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THE LORELI TECHNIQUE

[UNCLASSIFIED TITLE]

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ABSTRACT

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This report is a summary of all the work done to date on the Loreli technique. This tehchique was developed to produce highly accurate, acoustic-attack information from long-range sonars. The philosophy of Loreli is to establish an attack reference point near the target by means of an acoustic transponder, or Posit buoy, thus eliminating most of the errors which are inherent in equipment or are caused by the peculiar acoustic properties of the water medium. All data collected to date on antisubmarine attacks, both live and simulated, are presented. It now appears possible to approach a total attack error of as little as 200 yards at 20,000 yards, or 10 mils, with very simple equipment. Applications and continuing NRL work are discussed.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem 55S05-14
Project SF 001-03-03, Task 8137
BUSHIPS No. 1796

Manuscript submitted April 17, 1961.

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THE LORELI TECHNIQUE
[Unclassified Title]

INTRODUCTION

In February 1955 work was started under Bureau of Ships sponsorship to provide high-quality acoustic information for fire-control purposes at long ranges. These ranges already had been experimentally demonstrated by existing equipments and were expected to become characteristic of future equipments. After examining many possible approaches, it was decided to use the idea of placing an acoustic transponder in the vicinity of the target. This transponder would then be used as a reference point from which to pinpoint the target.

A transponder is a simple acoustic device which, upon receipt of a sonar pulse, immediately transmits an acoustic pulse of its own. This pulse is received by the sonar and indicates the position of the transponder on the sonar display. A vector can then be read from the transponder to the target and used to correct a fire-control system for a missile shot, or to direct a weapon carrier from the transponder to the target. This is analogous to the method used in naval gunnery where one shot is fired, the error or "miss distance" noted, a correction made, and another shot or salvo fired to hit.

In this approach the equipment requirements are considerably relaxed, and indeed much equipment is eliminated entirely, as will be seen later on in this report. There is no longer a requirement for high absolute accuracy or long-term stability in the series of components that make up the attack system. Instead, the requirement is for a reasonable resolving power of the sonar equipment, short-term stability only, and a low dispersion in any long-range missile that might be used. What happens is that the errors are essentially subtracted out. The range and bearing errors to both the transponder and the target are about the same, whatever they may be, so that the vector from the transponder to the target is accurate. This, of course, is also true of the unknown errors of acoustic medium produced by such things as horizontal thermal gradients or the bottom bounce path over unknown oceanographic topography.

A great many errors must be considered if a rigorous examination of ASW fire-control problems is made. Some of these are: sonar-equipment alignment errors, read-out errors, target-tracking and prediction errors, errors due to dead time, attack-vehicle or missile-control errors, the acoustic-medium error already discussed, and the temporal variance of all these errors. Because of the complexity of this problem and, more important, because of the lack of sufficient numerical information about some of these errors, it was decided to take a direct experimental approach and measure the sum total of all the errors. Two kinds of data have been collected: (a) from the Loreli attack simulator, and (b) from actual field trials using presently available sonar and weapon-delivery methods.

EXPERIMENTAL WORK

Since the key to the Loreli philosophy appeared to lie in sufficient resolving power, measurements were conducted on several occasions using two transponders as targets. By varying the transponder spacing, the resolution of various equipments and displays could be measured.

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In August 1955 a sector scan receiver was built and installed on the NRL 5-kc/s long-range, experimental sonar. This receiver scanned the sound beam, producing a television-like raster presentation of what was in the beam. Figure 1 is an example of the results. Then, because actual attack runs would first have to be conducted with an AN/SQS-4 sonar, the resolution experiments were repeated at shorter ranges with an AN/SQS-4 sonar and NRL display equipment. It was found that a target spacing of about 50 yards could be resolved at 10,000 yards. This is a resolving power of 5 parts in a thousand, or 5 mils. Figure 2 shows the sonar display for other values of range and target spacing. Subsequent tests showed that the convential difference-brightening display of the AN/SQS-4, properly aligned, had about one-half this resolving power, or 10 mils, and would be satisfactory. Figure 3 shows an AN/SQS-23 display. The resolving power of this equipment is about 8 mils. From an inspection of Figs. 1 through 3, one may determine the vector from one echo to the other. At the longer ranges, a submarine looks very much like a transponder except when it is moving fast enough to produce a wake.

Fig. 1- Example of resolution tests using a sector scan receiver installed on the NRL 5-kc/s long-range experimental sonar. In this test two transponders 80 yds apart were resolved at 18,500 yds.

Resolving power is only one factor affecting the accuracy of vectoring, and since a vector is taken from the center of one echo to the center of the other, the accuracy is better than might be thought from a consideration of the resolving power alone.

At the time that the resolution experiments were being conducted, a dynamic attack simulator was developed and built to study the problem with simulated long-range sonar and high-speed submarines. This simulator, which is still in use, generated a real time plot of a Loreli attack, with appropriate sonar time delays for the Loreli operator. Helicopters, hydrofoil boats, and fixed-wing aircraft have been simulated as attack vehicles against a variety of submarines operating at ranges out to the first convergence zone. Most targets have been fully evasive, and in many of the runs the submarine "skippers" also have been allowed to watch the attack as it was generated and to hear the commands the Loreli operator gave to the attacking vehicle.

The advantage of a short dead time for weapon delivery was domonstrated in the simulator runs. In the Loreli-helicopter case, the total dead time consists of: (time for sound to travel from the submarine to sonar) + (time to read and report latest vector) + (time between last vector report and weapon drop). Since the attacker is under continuous control, this last term can be quite small. However, as long as sonars are used, there is not much that can be done about the first term which, in a well-run, long-range attack, is the largest component of dead time. During the simulator runs it was discovered that when the speed of the attacker was more than 2.5 times that of the target, evasion became futile. Things happened so fast that the target appeared to be stationary.

Another interesting and very important fact that was demonstrated in the simulator work, and later in the field, was that there is no training requirement to produce Loreli operators. Naval officers and some types of enlisted men already have sufficient

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SPACING 700 YDS AVERAGE RANGE 2000 YDS | SPACING 100 YDS RANGE 6000 YDS | SPACING 150 YDS RANGE 8500 YDS

Fig. 2 - Resolution test using an AN/SQS-4 sonar and NRL display equipment. Transponder spacings and sonar-transponder ranges are as shown.

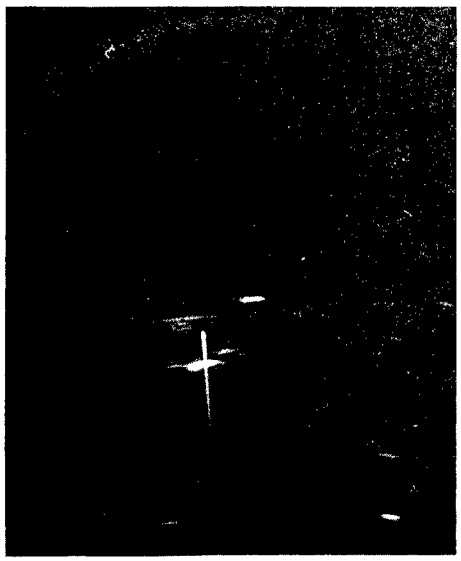

Fig. 3 - AN-SQS-23 TCD conventional difference-brightening display for transponder spacings of 600 yds at 8000-yd range

knowledge of vectoring techniques and do very well after only brief familiarization. Apparently there is no "learning curve." In fact, naval officers consistently outperformed the NRL scientists on the simulator.

Most of the time when vectoring, the operator has only to aim at the last target echo. Occasionally there is a need to lead the target to compensate for sonar time delay and target motion. This can be explained by pointing out that when the next echo of a series is received, the target is already further ahead along its track, by about one-half the spacing between the last two echos. Any person who has fired a gun at a moving target has a feel for "leading" the target.

The main difficulty in the conduct of the Loreli work has lain in collecting scientifically and operationally valid data. One problem that arose was the precise measurement of the miss distance when a simulated weapon is dropped on a maneuvering submarine. A distance-measuring-equipment (DME) buoy had to be developed to do this (1). Some experimental work was done vectoring the XCH-4 hydrofoil boat to a stationary target. However, it soon became apparent that the best presently available vehicle for collecting data was the helicopter, vectored by a surface ship, carrying a droppable transponder. This transponder also had to be developed.

Figures 4 and 5 show the entire attack equipment used for the Loreli-Helicopter experiments. It consists simply of the droppable transponder (Fig. 4), called a Posit buoy, and an elementary overlay (Fig. 5) for the sonar scope for reading the vector from the Posit buoy reference point to the submarine target.

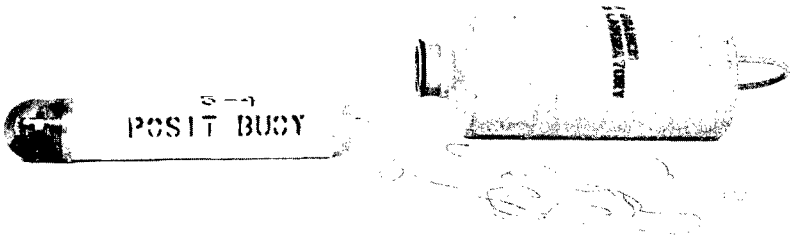

Fig. 4 - The Posit buoy, a droppable transponder

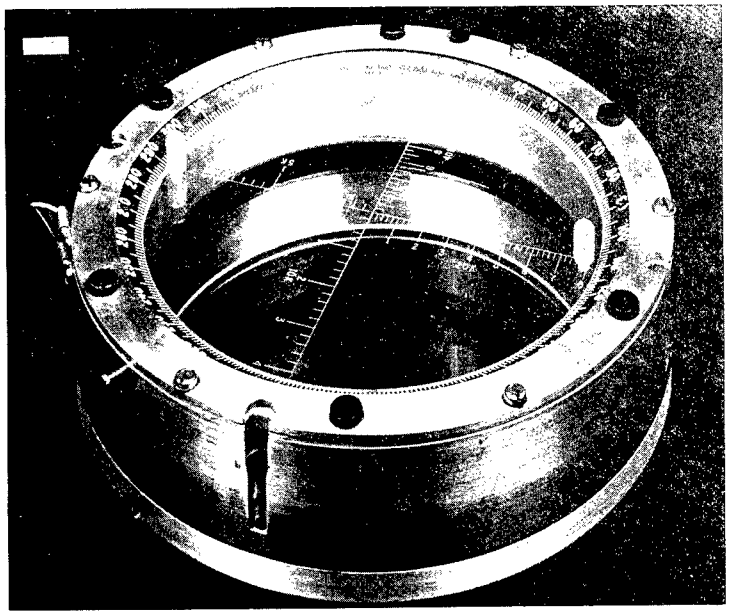

Fig. 5 - An overlay for the sonar scope, used to read the Posit buoy-target vector

The Posit buoy separates into two sections when it hits the water. The larger section is the float, which could contain lights and a radar transponder. It serves as a visual reference for the helicopter. The smaller section, which separates and sinks to a predetermined depth, is the transistorized acoustic transponder. The attack sequence is shown in Fig. 6. However, for data collection purposes, instead of dropping a live torpedo as shown, a DME buoy was used. This buoy is physically identical and electronically similar to the Posit buoy. It is interrogated by a modified recording fathometer on the submarine and the overall attack miss distances are recorded. The conventional Navy attack-assessment procedures also were carried out.

Since the object of the experiment was to get in as many runs as possible, certain restrictions were put on the field exercises. The submarine was restricted in depth in order to maintain the longest possible sonar contact range. At the start of the exercise,

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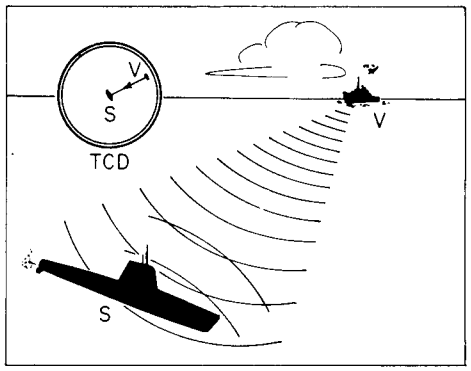
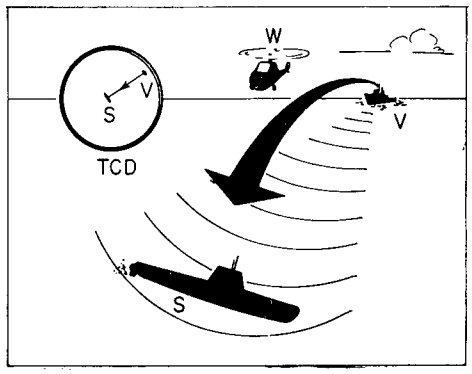
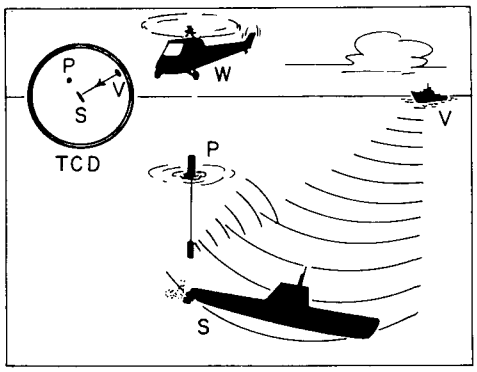


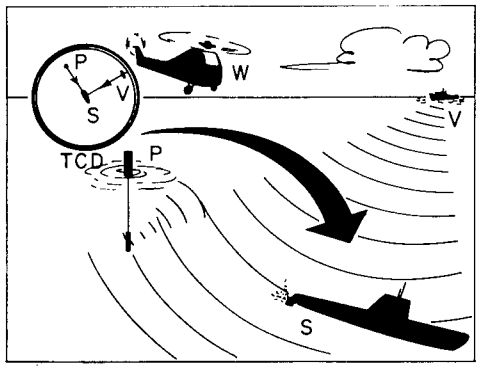
(a) Sonar contact on submarine S is made at long range (10 to 20 kyds) by detection vehicle V



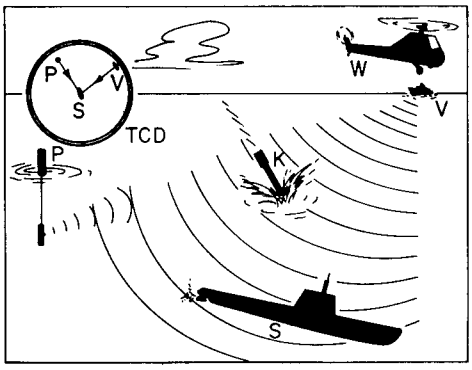
(b) Weapon carrier W is dispatched to vicinity of contact on vector range and bearing obtained from sonar display TCD



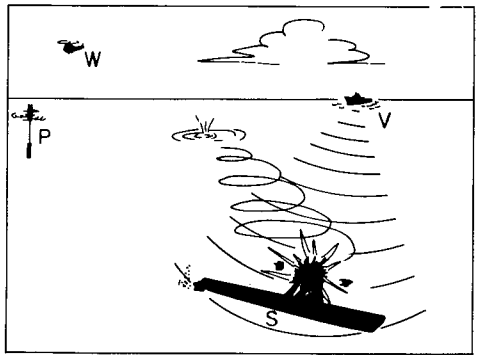
(c) Weapon carrier W reaches target area and drops transponder (Posit buoy) P



(d) Weapon carrier W circles over area, awaiting second vector from detection vehicle V obtained from sonar display TCD (vector P-S)



(e) Weapon carrier W flies vector P-S and drops weapon K



(f) Weapon carrier W circles over area to receive further instructions; if none required, returns to base

Fig. 6 - Attack sequence using the Posit buoy and helicopter

the submarine would proceed at maximum contact range at 3 to 6 knots. As the helicopter flew by and dropped the Posit buoy, the submarine would begin to take full azimuthal evasive action. When the DME buoy was dropped, the submarine reverted to the original conditions while an assessment of the miss distance was made. These actions simulated the situation of a submarine trying to sneak through a screen and only evading when under attack.

RESULTS

Figure 7 is a summary plot of all of the Loreli data collected to data, both on the attack simulator and in field experiments. Median miss distances are plotted against a logarithmic scale of the spread of sonar ranges to the target. Also shown are the 40-, 20-, 10-, and 5-mil error curves for a ready comparison of the results in those terms. Each set of data, or experiment, has been numbered and may be identified in Table 1, in which are summarized the kinds of run and vehicles used. Of most immediate interest are the field data obtained with surface ships and helicopters. These are described in detail in the following paragraphs.

Table 1
Loreli Data Summary Brief (See Fig. 7 for Plot of These Data)

Run Number	Kind of Run and Vehicles Used	Median Miss (yds)
1F	USS SARSFIELD with SQS-4 sonar. USS AMBERJACK evading helicopter-Posit.	135
2F	XCH-4 Hydrofoil Boat towing transponder at 45 knots. Stationary target.	93
3F	12-knot towed transponder. Stationary target.	80
4F*	Data from 1F beyond 2500-yard range.	70
5F	Helicopter-Posit. Stationary target.	39
6F*	USS NORFOLK with SQS-23 sonar. USS CHOPPER and USS BLENNY evading helicopter Posit.	230
7F*	USS BARRY with SQS-23 sonar. USS THREADFIN evading helicopter-Posit.	200
8S	PCH towing transponder at 45 knots against USS SKIPJACK (simulated).	150
9S	60-knot towed transponder against 17.5-knot evasive guppy (simulated). Also assumed noise blanking above 30 knots.	130
10	DASH/Loreli derived from NUOS report (Ref. 2).	100
11S	20 kyd helicopter-Posit. USS ALBACORE (simulated).	285
12S	1st Convergence Zone. 600-knot A/C vectored from ASW ship on contact. Drops Posit. Then vectored at 120 knots. Sub zig-zags through zone at 25 knots (simulated).	500
13S	Same as 12S with straight-running, 25-knot target.	175

*Further comment in text.
Note: F = field data, S = simulated data.

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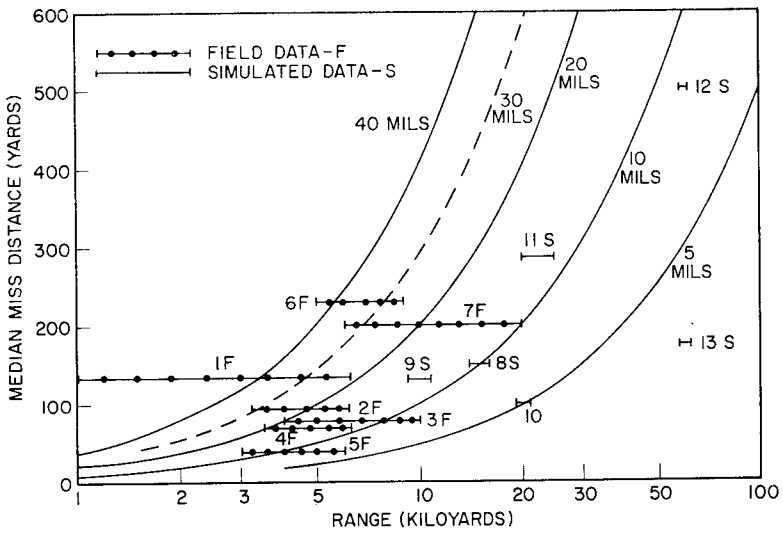

Fig. 7 - Summary plot of all Loreli data collected to March 1961 (from attack simulator and field experiments). The dashed line on the figure is 30 mils and represents the generally accepted requirement for the location accuracy of surface-ship sonar.

AN/SQS-4 Test with the USS SARSFIELD

Field tests of the Loreli attack technique with the 14-kc/s AN/SQS-4 were conducted in the Key West area during June 1958. The USS SARSFIELD was used as the echo-ranging ship, the USS AMBERJACK as the target, and HSS-1 helicopters as Posit buoy carriers and attack vehicles. All attack runs were conducted by personnel of the USS SARSFIELD with NRL personnel acting as advisors and observers.

During this period, sonar conditions were generally poor, which limited the sonar ranges to less than 2500 yards about 80% of the time and to less than 1500 yards about 50% of the time. Ranges up to 6300 yards were obtained for a period of about two hours.

A total of 32 successful attack runs were conducted, using the procedures outlined above, at sonar ranges varying between 950 and 6300 yards. A median miss distance of 135 yards was obtained for this series of runs (Fig 8). A miss-distance curve for the seven successful runs over 2500-yard ranges is shown in Fig. 9. It shows a miss distance of 70 yards. This improvement of miss distance with range can be expected since at short ranges the Posit buoy return is masked by reverberation. Since the transponder is a constant-power-level device, the reverberation level increases as the range is shortened.

In these tests it was observed that the personnel training problem was practically nonexistent for this attack technique. Personnel familiar with sonar operations were taught the vectoring technique in a few minutes, and helicopter pilots required only a short briefing for their part in the attack.

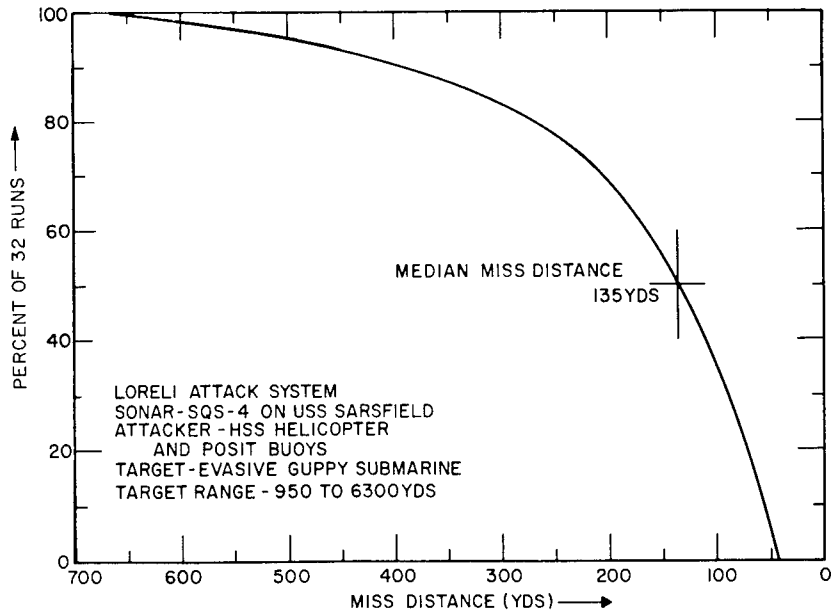

Fig. 8 - The percentage of total successful runs at which the miss distance was no greater than the value shown. For 50% of all the runs the miss distance did not exceed 135 yds.

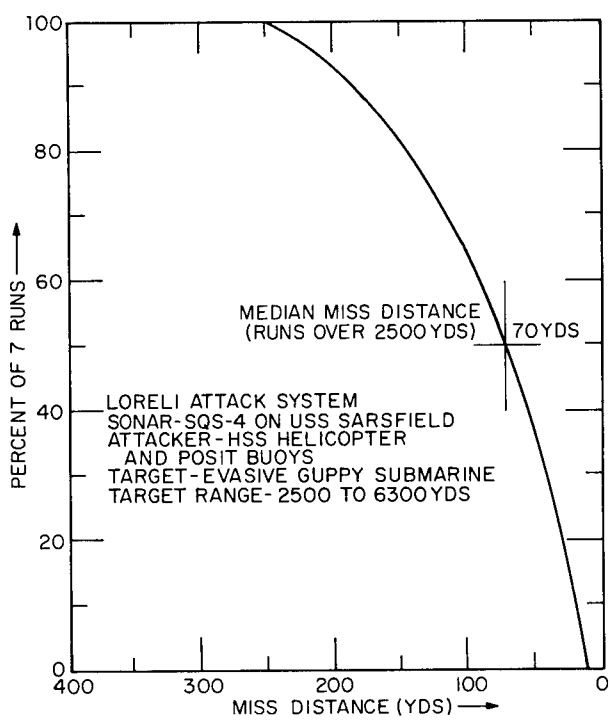

Fig. 9 - The percentage of the seven successful runs over 2500 yds at which the miss distance was no greater than the value shown. For 50% of all these runs the miss distance did not exceed 70 yds. (These data are part of those shown in Fig. 8 and point out the increase in system capability with increased target distances.)

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AN/SQS-23 Test with the USS NORFOLK

A short test period of three operating days (11 through 13 July 1960) was made available to NRL to conduct tests of the Loreli technique at medium sonar ranges with the AN/SQS-23 sonar. The USS NORFOLK was used as the echo-ranging ship, the USS CHOPPER and USS BLENNY as targets, and HSS-1 helicopters as the Posit buoy carriers and attackers.

During this period 21 successful attack runs were conducted at sonar ranges of between 5000 and 9000 yards. From the data plotted in Fig. 10 for these runs, a median miss distance of 230 yards was obtained. However, this miss distance does not accurately represent the ability of the Loreli technique because of communication difficulties encountered during the tests. It was not possible to have direct radio communication with the helicopter from the sonar display. All vectors had to be relayed through four talkers, causing long delays and many inaccuracies. It was also impossible to give vector corrections to the pilot in time to be effective.

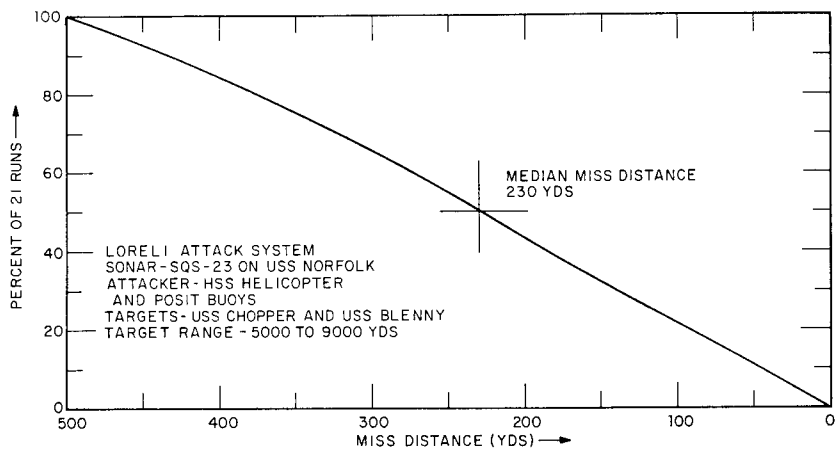

Fig. 10 - The percentage of total successful runs at which the miss distance was no greater than the value shown. For 50% of all the runs the miss distance did not exceed 230 yds.

AN/SQS-23 Tests with the USS BARRY

Medium-range tests of the Loreli technique with the AN/SQS-23 were again conducted during the period 14 to 24 February 1961 in the Key West area. The USS BARRY was used as the echo-ranging ship, the USS THREADFIN as the target, and HSS-1 helicopters as Posit buoy carriers and attackers. However, these services did not prove entirely satisfactory for a number of reasons. During the first part of the tests, water conditions were poor and considerable time was spent steaming around the operating areas looking for water conditions which would give satisfactory sonar ranges. These conditions were found in the southernmost areas about 50 miles from the sea buoy. This distance, and the rough water conditions encountered during this period, made it impossible to use a retriever boat for buoy recovery. Instead, the helicopters had to retrieve the buoys, and thus the

number of runs they could make was reduced to about three or four per flight. Also, considerable difficulty was encountered with the AN/SQS-23 sonar, particularly with the difference brightening and the cursor. The difference brightening did not work properly. Sum brightening was used on most of the runs, which increased the miss distance considerably. At the longer ranges the spots produced by sum brightening were 2000 to 3000 yards wide, making it difficult to pick an accurate vector. Also, the helicopters had mechanical trouble on a number of days and either had to return to base or could not fly at all. All these difficulties limited successful operations to three out of the eight days available. During these three days, 24 runs were attempted of which 13 were successful. Out of the 11 unsuccessful runs, the Posit buoy did not function properly on 5 runs, AN/SQS-23 difficulties prevented the completion of 4 runs, and communication difficulties 2 runs. Nevertheless, the median miss distance of 210 yards was obtained from the 13 successful runs (Fig. 11) at operating ranges of 6,000 to 20,000 yards for an average range of 13,000 yards. For the 10 runs at the longer ranges (10,000 to 20,000 yards), a median miss distance of 400 yards was obtained. This large median miss distance was due to the large sum-brightening spots and to the large vectors obtained between the Posit buoy and submarine target when radar was used to position the helicopter for the Posit buoy drop (the vectors were 3000 yards or more in length). However, when the helicopter was flown over the ship on the sonar target range and bearing, the drops were spaced 400 to 2000 yards from the target. But this method consumed considerable flight time.

Undoubtedly better results can be achieved when all these problems have been resolved. It is believed that a 200-yard median miss distance can be achieved at 20,000 yards. This would represent a total median attack error of 10 mils.

A generally accepted requirement for the location accuracy of surface ship sonar is 30 mils. A 30-mil dashed line has been added in Fig. 7 to show this relation to the Loreli data. Inspection shows that most of the field data and all of the simulator data fall below this line. It should here be noted that these data represent the total error involved in delivering a weapon on top of a submarine, rather than just the location error of the sonar equipment. Indeed, using the Loreli technique, it is possible to have the overall attack error less than the location error of the sonar used to control the attack. This well may have happened since the sonar equipment was never calibrated prior to any Loreli operation.

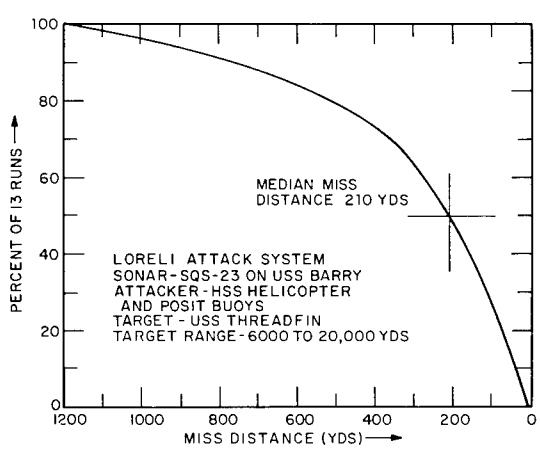

Fig. 11 - The percentage of total successful runs at which the miss distance was no greater than the value shown. For 50% of all the runs the miss distance did not exceed 210 yds.

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DISCUSSION

It is certainly realized that the delivery of a payload on top of the target is only part of the attack problem. Up to this point in the report only this has been considered, on the premise that the more precisely something can be dropped on top of or at some optimum position with respect to the target, the better. This is true only to an extent determined by the overall characteristics of a particular attack system. There is a complex relationship between delivery accuracy and the weapon performance attributes, such as lethal volume of effectiveness and cost. If inexpensive weapons can be precisely delivered with a simple technique, we can relax other related requirements. Most important, and often overlooked, is the need for near-perfect classification, mandatory with our present expensive weapons systems.

A precision delivery technique helps in the classification problem in the following way. Consider data point 5F from Fig. 7 and Table 1. In this experiment, drops were made on a stationary acoustic target by a HUP-1 helicopter achieving a median miss distance of 39 yards. This experiment can be compared directly to the tactic of delivering a short-range classification device, or "Classification Probe," on top of a slow-moving (creeper) type submarine. (It is worth emphasising that this target is the most difficult to classify correctly.) Such a probe has indeed been developed (3). It is the magnebuoy and has a 100 percent magnetic detection (and classification) range out to 150 yards, or a distance almost four times the drop error demonstrated above. If a Posit buoy is dropped along with the classification probe, the target can be tracked with respect to the probe to assure that it is within classification range. Other probe sensors are possible and are being investigated. Table 2 at the end of this report lists other Loreli applications.

Work is underway at NRL to make further use of the Loreli technique in the direct control of the weapons themselves and as a further aid in the classification problem. The philosophy here is to use the Loreli vector to aim the weapon directly at the target, to make use of the high-quality acoustic information readily obtainable at short range to classify, to make certain the weapon has acquired the target, and then to fire. The present philosophy for acoustic homing weapons is to require them to search, detect, classify, acquire, and home in on the target while evading countermeasures. This is a considerable task for even a sophisticated machine to undertake.

There are two specific approaches: CAATS and BATS. In the CAATS concept, a torpedo is controlled by an operator from an attack vehicle, as described above. Figure 12 illustrates the CAATS concept and shows an experimental rig holding an MK 43 torpedo. The BATS concept is similar, except that the weapons are underwater rockets. Figure 13 shows an experimental test sled being used in BATS acoustic, rocket-tracking experiments.

Continued Loreli data collection is planned with AN/SQS-23 and AN/SQS-26 sonars, both with NRL and with commercially procured Posit buoys, using helicopters and possibly DASH. Work will also be done with the large, ocean-bottom-mounted sonars under development for Project TRIDENT. Up until now, the attack problem has been to know the exact location of the submarine. With the bottom-mounted sonar arrays located miles out at sea, the exact location of the attack-controlling sonar may also not be known. However, when employing the Loreli technique this information should not be necessary.

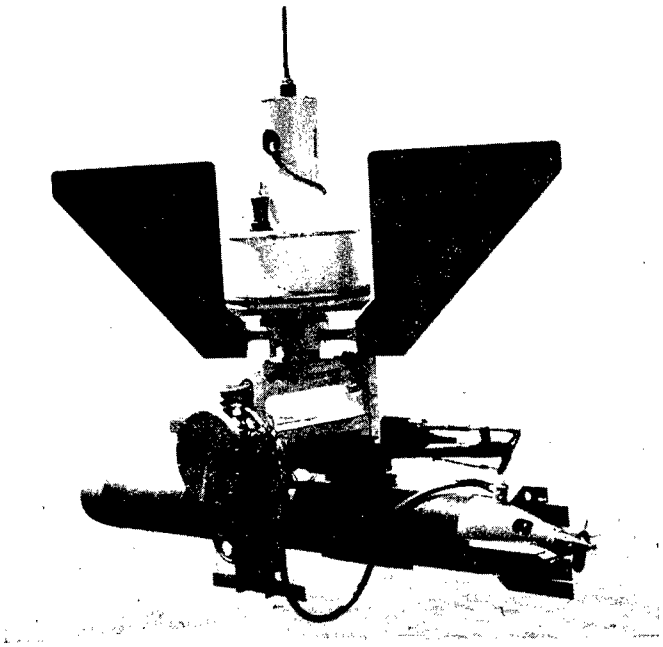

Fig. 12 - A MK 43 torpedo which is directly controlled by the sonar operator (using the Loreli vector), illustrating the CAATS concept (see text)

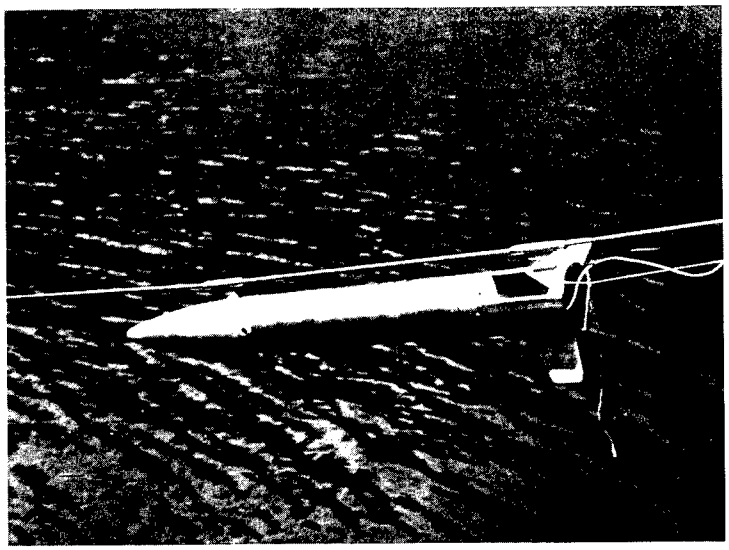

Fig. 13 - A rocket test sled (produced by Aerojet General Corporation) illustrating the BATS concept (see text)

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Table 2
Some Loreli Applications

1. Loreli-Posit (as described in text)
2. Loreli-DASH (as recommended in Ref. (2))
3. PCH or DDH, 2-vehicle application, or single vehicle with ancillary vectoring buoy
4. Error correction for ASROC
5. Basis for "garden hose" application using many cheap missiles
6. Basis for new missile system built around Loreli and spin-stabilized rockets
7. In guided torpedoes for final acquisition vector
8. As basis for control of short-range attack system, such as CAATS and BATS (see text)
9. Placement of Classification Probes, e.g., the magnebuoy

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