT STATION ARRIVAL TIMES
      I=0
   15 I=I+1
   17 FORMAT( I2.6X.I2.5X.I2.4X.I2.I3.2X.I2.3X.F3.0.2X.F5.3.9X.I2)
      READ 17.JSHOT.IDAY(I).IMO(I).IYR.IHR.IMN.TSC.TFACT.ISTN
      IF(JSHOT.NE.ISHOT)GO TO 20
```

```
   18 SLAT(I)=RLAT(ISTN)
      SLNG(I)=RLNG(ISTN)
      SCAV(I)=RCAV(ISTN)
      NSTN(I)=ISTN
      TAR(I)= 3600.*FLOAT(IHR)+60.*FLOAT(IMN)+TSC*TFACT+86400.*FLOAT(
     1   IDAY(I)-IDAY(1))
      ISHOT=JSHOT
      GO TO 15
   20 IF(I.EQ.1)GO TO 18
      IMAX=I-1
      X=XZERO
      Y=YZERO
      T=TAR(1)-1689.
C START ITERATION
COMPUTE COEFFICIENTS
      ITNO=0
   25 ITNO=ITNO +1
      DO 30 I=1.IMAX
      CALL GCD(SLAT(I).SLNG(I).Y.X.RANGE(I).SINBTA(I).COSBTA(I))
      AVLAT=.5*(Y+SLAT(I))
      CRAD(I)=SCAV(I)/RAD(AVLAT)
   30 D(I)=CRAD(I)*(TAR(I)-T) -RANGE(I)
      CALL LSTSQ3(SINBTA.COSBTA.CRAD.D.DX.DY.DT.RES.IMAX)
      X=X-DX
      Y=Y-DY
      T=T+DT
      Y=ABS(AMOD(1.5707963-Y.6.2831853))
      IF(Y.GT.3.1415927)Y=6.2831853-Y
      Y=1.5707963-Y
      X=AMOD(X.6.2831853)
      IF(ABS(X).GT.3.1415927)X=SIGN(6.2831858-ABS(X).-X)
      IF(ITNO.GT.29)GO TO 32
      IF(ABS(DX).GT..158E-5.OR. ABS(DY).GT.158E-5)GO TO 25
C OUTPUT RESULTS
   32 PRINT 35.ISHOT
   35 FORMAT(1H1.     41HLEAST SQUARES SOURCE LOCATION OF T.I.SHOT.I3 //
     1 27H  ARRIVAL TIMES AT STATIONS /40H   STATION   DATE         GCT
     2 RESIDUAL /39H   NUMBER  MO DY YR  HRMN  SEC   METERS /  )
      DO 38 I=1.IMAX
      RESOUT=6371000.*D(I)
      JTIME=ITIME(TAR(I))
      SEC= AMOD(TAR(I).60.)
   38 PRINT 36.NSTN(I).IMO(I).IDAY(I).IYR.JTIME.SEC.RESOUT
   36 FORMAT(2I6.2(1H/.I2).2X.A4.F6.2. F8.0)
      PLATNS=N
      IF(Y.LT.0.)PLATNS=S
      PLAT=57.2957795*GODT(ABS(Y))
      ILATDG=PLAT
      ILATMN= 60.*AMOD(PLAT.1.)
```

```
      ILATSC= AMOD(3600.*PLAT,60.)
      PLNGEW=E
      IF(X.LT.0.)PLNGEW=W
      PLNG= 57.2957795*ABS(X)
      ILNGDG=PLNG
      ILNGMN=60.*AMOD(PLNG,1.)
      ILNGSC=AMOD(3600.*PLNG,60.)
      JTIME=ITIME(T)
      SEC= AMOD(T,60.)
      IO=2
      RESOUT=6371000.*RES

      PRINT 40
   40 FORMAT(///61H SHOT    DATE      GCT         LATITUDE    LONGITUDE   RMS
     1     NO.    /
     2           64H        MO DY YR HRMN SEC     DG MN SC    DEG MN SC   RES
     4 ITERATIONS   )
      PRINT 41,ISHOT,IMO(1),IDAY(1),IYR,JTIME,SEC,ILATDG,ILATMN,ILATSC,
     1 PLATNS,ILNGDG,ILNGMN,ILNGSC,PLNGEW,RESOUT,ITNO
   41 FORMAT(2H 2,2I3,2(1H/,I2),1X,A4,F6.2,I4,2I3,A1,I5,2I3,A1,F6.0,I5)
      PUNCH 42,ISHOT,IMO(1),IDAY(1),IYR,JTIME,SEC,ILATDG,ILATMN,ILATSC,
     1 PLATNS,ILNGDG,ILNGMN,ILNGSC,PLNGEW,RESCUT
   42 FORMAT(2H 2,2I3,2(1H/,I2),1X,A4,F6.2,I4,2I3,A1,I5,2I3,A1,F6.0,26X)
      TLAPSE=(FLOAT(IABS(IBCLK)) -GOTIME)/60.
      GOTIME=IABS(IBCLK)
      PRINT 45,TLAPSE
   45 FORMAT(//18H COMPUTATION TIME= ,F7.3, 4H SEC )
C SET UP FOR NEXT SET
      IDAY(1)=IDAY(IMAX+1)
      IMO(1)=IMO(IMAX+1)
      I=1
      GO TO 1
      END
```

APPENDIX VI

SOURCE LOCATIONS OF 248-lb SHOTS

The following is a tabulation of probable source locations for the TI 248-lb shots. Three sets of figures are given for each shot.

a) The output of the GM DRL program
b) The radar-derived position of the plane at the time of drop
c) The output of the University of Hawaii epicenter location program

Lines a) and c) differ only in that the University of Hawaii program used only the MILS data, while the GM program used additional data from two West Coast stations.

In the column marked Res-RMS, the GM station residual is expressed as rms meters, whereas the University of Hawaii residual is apparently expressed as the mean of the absolute value of the residual in seconds. There is no residual expressed for the radar fixes. Since these source cards are in the same format as the TI source logs, the extra three numbers refer respectively to shot depth (meters), charge weight (pounds), and local water depth (meters).

```
SOURCE POSITIONS OF T.I. 248-LB ALEUTIAN SHOTS AS COMPUTED BY

1.GM/DRL PROGRAM USING U.OF H. DATA PLUS WEST COAST HYDROPHONES
2.NAVIGATIONAL RADAR. AS REPORTED IN U.S.C+GS MEMO DATED 1 OCT 1964
3.U.OF HAWAII PROGRAM USING MILS HYDROPHONE DATA

       MO DY YR HRMN SEC    DG MN SC     DEG MN SC   RES
SHOT    DATE      GCT       LATITUDE     LONGITUDE   RMS
2 65   9/17/64 2259 55.74   51 27 22N    176 39 12W 2154.
2 65   9/17/64 2259 51.00   51 35 00N    176 38 24W     38.     248.   183
               2259 54      51.5 N       175.6 W     1.3

2 66   9/17/64 2315  1.62   51 13 32N    176 38 13W 5061.
2 66   9/17/64 2314 59.00   51 25 00N    176 38 24W     38.     248. 1428
               2314 54      51.3 N       176.6 W     3.5

2 67   9/17/64 2331 41.85   51  7 27N    176 37 52W 4268.
2 67   9/17/64 2331 34.00   51 15 00N    176 38 24W     38.     248. 3480
               2331 36      51.2 N       176.6 W     3.0

2 68   9/18/64 -014-33.20   50 38 29N    176 36 49W 4057.
2 68   9/17/64 2345 26.00   51 05 00N    176 38 24W     38.     248. 3850
               2345 28      51.0 N       176.6 W     2.9

2 69   9/18/64 0030 27.16   50 59  3N    176 31 50W 7039.
2 69   9/18/64 0030 37.00   50 55 00N    176 38 24W     38.     248. 3380
               0 30 29      51.0 N       176.5 W     2.7

2 70   9/18/64 0044 39.68   50 49  2N    176 35 23W 5192.
2 70   9/18/64 0044 45.00   50 45 00N    176 38 24W     38.     248. 4395
               0044 42      50.8 N       176.6 W     2.2

2 71   9/18/64 0100  5.31   50 48 11N    176 35  0W11137.
2 71   9/18/64 0100 13.00   50 35 00N    176 38 24W     38.     248. 6220
               0100 15      50.7 N       176.6 W     2.9

2 72   9/18/64 0115 14.08   50 28 39N    176 36 45W 3926.
2 72   9/18/64 0115 19.00   50 22 51N    176 40 00W     38.     248. 6960
               0115 20      50.4 N       176.6 W     2.6

2 73   9/20/64 2159 57.59   51 53 22N    174 46 11W 2813.
2 73   9/20/64 2159 58.00   51 52 27N    174 43 18W     38.     248.  156
               2159 56      51.9 N       174.8 W     1.1
```

```
SOURCE POSITIONS OF T.I. 248-LB ALEUTIAN SHOTS AS COMPUTED BY

1.GM/DRL PROGRAM USING U.OF H. DATA PLUS WEST COAST HYDROPHONES
2.NAVIGATIONAL RADAR. AS REPORTED IN U.S.C+GS MEMO DATED 1 OCT 1964
3.U.OF HAWAII PROGRAM USING MILS HYDROPHONE DATA

       MO DY YR HRMN SEC     DG MN SC    DEG MN SC  RES
 SHOT    DATE     GCT        LATITUDE    LONGITUDE  RMS
 2 74   9/20/64 2150 14.99   51 55 59N   175 26 37W 1718.
 2 74   9/20/64 2150 18.00   51 52 54N   175 23 24W    38.      248.   145
                2150 08      52.0 N      175.4 W    1.3
 2 75   9/20/64 2236 30.32   51 41 23N   175 55 39W 4981.
 2 75   9/20/64 2236 25.00   51 45 12N   175 55 00W    38.      248.   180
                2236 33      51.7 N      175.9 W    1.3

 2 76   9/20/64 2132 47.07   51 36 28N   176 14 17W 3134.
 2 76   9/20/64 2132 43.00   51 40 30N   176 15 24W    38.      248.   165
                2132 47      51.6 N      176.2 W    1.3

 2 77   9/20/64 2046 55.66   51 31  7N   177 13 14W 1392.
 2 77   9/20/64 2046 46.00   51 40 30N   177 04 00W    38.      248.   120
                2046 57      51.5 N      177.2 W    1.1

 2 78   9/20/64 2032 41.59   51 28 46N   177 28 41W 1070.
 2 78   9/20/64 2032 30.00   51 40 12N   177 24 24W    38.      248.   137
                2032 44      51.4 N      177.5 W    1.1

 2 79   9/20/64 2022 34.17   51 39 31N   177 53 49W 3469.
 2 79   9/20/64 2022 38.00   51 35 00N   177 47 48W    38.      248.   147
                2023 08      51.2 N      177.9 W    0.9

 2 80   9/20/64 1943 56.75   51 39 43N   178 18 17W 8654.
 2 80   9/20/64 1943 59.00   51 33 42N   178 15 21W    38.      248.   210
                1944 07      51.5 N      178.3 W    4.8

 2 81   9/20/64 2323 19.35   51 29 59N   178 46 18W 5619.
 2 81   9/20/64 2323 07.00   51 28 42N   178 37 21W    38.      248.   320
                2323 25      51.4 N      178.7 W    2.7

 2 82   9/21/64 -007-29.44   51  6 49N   179 22 16W 2571.
 2 82   9/20/64 2352 21.00   51 12 24N   179 15 00W    38.      248.  1815
                2352 26      51.2 N      179.4 W    1.8

 2 83   9/21/64 0018 25.33   50 56  3N   179 35 20E 2461.
 2 83   9/21/64 0018 07.00   51 12 00N   179 29 24E    38.      248.  1095
                0018 22      51.0 N      179.6 E    1.8
 2 84   9/21/64 0040 57.33   51 27 21N   178 57 10E  625.
 2 84   9/21/64 0041 02.00   51 19 54N   178 59 00E    38.      248.   210
                0040 55      51.5 N      178.9 E    0.5

 2 16   9/21/64 0105 19.69   50 52 24N   179 13 58E 3195.
 2 16   9/21/64 0105 10.00   50 59 30N   179 10 36E    38.      248.  3300
                0105 20      50.9 N      179.3 E    2.5
```

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13 ABSTRACT

(U) Experimental results of SOFAR velocity measurements made between Hawaii and the California coast and between Hawaii and certain islands in the Pacific in the summer of 1964 are given. Explosive source stations were located off Oahu, Hawaii, and the Aleutian Islands. A source location program for the IBM 7040 computer was developed and used to locate explosive sound sources from signals received at a widely spaced ensemble of receiving stations. Signals were recorded by various stations in the North Central Pacific and also by an acoustic monitoring buoy station anchored off the California coast. The objectives of the experiment were to obtain a measurement of the average propagation velocity in the Northeast Pacific over various long path lengths based on a statistically significant number of readings, and a measurement of the stability of this velocity over a period of several days. (U)

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