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ANALYSES OF 1963 LORAD DETECTION TESTS IN THE HAWAIIAN AREA.(U)

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# ANALYSES OF 1963 LORAD DETECTION TESTS IN THE HAWAIIAN AREA.

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San Diego, California

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Semi-operational testing of the LORAD system was conducted in the Hawaiian Area from 29 April to 17 June 1963. These tests were designed to demonstrate the effectiveness of LORAD for ASW, with both conventional and high performance submarines as targets.

This paper will illustrate briefly the types of tests conducted and report some of the results obtained. The computer detection program used to perform the analysis reported here and which was also used as the on-line computer program during these tests will be discussed. The evolution of this program will also be described.

## Basic LORAD Philosophy

LORAD which is taken from the words Long Range Active Detection is a program to develop an active sonar system for the detection of submarines: in deep water at ranges to 100 miles, and shallow water at ranges to 30 miles. Ranges up to 100 miles are achieved through the use of convergence zone phenomena. (detailed discussion of this phenomena are given in the 1956 LORAD Summary Report - NEL No. 698). In shallow water, ranges to 30 miles are achieved by surface duct transmission.

The LORAD system utilizes a pseudo-random noise correlation scheme in which a deltic heterodyne correlator time compresses and correlates the incoming echoes with a stored reference of the transmitted noise sequence. (See Figure 1.)

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*Diagram of the 120° Lorad system*

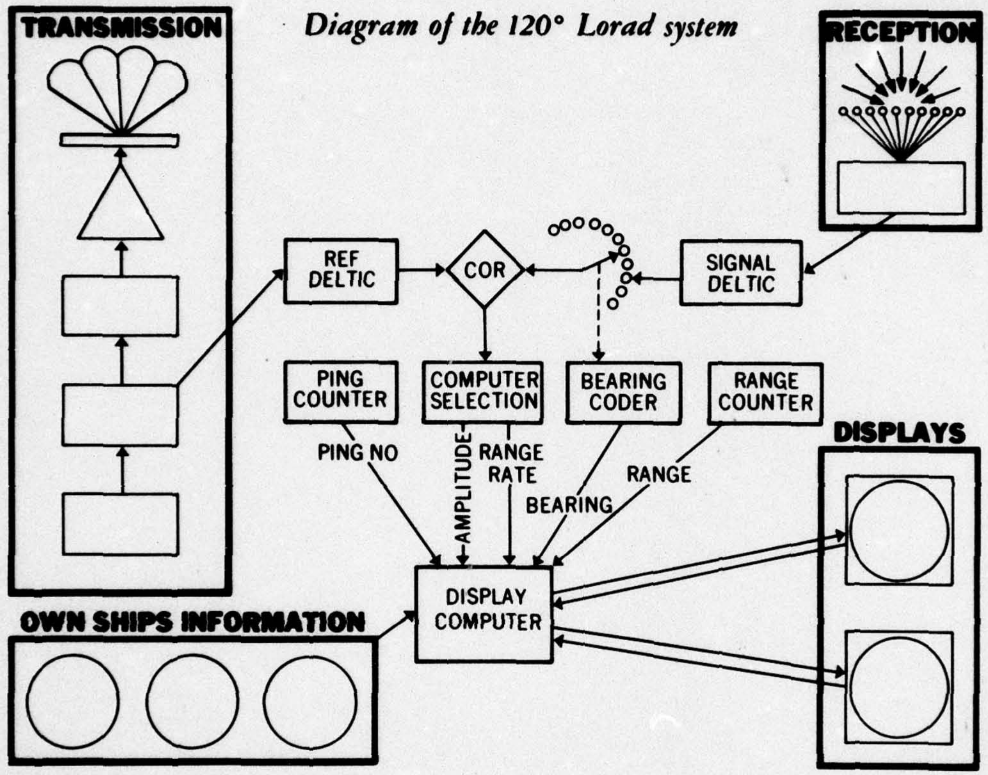

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FIG. 1. - Diagram of a 120° LORAD System

An AN/USQ-20 computer is used on-line for post detection analysis and it is this aspect of the system at which the major part of this paper is aimed.

The LORAD equipment is composed of modules each of which covers an azimuth angle of 120°. Thus a surface-ship LORAD employing a large transducer mounted deep beneath the ship's keel would employ three modules in order to get 360° coverage. A submarine with a bow-mounted transducer might employ two or perhaps only one module to get 240° or 120° coverage respectively.

A scaled version of an operational LORAD system has been installed aboard the USS BAYA (AGSS-318) for evaluation. This

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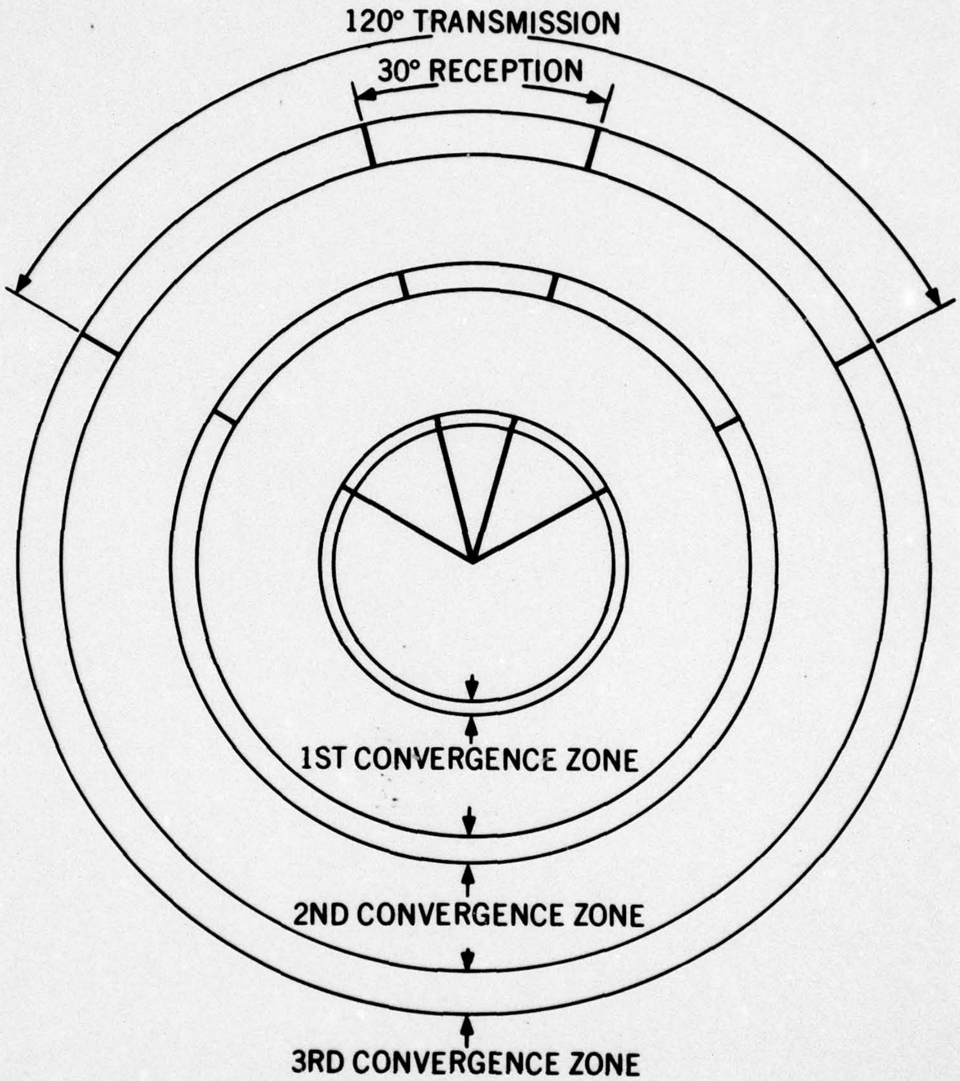


*Coverage of an Operational Lorad system*

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system provides all the functions of an operational system and consists of a single 120° transmission system. However, for economy reasons, only a portion of the signal processing equipment is implemented, providing for a 30 degree sector in bearing (See Figure 2).

FIG. 2. - The coverage of an operational LORAD system

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Therefore the BAYA is capable of ensonifying an area 120° in azimuth but signal processing is limited to only a 30° segment of the ensonified area. Presently the 30° sector used for LORAD studies is an area centered on the bow.

<u>Pre-processing</u>

The format of the data which the computer processes is shown in Figure 3.

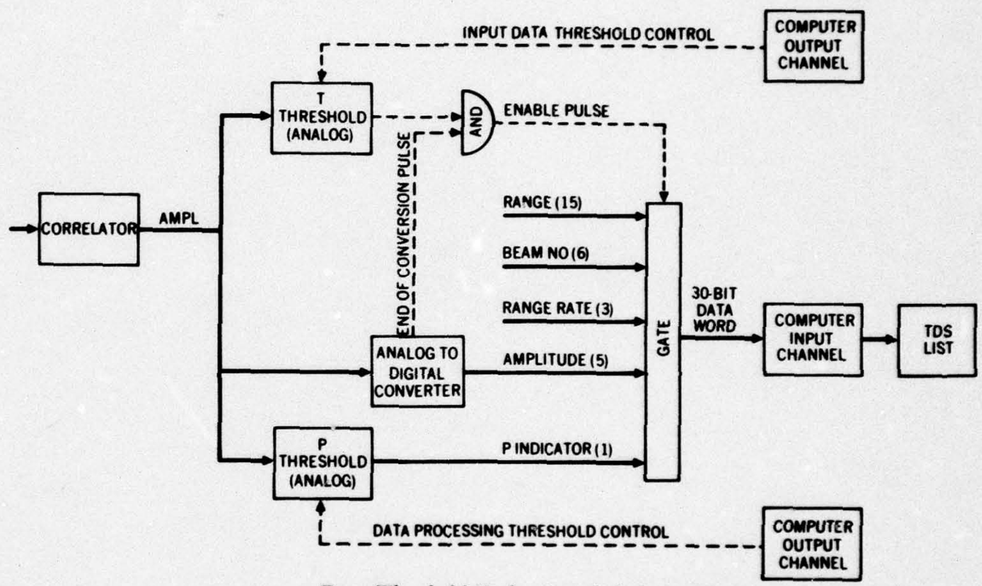
FIG. 3. - Format of LORAD data word

The first bit is an "indicator" bit which will be described later. The next five bits describe the amplitude of the correlation sample. The next three bits describe the range rate of the sample and the next six bits describe the bearing upon which the sample was taken. The last 15 bits represent the range of the sample determined by round-trip propagation time.

Figure 4 shows the threshold mechanism used to limit the data entering the computer.

FIG. 4. - Data threshold mechanism of the LORAD system

| | | | | | |
|---|---|---|---|---|---|
| BITS | 1 | 5 | 3 | 6 | 15 |
| DATA | IND | AMPL | $\dot{R}$ | BEARING | RANGE |




*Data Threshold Mechanism of the Lorad System*

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A correlation sample comes in to the analog-to-digital converter as a voltage, the amplitude of which depends upon the degree of correlation in the correlator. In addition to being converted into digital form by the converter, this voltage is also impressed upon the "T" threshold circuit. This threshold, which is adjusted by the computer to admit about 15,000 words per transmission, will only be exceeded by about two percent of the correlation samples. When exceeded, a control signal out of the threshold circuit and through a timing AND circuit will open the gate to let the data pass into the computer. These words are placed in a reserved section of the computer memory called the Temporary Data Storage (TDS) list. This list is also recorded on magnetic tape for later analysis in the laboratory.

In addition to the "T" threshold, another circuit known as the "P" threshold is shown. While it is identical in construction, the "P" threshold performs an entirely different function. "P" is normally set much higher than "T" so that only a small percentage of the words that get into the computer will also exceed the "P" threshold. When the "P" threshold is exceeded, its output sets the "indicator bit" of the data word to a "one". This is an indication to the computer to perform an analysis of this word and the words surrounding it in range and bearing. Again, the computer has a feedback path to the "P" threshold which keeps "P" adjusted to a point such that the computer does not detect more clusters than it has room to retain in a storage list for later history reference.



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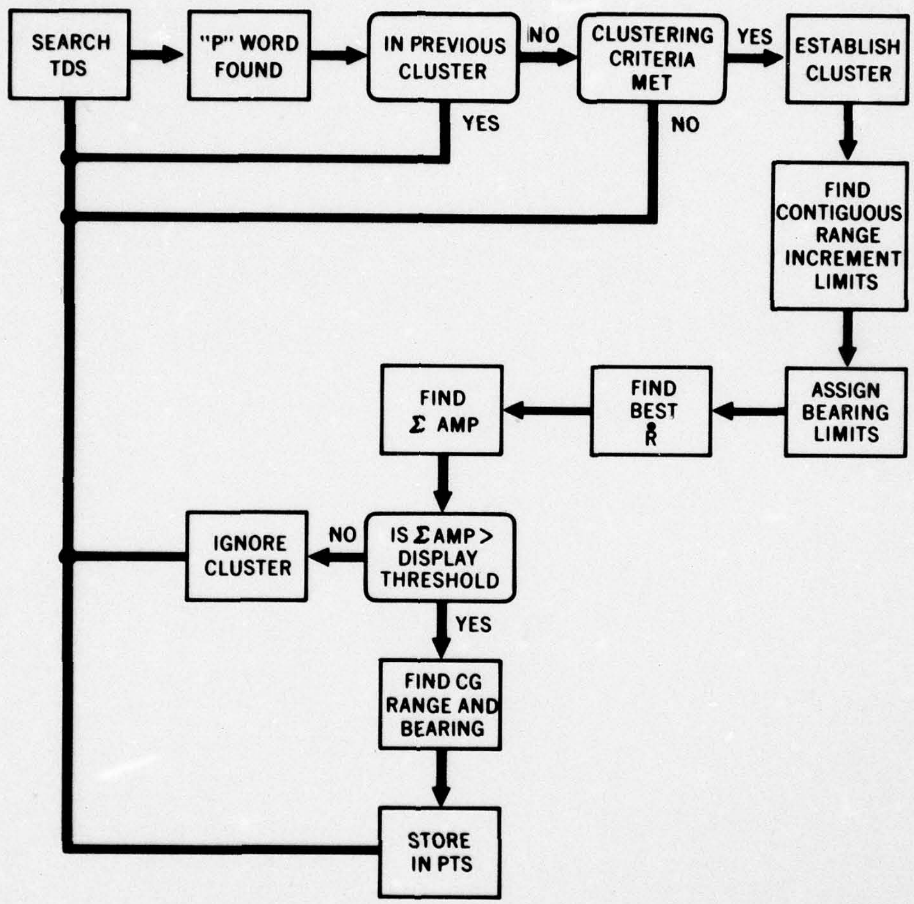
<u>Data Processing</u>

A simplified flow diagram of one of the LORAD processing programs is shown in Figure 5.

FIG. 5. - LORAD processing program

When a "P" word is found in the TDS list which is not in a previously formed cluster, a new cluster is formed whose range extent is fixed about the range of the flagging "P" word. The bearing extent of the cluster is the full $30^\circ$ of the system. The best range rate of the cluster is determined and then an amplitude sum of the words within the cluster having the best range rate is calculated If




***Lorad Processing Program Used in Hawaiian Tests***

this amplitude sum exceeds a display threshold, the center of gravity in range and bearing of the cluster is calculated and stored in the Probable Target Storage (PTS) list for display and tracking, then the search of TDS is resumed. If the display threshold is not exceeded the cluster is disregarded and the search of the TDS list is resumed. The display threshold is a means of controlling the total number of target and non-target clusters to be retained per ping for display and tracking purposes.

Data Analysis

In the laboratory, various computer processing programs such as discussed previously were used to analyze digital data which had been recorded during detection tests at sea. The data used were from a number of different sea trips and included targets of various aspects and echo sizes. A great deal of work was performed on these analysis results to confirm that all targets had been found or that certain targets had been found by one method but not by another.

Processing programs with little or no display thresholding were used in searching for clusters, and the information about these clusters was printed out on hard copy for further scrutinizing. These data were then searched for targets by referring to DRT plots made by the target boat during the tests, and to the log kept by the LORAD operating personnel on the BAYA corresponding to the particular data.

The majority of the targets were found very quickly with the use of the LORAD log and the targets DRT plot. Additional suspected small targets were found by hand tracking the previously found targets. Next, a plot was made on a high speed printer of each target and suspected target (See Figure 6).

FIG. 6. - High speed printer plot of typical target cluster

The figures at the bottom of the plot in Figure 6 refer to the 16-2$^\circ$ beams in the 30$^\circ$ signal processing equipment implemented on the BAYA. The figures on the left represent range in miles. The figures at the top are some data gathering aids such as the identifying ping number, frequency, etc. Each word in the cluster is represented by a number for the correlation amplitude of that sample and a figure for the range rate of the sample. Range rate codes are A, B and C for opening 6, 12 and 18 knots respectively; W, X, Y and Z represent 6, 12, 18 and 24 knots closing respectively. Where a correlation sample has no figure associated with it the range rate of the sample is zero.

A suspected target was assumed to be an actual target if it showed range and/or bearing clustering characteristics. The minimum clustering characteristic was arbitrarily set at two words, one or both having the "P" indicator set, on the same or adjacent range increments, having the same range rate, and within 2 beams of each other. A plot was also made of the predicted area in which a target cluster should have been, according to an analysis track, but was not detected. In some instances the target was found but had been overlooked, for some reason, by the detection program.



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22724A 100 1647*20 131.6 CG 32.849 MI 133.5

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32.873 | | | | | | | | | | | | | | | | |
| 32.871 | | | | | | | | | | | | | | | | |
| 32.869 | | | | | | | | | | | | | | | | |
| 32.867 | | | | | | | | | | | | | | | | |
| 32.865 | | | | | | | | | | | | | | | 9Y | |
| 32.863 | | | | | | | | | | | | | | | | |
| 32.861 | | 8X | | | | | | | | | | | | | | |
| 32.859 | | | | | | | | | | | | | | | | |
| 32.857 | | | | | | | | | 9A | | | | | | | |
| 32.855 | | | | | | | | | 8X | | | | | | | |
| 32.853 | | | | | | | | | 10X | | | | | | | |
| 32.851 | | | | | | | | | 8X | 8X | | | | 10X | 11X | |
| 32.849 | | | | | | | | | 15X | 13X | | | | | | |
| 32.847 | | | | | | | | | | 9X | | | | | | |
| 32.845 | | | | | | | | | | | | | | | | |
| 32.843 | | | | | | | | | | | | | | | | |
| 32.841 | | | | | | | | | | | | 8W | | | | |

The individual characteristics of each target were analyzed, especially those targets which were not detected by normal means. After analyzing these clusters, a detection program was written which would detect all of the targets analyzed and would also discriminate against a large percentage of the noise.

Data Processing Program Used in Hawaiian Tests

FIG. 7. - Data processing program used in Hawaiian tests

In the new detection program, Figure 7, the search of TDS is similar to the previous program. Here though, every "P" word does not initiate the formation of a cluster automatically. A test is made to determine that a cluster does actually exist and that the "P" word is not just a large amplitude noise word. This test simply checks those words in the vicinity of the "P" word in the list to see if the arbitrary minimum clustering criteria described above has been met. If this criteria is met, a cluster is formed. If not, the "P" word is ignored and the search of TDS



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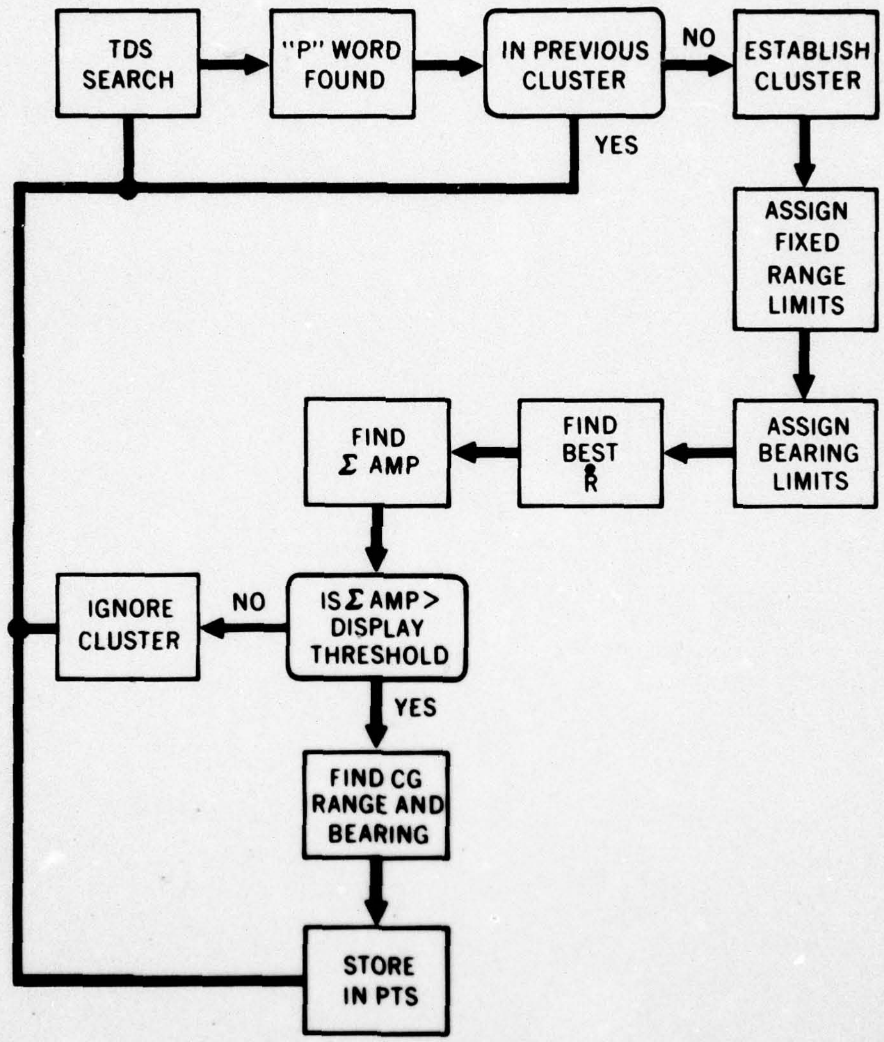



*Lorad Processing Program*

is resumed. This test eliminates the noise which is not cluster-like and it does so before a cluster is formed, rather than afterwards as was done in the previous detection programs. Because a majority of the "P" words which initiated the formation of a cluster in the previous detection programs are ignored, the average running time of the new program is some three times faster. (The memory space occupied by each is about the same).

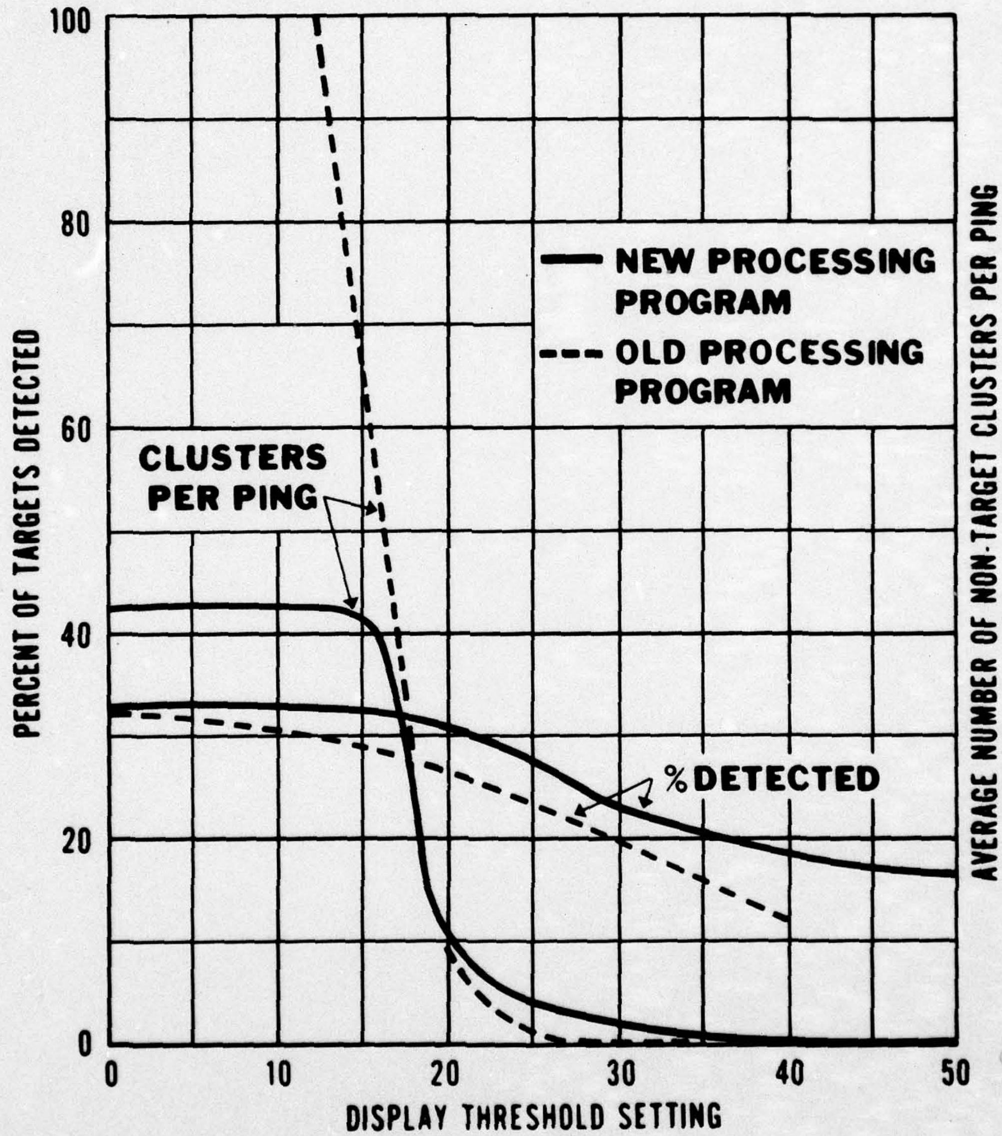
If a cluster is to be formed, its range and bearing limits are determined. The bearing limits are the full 30° of the system as in the previous program. However, the range limits are determined by the extent of contiguous range increments in each direction from the "P" word. The range extent of the cluster is determined by the cluster itself, rather than being a fixed length, thus reducing the possibility of influencing the target with noise and also eliminating the possibility of splitting large clusters. While noise may have no adverse effects on large clusters, it could certainly affect the range and/or bearing determination of a very small target cluster. On the other hand, small targets should not be affected by a fixed range extent limit, but a large target cluster may be split, initiating the formation of two clusters instead of one. These two clusters while being very close in range and bearing to the actual target, nevertheless usually differ from the actual location.

After the range and bearing limits of the cluster have been assigned, the best range rate of the cluster is determined and the amplitude sum of the words within the cluster on the best range rate is calculated. If this amplitude sum exceeds the display threshold, the center of gravity range and bearing of the cluster is calculated and stored in the PTS list, then the search of TDS is resumed. If the amplitude sum fails to exceed the display threshold, the cluster is ignored and the search of TDS is resumed.

A computer program was developed to compare this detection program and its predecessor, using some data recorded during the Hawaiian tests. The data used for this comparison were from an entire run with the USS SWORDFISH, which will be described later. The data corresponding to one TDS list were processed a number of times by the new detection program using various display thresholds. The number of clusters stored in the PTS list was counted and the running time of the detection program was measured for each threshold setting. An additional run was made at a low-display threshold setting and the information about each cluster was printed on hard copy for varification that the target had been found. This procedure was repeated using a total of 100 pings. A table was developed by the computer showing display threshold versus total number of clusters and the average processing time using that threshold.

The above procedure was then repeated using the older detection program. The number of actual targets was subtracted from the total number of clusters and an average number of non-target clusters (target-like noise clusters) per ping for a number of display threshold settings was calculated. The percent of targets detected (number of targets detected/number of targets potentially detectable) for the same display threshold settings was also calculated. The number of non-target clusters per ping and the percent of targets detected for each detection program was then plotted on a single graph as a function of display threshold setting. (See Figure 8).

FIG. 8. - Percent of Targets Detected versus Display Threshold Setting and Average Number of Non-Target Clusters/ Ping versus Display Threshold Setting



100
80
60
40
20
0
PERCENT OF TARGETS DETECTED
NEW PROCESSING PROGRAM
OLD PROCESSING PROGRAM
CLUSTERS PER PING
%DETECTED
0
10
20
30
40
50
DISPLAY THRESHOLD SETTING
AVERAGE NUMBER OF NON-TARGET CLUSTERS PER PING

The important thing to note is the relationships of the total number of clusters/ping to the percent of targets detected at the low threshold end of the curves. The curves for the old processing program show that the operating threshold for the system, using the 100 pings in the test, should be at least 17 to keep the average number of echoes/transmission at a tolerable rate. At this level we attained 28% detection. The curves for the new processing program show that the detection threshold can be reduced to zero and obtain an additional 5% detection while still maintaining a tolerable number of echoes/transmission. This new detection technique seems to lend itself very well to automatic tracking techniques which are now being investigated in the LORAD program.

In some recent detection tests in the laboratory, using the new detection program, the "P" indicator of the data words was completely ignored. This had little or no effect on the total number of clusters selected. However the total running time was about doubled. Therefore the necessity of the "P" indicator and "P" threshold circuitry are still evident, but for a different reason. The "P" indicator is no longer needed to limit the number of clusters to be stored in PTS, but it is needed to speed up the running time of the detection program.

Hawaiian Detection Tests

LORAD system tests were conducted in the Hawaiian area during the period from 29 April to 17 June 1963. The BAYA accompanied by the USS REXBURG (EPCER-855) departed from San Diego on 10 April 1963, after very tight loading schedules and calibration testing of a new LORAD projector. Delivery of this projector was late and forced the sailing date to be postponed from an earlier date of 4 March 1963. The services of two submarines, the USS BREAM and the USS BLUEGILL were lost because of the postponement. However, the services of the USS STERLET and USS SWORDFISH were acquired so that total operating time remained the same.

Echo-repeaters, which were designed and constructed at the U. S. Navy Electronics Laboratory, for use as artificial targets in the LORAD program, were carried aboard the REXBURG. Each echo-repeater consisting of a buoy, a hydrophone, an amplifier and a transmitter simply amplifies and retransmits the LORAD signal as picked up through its hydrophone. The equivalent target strength of the amplifier can be adjusted to represent targets of various aspects.

During the transit to Pearl Harbor four detection tests were conducted, in separate areas, with an echo-repeater. The first area was approximately 700 miles due west of San Diego. The three succeeding areas were spaced at about 500 mile intervals to Pearl Harbor. Each area was selected for having a uniform depth



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to support convergence zone echo ranging tests. The north/south variance between stations provided different oceanographic conditions for each station.

The purpose of these tests was to thoroughly shake down the LORAD system in preparation for later tests in Hawaiian waters. Echo ranging was conducted at the first, second and third convergence zones. Results were good in the first and second zones but meager in the third zone attempt. Some breakdowns occurred in the transistorized power amplifiers and inductor switching mechanism for the new projector installed prior to sailing. However, by isolating the faulty sections of the transducer and making whatever repairs possible at sea, the system was kept operating at all stations. LORADAC, the communications portion of the system, was very satisfactory. Messages were transmitted by the BAYA's outgoing pings. A large proportion of these messages were received and interpreted by the receiving equipment aboard the REXBURG in spite of heavy sea conditions which made quiet listening difficult.

Week of 29 April, USS BARBEL (SS-580)

The first operating week with a submarine target in the Hawaiian area was with the USS BARBEL (SS-580). This week's operation was the first time that the LORAD system had been used with a high performance submarine as a target. While the BARBEL is a diesel powered submarine, its ALBACORE type hull makes its performance capabilities almost equal to the latest type nuclear boat. The main objective of this week's operation was to determine the LORAD system's detection capabilities with a high performance target.

In spite of equipment problems with the signal processing equipment on the BAYA, and lack of station keeping on the BARBEL to obtain accurate initial positioning for the start of the events, much valuable data was obtained. Because of the above mentioned problems, the tests were all conducted at first convergence zone ranges.

Echoes showing opening and closing range rates up to 10 knots were seen. Also the target made runs at various depths between 600 feet and periscope depths which were detected and tracked successfully by the BAYA. LORADAC messages were transmitted and successfully received. Results for this week in the first zone, during the period when the equipment was operating properly were: 45 beam aspect echoes from 136 transmissions (33% detection); 24 bow aspect echoes from 81 transmissions (29% detection).

These and subsequent figures are a result of laboratory analysis. However, very few targets were found in the analysis which were not confirmed during sea tests.



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Week of 6 May, USS PICKEREL (SS-524)

The next week of operation was conducted with the USS PICKEREL (SS-524) as a target. The primary purpose of operations was to attempt target intercept by aircraft where the only information concerning the target location was transmitted by LORADAC. The P2V aircraft arrived on station at 1000 each day and secured the same day at 1600 for three consecutive days. The tests consisted in general, of the BAYA being submerged on station, echo ranging on the PICKEREL. The PICKEREL was conducting either programmed or unalerted runs. The runs were planned so that the target would present bow, stern, and quarter aspects and provide different range rates. The REXBURG stood by near the BAYA's position to act as a point of reference for the aircraft. When the BAYA obtained echoes from the PICKEREL, a digitally coded message was included in the next transmission containing range and bearing information. The aircraft, upon arrival in the area, dropped a sonobuoy near the REXBURG and monitored the BAYA's signal. When the aircraft received the information about target location via LORADAC, it then proceeded to the target area based on this information. Upon arrival at the suspect area, the aircraft dropped a flare and a PDC (Practice Depth Charge). When the PICKEREL heard the explosion it surfaced to reveal its location. Runs were made with the target submarine operating in the first convergence zone as well as the 10-20 miles range area from the BAYA. These tests proved quite successful. There were two localizations within about two miles of PICKEREL and one localization within a few yards of PICKEREL. Other localizations were considerably off target. However, it was demonstrated that this type of communication is feasible despite the large amount of error that could have existed in these tests. If the BAYA and the aircraft had been equipped with SINS, the problem would have been simpler and results much more accurate. During the operating time when the aircraft was not on station, echo ranging exercises, similar to the preceding week's runs, were conducted.

Results for this week, from surface duct and first zone tests, were 126 beam aspect targets from 192 transmissions (66% detection); 16 bow aspect targets from 33 transmissions (48% detection) and 55 stern aspect targets from 168 transmissions (31% detection).

Week of 13 May, USS CARBONERO (SS-337)

The vulnerability of the high power sonar signal on the BAYA to enemy localization was the subject of the week's operation with the USS CARBONERO (SS-337). After initial positioning, BAYA, simulating an area sweep operation, was to start echo-ranging for a period of three to five hours, at which time CARBONERO would try to localize BAYA's source. At the end of this period BAYA was to surface for eight to twelve hours for transit to another area and



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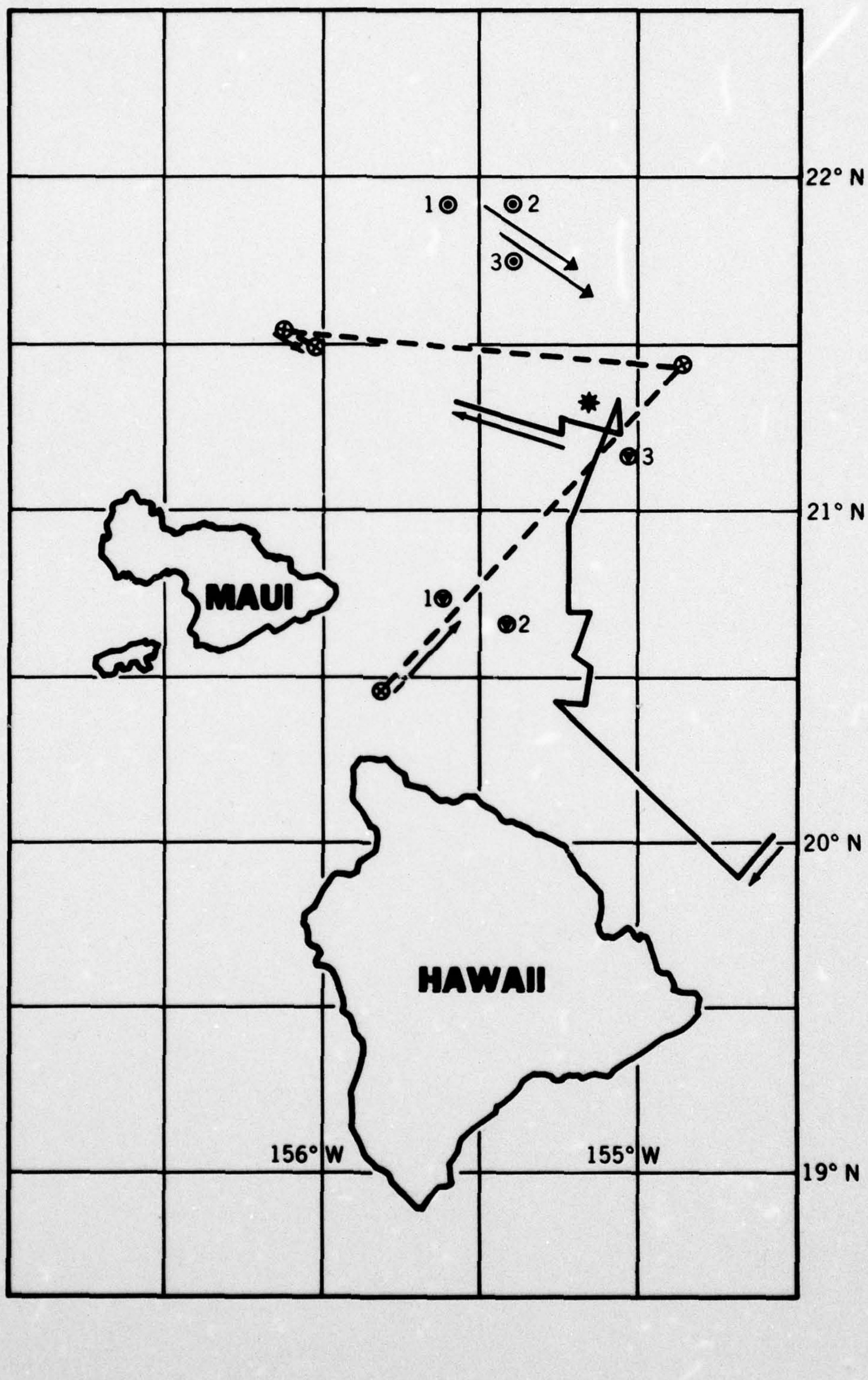
begin another sweep operation. This would continue until CARBONERO found BAYA and contacted BAYA on UQC to terminate the event. CARBONERO could submerge or surface and was restricted to ten knots maximum speed.

A P2V aircraft was to arrive in the area at a scheduled time when BAYA was submerged and independently attempt to establish the location of BAYA using sonobuoys or other means. Aircraft intercept of BAYA was to be signaled by dropping three PDC's at one to two second intervals. BAYA would then acknowledge by firing a flare.

FIG. 9. - Plot of vulnerability run with USS CARBONERO and P2V aircraft



22° N
21° N
20° N
19° N
156° W
155° W
MAUI
HAWAII
1
2
3
1
2
3

In Figure 9 dashed lines connect the three positions of BAYA. Numbered triangles refer to the corresponding three positions of the echo-repeater. The three dots near the second position of BAYA indicate the sonobuoy pattern dropped by the P2V when BAYA was at its second position. The star (splash) indicates area of P2V attack. The solid line indicates the maneuvering of the CARBONERO.

The initial range to the CARBONERO from the BAYA was about 80 miles. (See Figure 9). The CARBONERO, as seen on the plot, obtained a bearing on the BAYA's signal and commenced a closing run. An area was chosen for the BAYA to begin its schedule in which the path between BAYA and CARBONERO was bottom limited because of shallow water (about 400 fathoms) in an attempt to confuse the CARBONERO by using the echo repeater. This attempt seems to have succeeded from a look at the plot. Shortly after the closing run was started the BAYA surfaced and commenced its run to the new position.

The CARBONERO obtained a new fix when the BAYA commenced its second transmission schedule, and started a new closing run. The plot of CARBONERO's course shows frequent changes to try to establish a base line for a range fix. On this run CARBONERO did not approach BAYA closer than about 50 miles.

CARBONERO obtained more accurate bearing fixes during the third BAYA transmission schedule. In spite of this, CARBONERO was not able to get closer than about 35 miles before the end of the event. NEL observers aboard the CARBONERO, reported that while bearing determination, though broad, was not difficult, the estimate of range <u>was</u> difficult to achieve.

The aircraft dropped several patterns of sonobuoys and made two attacks on the suspected position of the BAYA but had made errors in interpreting the signals from their sonobuoys and were off by about 15 miles. It is assumed that with practice the aircraft would have had little difficulty in localizing BAYA's source.

<u>Week of 3 June, USS STERLET (SS-392)</u>

The objective for this week was to test LORAD's ability to locate and track a target submarine in shallow water and in ocean areas that are bottom limited for convergence zone detection. The USS STERLET (SS-392) served as a target.

The first event was conducted in the shallow waters of Penguin Bank located west of Molokai Island. This area, about twenty-five miles long and twelve miles wide, is quite flat and has an average depth of about 200 feet. With the BAYA hovering at 90 feet keel depth at the north eastern end of the bank, the STERLET made an opening run at periscope depth. The run was programmed so that the target would present alternately beam and stern aspect.



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STERLET was tracked from six to twelve miles at about 50% detection before it was lost.

The other events of the week's operations were conducted in an area about 50 miles south of Pearl Harbor. Here the maximum depth is about 2500 fathoms which is the predicted minimum depth to allow convergence zone echo ranging in the Hawaiian area. The tests were conducted with the target making runs between ranges of about five and thirty-five miles. In one run the STERLET was tracked at 43% detection from eight miles to 13.5 miles before it was lost. In a similar run efforts were made to obtain bottom bounce echoes off the target by tilting the transducer. This was done at times when the echoes were coming in strongly via the surface channel. Invariably the echoes would disappear when the transducer was tilted.

An event was conducted to examine a target's capability for concealment by moving into a bottom limiting area. The STERLET took initial station at thirty-four miles from BAYA's position in water deep enough for zonal detection. Maintaining approximately the same range, STERLET made a run which took her into bottom limiting waters. (See Figure 10.)

FIG. 10. - Convergence zone bottom limiting tests

STERLET was tracked solidly for a period of thirty minutes and then it disappeared when it apparently entered the shallower water.


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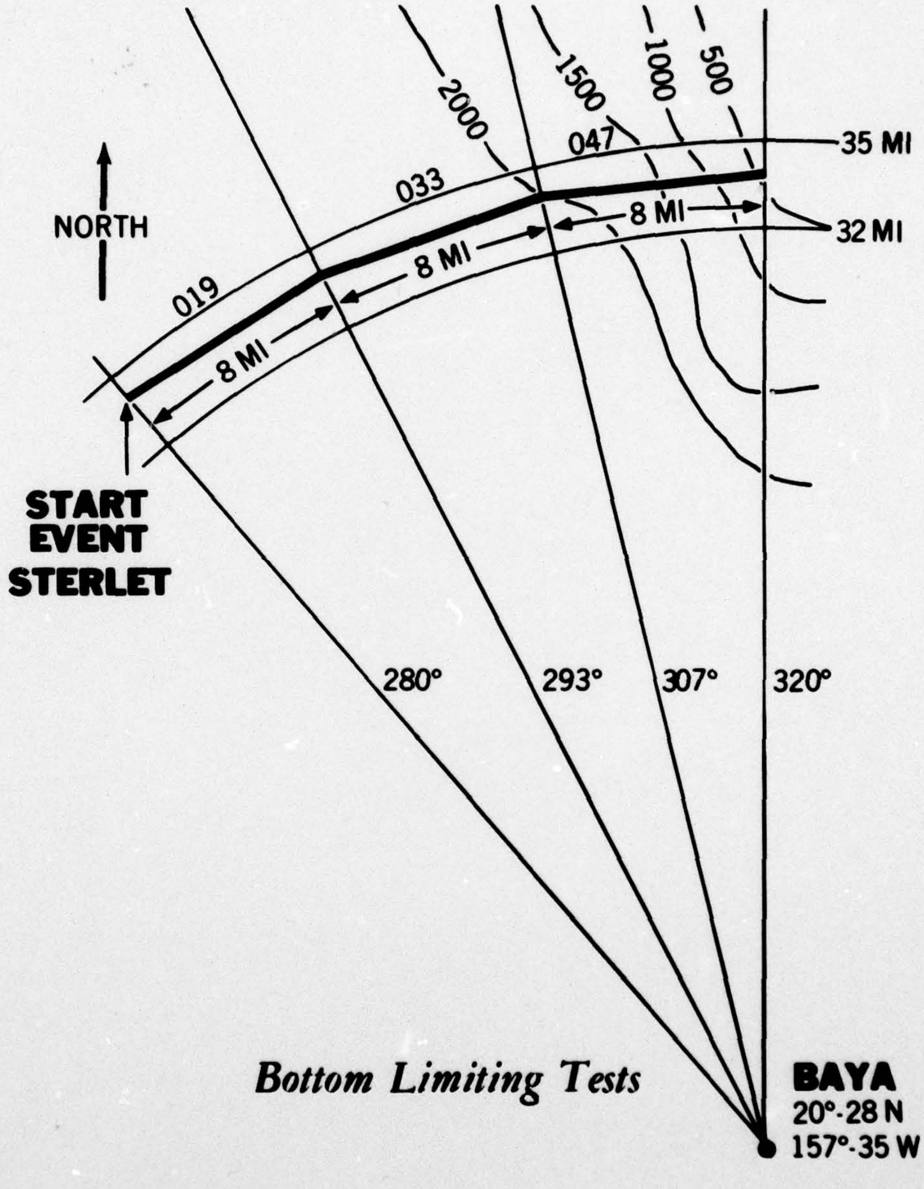


*Bottom Limiting Tests*

Week of 10 June, USS SWORDFISH (SSN-579)

This week of tests consisted of echo ranging on a high performance target in deep water. The tests were conducted in 3000 fathom water depths east of Maui Island. The events included: programmed runs between five to thirty-five mile ranges from BAYA; programmed runs in the first and second zones; and an unalerted run in the first zone. Results were better this week than for any of the previous weeks in the series of operations. Echoes were obtained during all the events attempted. An unalerted run was conducted in an area ten miles wide and six miles deep, whose center was located at the approximate center of the convergence zone from the BAYA. The SWORDFISH was unrestricted as to course, speed and depth provided it stayed within the area specified. The DRT plot of the SWORDFISH is shown in Figure 11. The arrows represent echoes received from the SWORDFISH.

FIG. 11. - DRT plot and track constructed from LORAD data of USS SWORDFISH unalerted run

The data recorded during this entire unalerted run was the data used in the program comparison analysis mentioned previously.

The overall results for this week were: from surface duct and first zone tests, 123 beam echoes from 228 transmissions (54% detection); 17 stern echoes from 48 transmissions (35% detection), 45 bow echoes from 90 transmissions (50% detection); from second zone tests, 24 beam echoes from 54 transmissions (45% detection), 11 bow echoes from 27 transmissions (41% detection).



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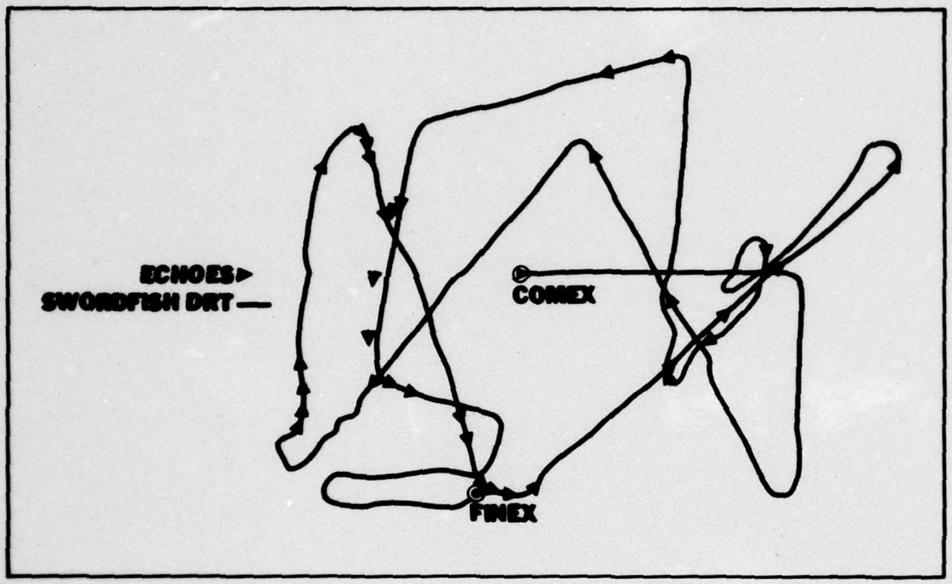
ECHOES
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This week's operation concluded the LORAD testing in the Hawaiian area.

The BAYA returned to NEL on 25 June, where the signal processing equipment was offloaded and assembled in a laboratory area for further testing and data analysis purposes. At the present time BAYA is in the San Francisco Naval Shipyard in preparation for further testing in the central and western Pacific waters during 1964.

Summary of Results

During the Hawaiian tests submarine echoes were received at sub-zonal, first and second zones at range rates from eighteen knots opening to twenty-four knots closing.

It was demonstrated that BAYA, while submerged, could vector an aircraft via LORADAC, to intercept a submerged target at a range of thirty-three miles, the maximum range attempted.

During a thirty-five hour source vulnerability test, the conventional submarine CARBONERO did not approach closer than thirty-five miles of BAYA's position. The P2V aircraft was unable to achieve a good localization.

Detection of a submarine target in shallow water was found to be feasible. Echoes were received in a 200 foot water depth between ranges of 6.8 and 11.5 miles.

Many useful data were gathered during the tests which permits an evaluation of propagation loss versus detection; reverberation levels versus detection capability; and the use of propagation loss examination to determine zonal boundaries.

The results of the Hawaiian tests are described in much more detail in a yet to be published NEL report entitled LORAD Limited Operational Tests.[3]

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