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Pacific Oceanographic Group

Nanaimo, B.C.

August 15, 1949

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ABSTRACT

The target characteristics of a Fleet type submarine, "USS Baya", were examined under favourable experimental conditions by the Recognition method. This method consists of determining the target extent by standard asdic gear and interpreting the observations in terms of effective source levels. Relative target strengths are equivalent to the differences in effective source levels at which the targets are equally recognized.

The principle echoing surface was in the region of the conning tower. Stern echoes were strongest on the stern and quarters. Several portions of the submarine contributed to the high target strength at beam aspect.

The average strength of the conning tower was 9.8 ± 2 db. The remainder of the submarine contributed 1.7 db on the average, to give a mean target strength of 11.5 ± 2 db. This is equivalent to the theoretical target strength of a sphere 45 feet in diameter.

The range of 50% recognition of the submarine was approximately 3000 yards under the ranging conditions encountered.

THE TARGET STRENGTH OF A FLEET SUBMARINE

INTRODUCTION

During November 1948, a joint project of American and Canadian naval research groups was carried out in Canadian waters to investigate the target characteristics of a Fleet-type USN submarine. This was the first occasion on which the target properties of a Fleet submarine were examined with precision. During the war years, operational submarines were not generally available for detailed assessment. Furthermore, areas with oceanographic conditions suitable for this type of research were unknown.

The demonstration of the suitability of Nodales channel for underwater sound research (reference 1) prompted the organization of this project. Three research establishments were involved:

1. United States Navy Electronics Laboratory (USNEL).
2. Pacific Naval Laboratory (PNL).
3. Pacific Oceanographic Group (POG).

The task force consisted of:

1. USS "Baya".
2. USS EPCE (R) 857.
3. HMCS "Rockcliffe".
4. HMCS "Cedarwood".
5. HMCS "Ehkoli".

and several Canadian Naval auxiliary vessels.

The Canadian and American groups used different methods of target assessment. The use of dissimilar approaches was to provide a comparison between the results of the Canadian (Recognition) method, and of the American (direct measurement) method.

In addition to accomplishing the comparative assessment of submarine target strength, a large mass of data on underwater sound characteristics was obtained. These data have demonstrated the validity of assumptions upon which the Recognition theory is based and have contributed much to an understanding of some of the fundamental factors in sound ranging. A discussion of these observations will be circulated as a Technical Report (reference 7).

The present report is concerned with the Canadian determination of submarine target strengths. It has been prepared by the Pacific Oceanographic Group because of that group's familiarity with the method and the theory upon which it is based. However, the data represent the contribution not only of personnel of the Pacific Naval Laboratory and the Canadian vessels, but of the U.S. scientists and naval personnel whose co-operation is gratefully acknowledged.

RECOGNITION THEORY

The recognition of an echo from a submarine target depends upon the interrelation of many independent factors, - the type of gear, the water conditions, the character of the surface and bottom boundaries, the range, and the size and reflectivity of the target. Most of these factors are continually fluctuating in their contribution, so that recognition depends upon the probability of the effect of the factors favouring recognition outweighing those preventing recognition.

An echo on the chemical recorder of an asdic set either can, or cannot be recognized. If a single pulse is transmitted, the echo will be recognized if the favourable factors outweigh the unfavourable factors by a definite ratio. When this condition is not met, the echo will not be recognized. If a large number of pulses are sent out under similar controllable conditions, the proportion of recognized echoes approaches a definite value. This proportion is called the "recognition" of the target under those conditions.

Recognition increases with increasing sound field if all other conditions remain unchanged. If, on the other hand, the target strength is decreased, recognition will decrease. If the field at the target is increased by the same amount that the target strength is decreased, recognition will remain unchanged. This principle is the basis for the determination of target strength by the Recognition method. By definition, the strengths of two targets differ by the amount the sound field must be altered to obtain equivalent recognition (of 50%), all other conditions being equal.

METHOD

The trainable asdic transducer is used to alter the sound field at a target without changing other recognition factors, such as range or reverberation level. As the transducer is trained off the target, both the source level and the receiver sensitivity on the target bearing are reduced. This combined effect can be expressed as a change in "effective source level" describing the total effect



Figure 1. Nodales Channel.

on recognition as due to a change in sound field alone, and presuming the receiver sensitivity to be constant with bearing. The effective source level is referred to the maximum level of the asdic beam at the same range.

The relation between effective source level and oscillator bearing is available from the transducer pattern, which can be measured with suitable monitoring gear (reference 2). It is convenient to express the relation in terms of the angular extent of the asdic beam. The operational term "extent of target" is the angular extent of the asdic beam over which a target is recognized. By referring to the transducer pattern, the extent of target can be expressed as the effective source level at, or greater than which, the target is recognized.

In operational terms, the recognition method consists of comparing the extents of two targets under similar conditions. When the comparison is expressed as the differences in effective source levels, the relative target strengths are immediately available.

Given the information available from a transducer pattern, operational gear and procedures can provide the basic data for target strength comparisons. The Recognition theory provides a method for interpreting these data in quantitative terms.

The USNEL method of target assessment involved the direct measurement of sound level at the target and of the echo level at the ranging ship. Quantitative target strengths can be derived from these measurements. It is hoped that the joint project will demonstrate the acceptability of the Recognition theory for interpreting these data in operational terms. This demonstration must await the publication of USNEL results.

TARGET ASSESSMENT

The following sections will be concerned with the examination of the target properties of the Fleet submarine in Nodales Channel. The oceanographic conditions of the area will be described. A discussion of standard targets will be followed by the treatment of data demonstrating the recognition analysis. Finally, the submarine observations will be summarized.

Oceanographic Conditions

The principle features of Nodales channel (figure 1) as they affect underwater sound studies have been described in a previous memorandum (reference 1). During the submarine examinations in late November 1948, slight upward refraction was present at all times, the temperature structure changing from isothermal to positive during the period. Heavy rainfall contributed a variable



Figure 2. H.M.C.S. "Ehkoli."



Figure 3. H.M.C.S. "Cedarwood."

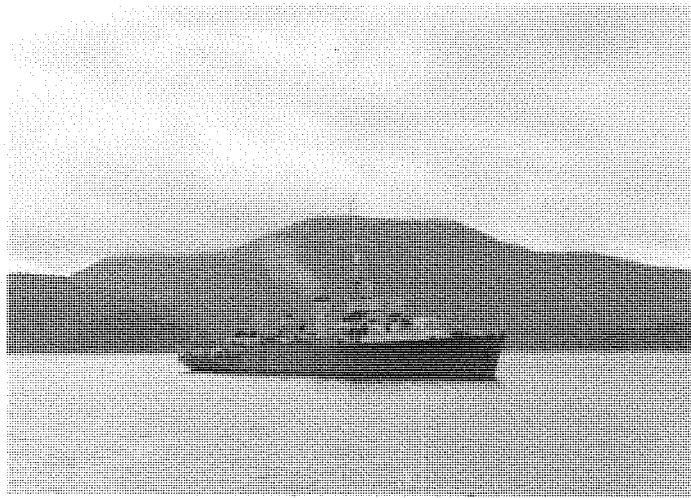


Figure 4. H.M.C.S. "Rockcliffe."

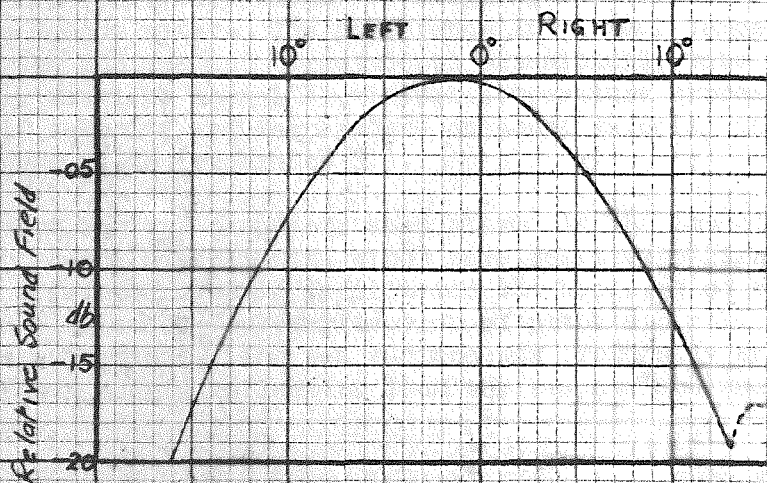


FIG 5A TRANSUCER PATTERN - JAMES ROCKCLIFFE
 Sound Field of Transducer bearing relative
 to monitoring ship

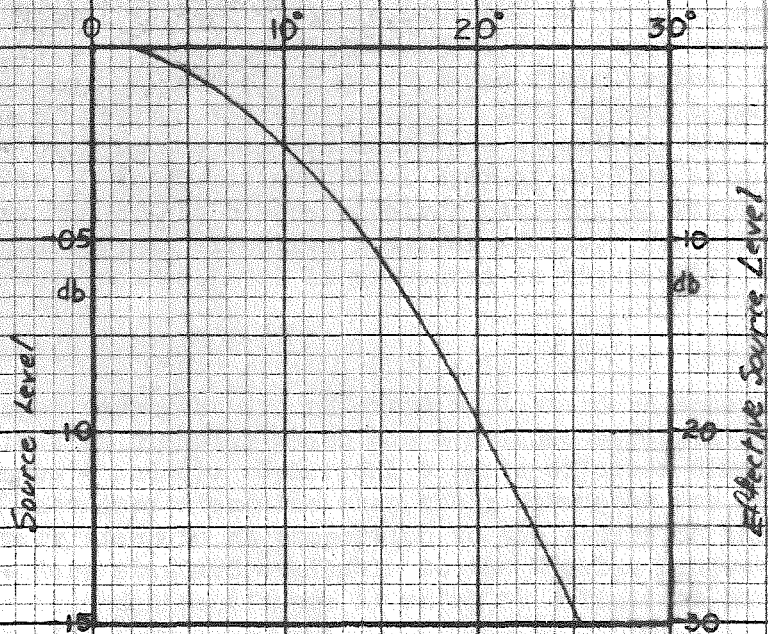


FIG 5B RELATION BETWEEN EXTENT
 AND EFFECTIVE SOURCE LEVEL

surface layer of water which was slightly less saline and colder than the deeper water. The difference in virtual temperature between the surface and target depth occasionally rose to 1.5° but generally was less than 1°F (virtual temperature expresses the effect of salinity and temperature on sound velocity in terms of temperature alone (reference 5)).

Except for two occasions when storms in the immediate vicinity interrupted the experiments, winds were relatively light. The absence of wind and swell facilitated the handling of heavy target gear and eliminated the complication of pitch and roll from the target examinations. The sea surface was frequently smooth, and image interference due to reflection from the sea surface was evident at all times.

Oceanographic monitoring was carried out by HMCS "Enkoli" (figure 2) with supplementary observations by HMCS "Cedarwood", (figure 3) and the ranging ships.

Transducer characteristics

The Canadian examinations were carried out by HMCS "Rockcliffe" (figure 4) equipped with standard 144 asdic equipment. Monitoring equipment installed in HMCS "Cedarwood" assessed the sound field conditions from day to day. The same observations provided a measurement of Rockcliffe's transducer pattern, which is reproduced in figure 5(a). The data show that the lobe was not symmetrical about zero bearing. A drop of 10 db in sound field at the target occurred when the transducer was trained 11.5° left of the target bearing, but only 8.8° to the right. Expressed as extent, the sound field was within 10 db of maximum level over an angular extent of 20.3°. Including the effect of the receiver pattern, an extent of 20.3° corresponded to an effective level of -20 db. The relation of extent to effective source level is presented in figure 5(b).

The standard target

Target strengths are referred to a standard spherical target twelve feet in diameter which has a defined strength of unity (references 4 and 6). Spherical targets of other dimensions can be used as secondary standards when their strengths are referred to the primary standard in proportion to the square of their diameter. The secondary standard available to the Nodales project consisted of a ten-foot sphere (figure 6) which by definition had a target strength of:

$$\left(\frac{10}{12}\right)^2 = 0.7 = -1.6 \text{ db}$$

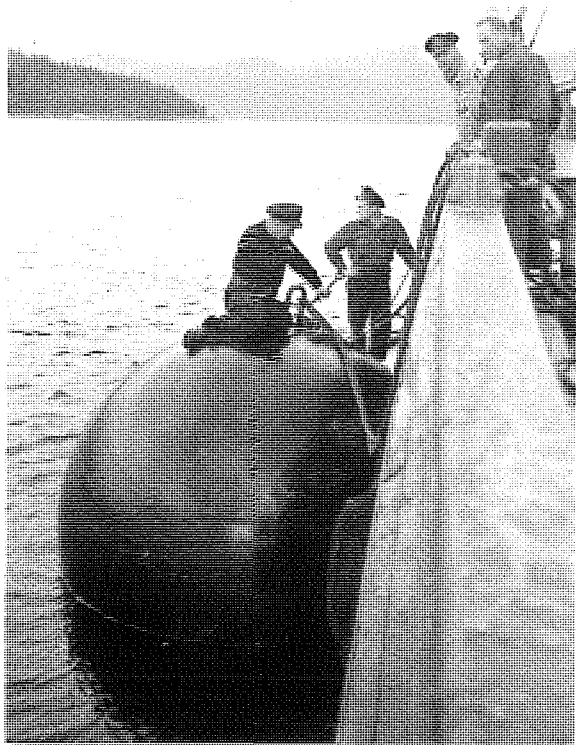


Figure 6. Ten-foot sphere.

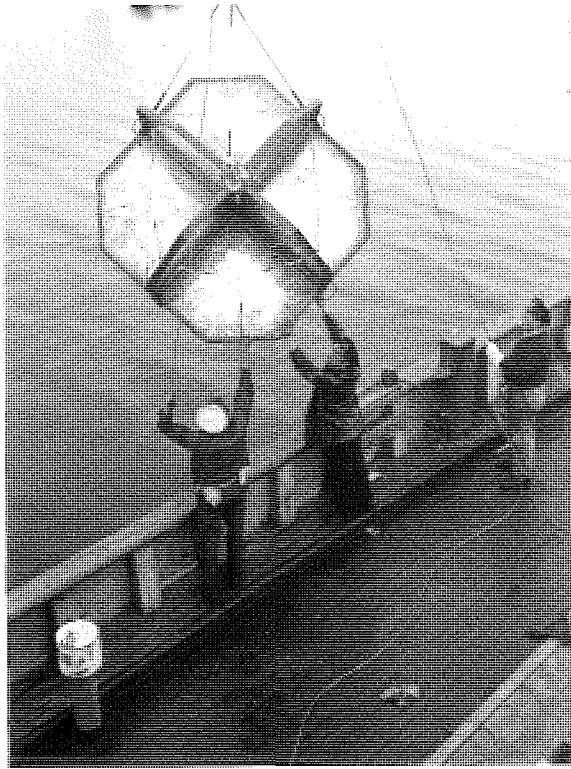


Figure 7. Six-foot triplane target.

The triplane

The ten-foot sphere has several disadvantages. It is bulky and difficult to handle. In proportion to its size it is a relatively weak target. Consequently a six-foot triplane (figure 7) was selected as a working standard. A preliminary study (reference 3) has demonstrated that triplane targets built to the same structural specifications have identical target strengths.

The strength of the triplane must be assessed in terms of the primary standard. To this end, target strength comparisons between the ten-foot sphere and the triplane were made during the submarine examinations. Having calibrated the working standard, the relative strengths of the triplane and submarine could be expressed in terms of the primary standard.

The target strength of the six-foot triplane

Target line A line of targets was set by HMCS "Cedarwood" in Nodales channel immediately adjacent to the area of submarine examination. It consisted of the following:

1. The ten-foot sphere (positive buoyancy), anchored to the bottom and submerged to a low-water depth of 153 feet.
2. A six-foot triplane target (negative buoyancy) buoyed from the surface and submerged to a depth of 156 feet to center.
- 3,4. Two fourth-class buoys at the surface
5. An anchor buoy similar to that buoying the triplane.

The individual targets were separated by a range of 100 yards or greater and could be identified on the chemical range recorder by this range difference.

Recognition data The ranging ship (HMCS "Rockcliffe") made a series of runs on the target line at intervals during the submarine examinations. The speed of approach was generally less than two knots. The targets were maintained in approximate transit and the asdic beam was trained across the target bearings in $2\ 1/2^\circ$ steps from 15 degrees on either side. The use of a constant step interval across the target is a departure from standard operational procedure. This modification was introduced to eliminate the effect of aural recognition on extent determination, since all recognition values were determined from chemical recorder traces. It also simplified the analysis of the chemical range record. Extent was defined as the number of recognized echoes, less one, multiplied by the step angle ($2\ 1/2^\circ$). Maintaining the targets in transit allowed easy identification of each by their difference in

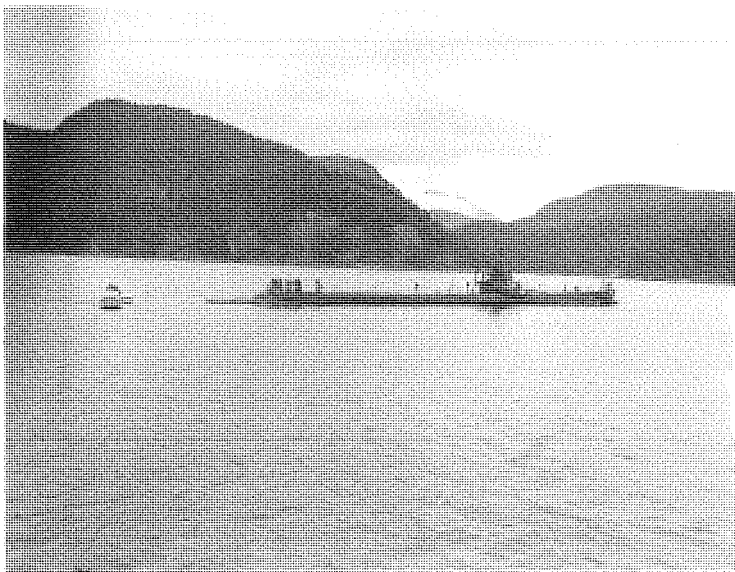


Figure 8. U.S.S. "Baya."

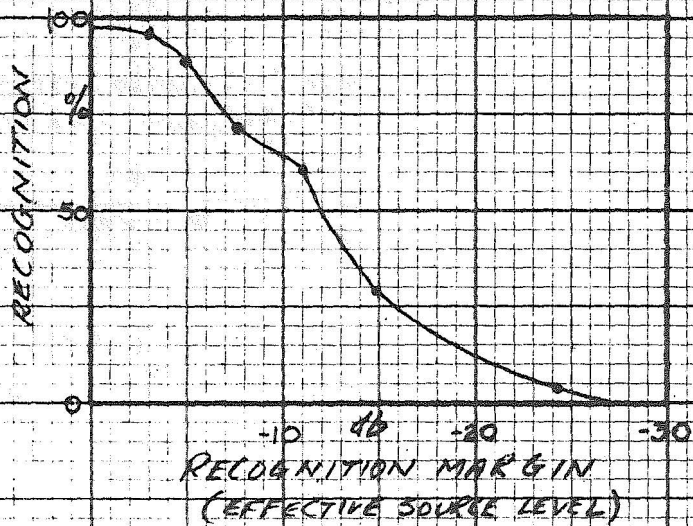


FIG. 9. RECOGNITION OF SIX-FOOT TRIPLANE
750-850 yards, No dates, Nov-Dec 1948

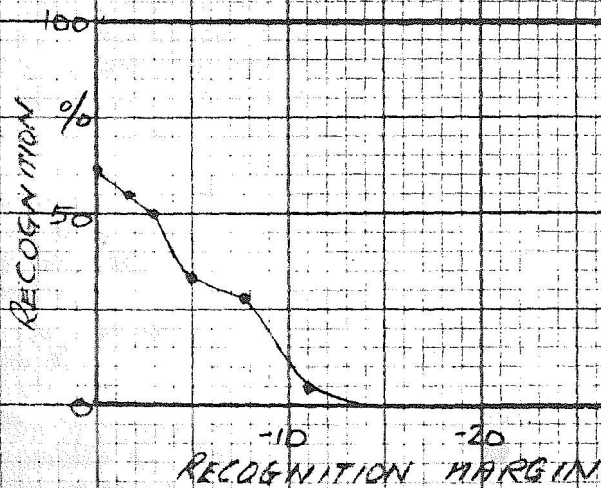


FIG. 10. RECOGNITION OF TEN-FOOT SPHERE
750-850 yards, No dates, Nov-Dec 1948

range, and one observation of the extent of each of the five targets was obtained in approximately 12 transmissions.

The data were summarized in intervals of 100 yards and recorded as the number of recognized echoes in each observation. A typical treatment of data is outlined in the following table.

Table I

Recognition of six-foot triplane target, 750-850 yards range, 156 feet deep, Nodales channel Nov. 17 - Dec. 1, 1948.

A	B	C	D	E	F
Echoes recognized	Frequency	Cumulative frequency	Cumulative proportion	Extent (A-1) x 2.5°	Effective source level (db)
10	1	1	.04	22.5	-24.2
9				20.0	-19.2
8	7	8	.29	17.5	-14.9
7	9	17	.61	15.0	-11.0
6	3	20	.72	12.5	- 7.8
5	5	25	.89	10.0	- 5.0
4	2	27	.96	7.5	- 3.0
3				5.0	- 1.7
2				2.5	- 0.5
1				0	0
0	1	28	1.00		

Table I indicates that out of 28 separate observations of the extent of the triplane target within the range interval centred at 800 yards, ten echoes were recognized in one observation, eight echoes in seven observations, and that no echoes were recognized in one cut across the target. Column C summarizes the number of occasions in which echoes of the designated number or more were recognized and column D expresses this as a proportion of the number of observations. For example on 17 out of 28 occasions (61%), seven or more echoes were recognized. Expressing the number of echoes recognized indicates that recognition of the target occurred 61% of the time at an effective source level of -11.0 db. Columns D and F provide the data necessary for plotting a recognition margin curve (figure 9).

The properties of recognition curves are discussed in detail in reference 4. For the present purpose it is sufficient to remark that the curve describes the effect on recognition of altering the source level while maintaining all other controllable factors constant. At this range, the triplane target is recognized 96% of the time at an effective source level of -3 db, and recognition drops to 50% when the effective source level is -12 db.

Similar data for the ten-foot sphere at the same range are summarized in figure 10. This target is recognizable 50% of the time at an effective source of -3 db. The difference in effective source levels at which 50% recognition of each target occurs is 9 db. According to the recognition theory this figure implies a difference of 9 db. in target strengths.

The average of data at all ranges at which the sphere showed at least 50% recognition was used to evaluate the relative target strengths. The triplane was found to have an average target strength 8.9 db greater than the sphere. In terms of the standard, the target strength of the triplane was:

$$8.9 - 1.6 = 7.3 \text{ db}$$

As a target, therefore, the triplane was equivalent to a sphere 28 feet in diameter.

THE TARGET STRENGTH OF THE SUBMARINE

The procedure

The examination of the submarine "USS Baya" was concentrated in the range interval 1000-1500 yards. At these ranges small temperature fluctuations have less effect on the average sound field gradient than at longer ranges.

The American procedure required at stationary target. Currents in the channel were not sufficiently strong to allow Baya to plane at anchor. The submarine submerged in the center of the channel to a deck level of 150 feet from two fourth-class buoys, one each at bow and stern. The head bearing of the submarine was passed to the ranging ship by radio.

HMCS "Rockcliffe" approached the submarine at a speed of about 2 knots evaluating the extent of target at various aspects. Approximately 70 runs averaging 20 minutes each were made on the submarine. The angle of approach was adjusted so that the target was examined at all aspects. This adjustment was simplified by the submarine's ability to maintain any required orientation in the channel by slight use of her engines.

The aspect of the submarine was measured in degrees clockwise from the bow. It was presumed that the target characteristics were symmetrical about the fore and aft line and observations of aspects greater than 180° were combined with the corresponding relative aspect on the starboard side. Observations were grouped in 10°

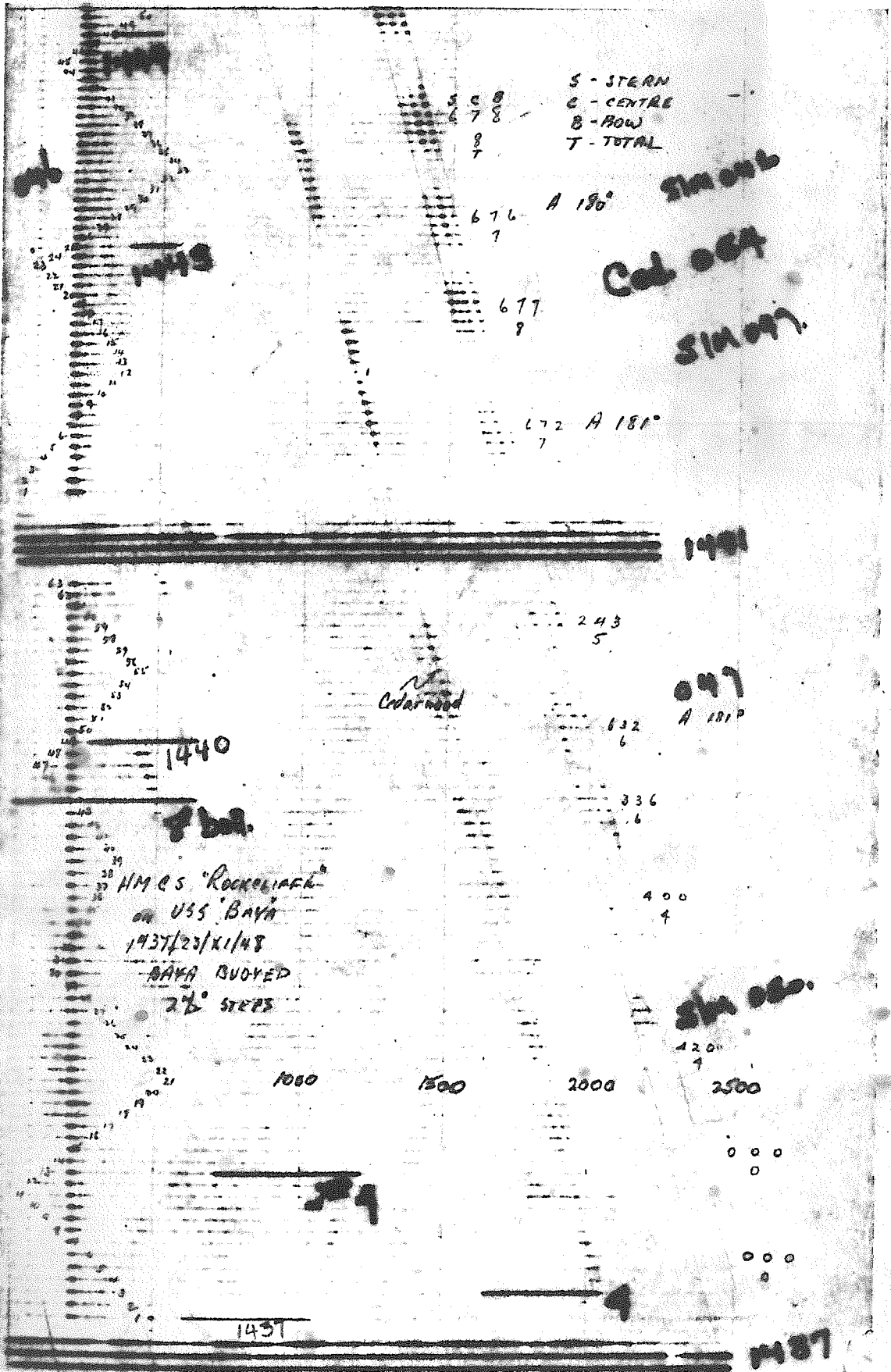


Figure 11. Range recorder trace of an approach on stern aspect of a buoyed submarine.

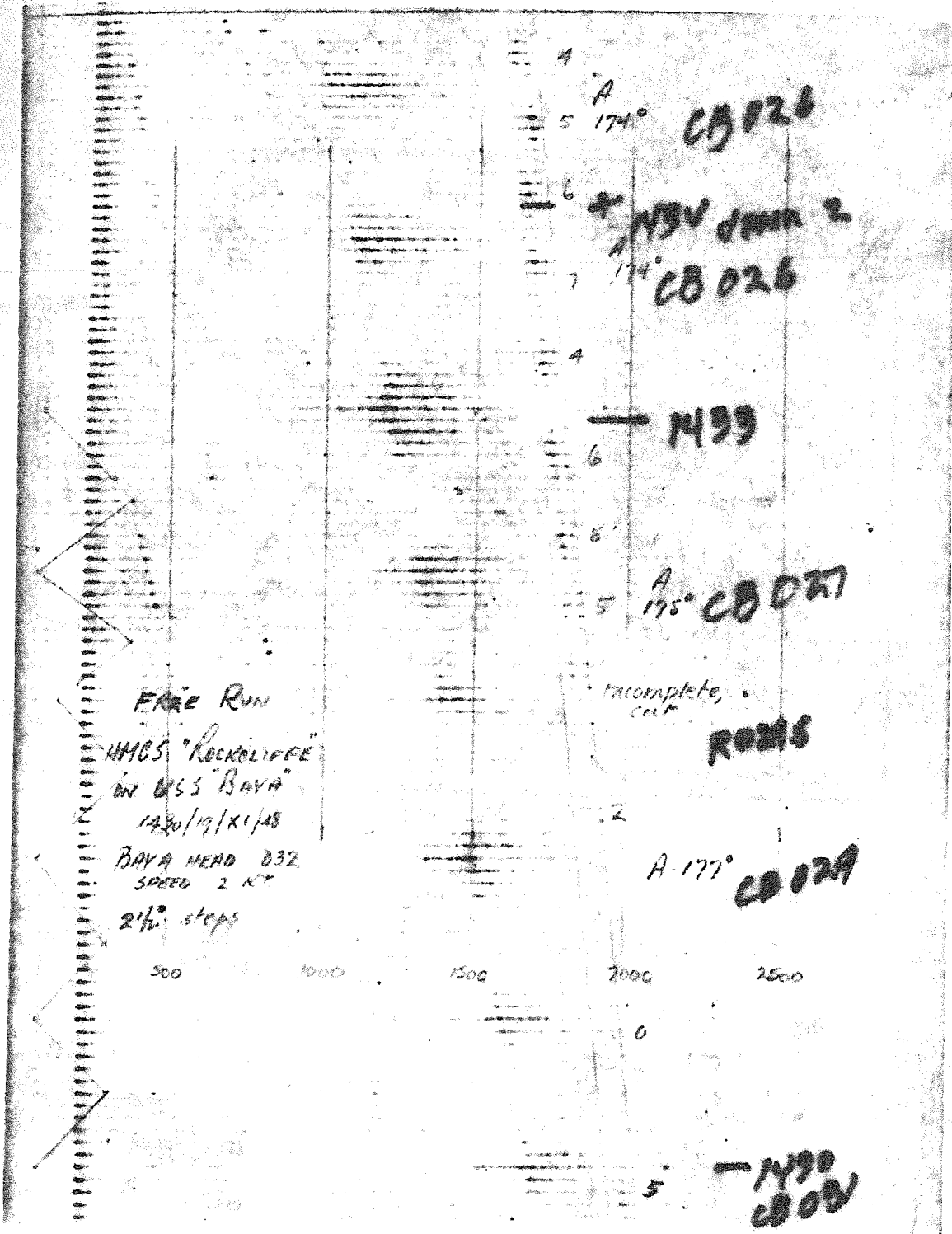


Figure 12. Range recorder trace of an approach on stern aspect of an unbuoyed submarine.

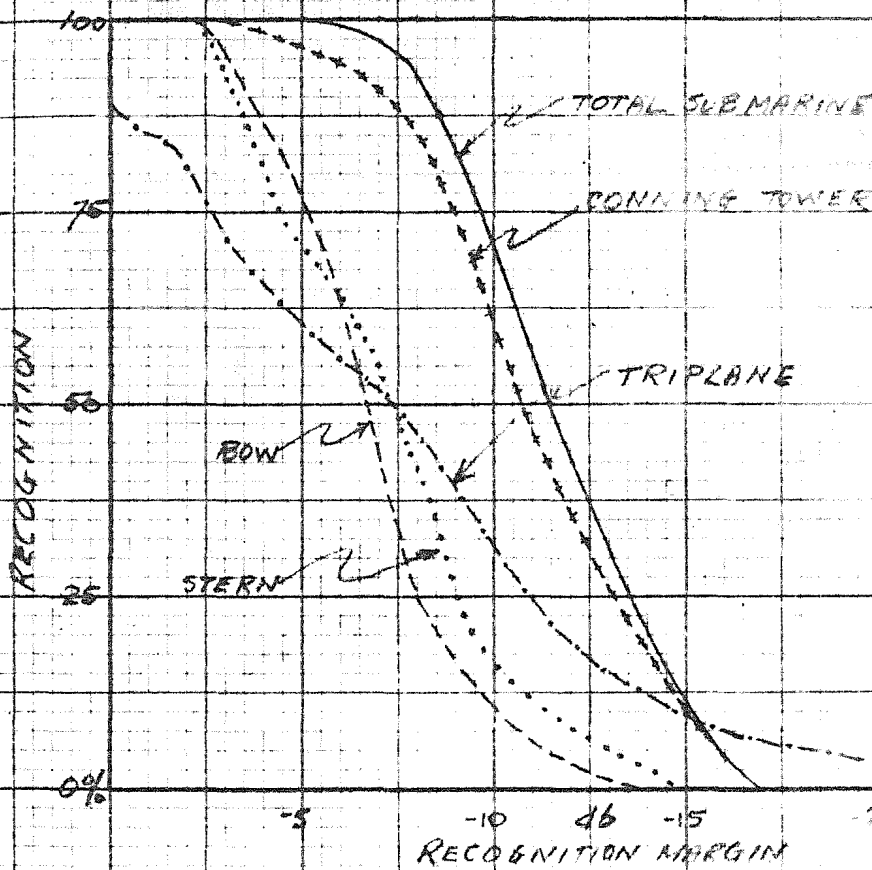


FIG. 13 RECOGNITION OF UNBUOYED SUBMARINE
 950-1550 yards Natalles, NOV-DEC 1948
 ASPECT 110°

intervals. For example, aspects of 035° - 044° and 316° - 325° were combined, and considered to represent an average aspect of 040° .

Echo characteristics

A short (8 ms) pulse length was used. This reduced reverberation to low levels and provided excellent resolution of echoes on the chemical recorder. Figure 11 illustrates a typical range record of a run on the stern aspect of the buoyed submarine.

The approach was from beyond 2500 yards and the first echoes were recognized at about 2100 yards range. At 2000 yards the submarine is represented by three distinct echoes from the same transmission which presumably are due to the two buoys and to the conning tower. At 1500 yards, four distinct echoes are apparent, the additional one being presumably from the small dan buoy which supported the antenna of the radio link.

Figure 21 shows that several discrete echoing surfaces are present in an unbuoyed submarine. This record represents a run on Baya cruising at 2 knots without buoys. Careful inspection of the trace shows that the principal echoing surfaces vary in position along the submarine. This may be due in part to fluctuation of sound field with range as a result of image interference.

It is evident that the bow and stern echoes of a buoyed submarine cannot be disregarded as being due to the buoys alone. Consequently the recognition of the several parts of the submarine was determined individually for each echo from the range recorder data.

Recognition of different parts of the submarine

The submarine echo was divided into three parts, representing the stern, the conning tower, and the bow. This separation was not practical within 15° of the beam aspect because the bow and stern at these aspects differ only slightly in range. Comparing the recognition of the bow and stern with the recognition of the fourth-class buoys in the target line, it was possible to estimate the contribution of the buoys and to eliminate their effect (reference 4).

The recognition curves of the conning tower, the bow and the stern, eliminating the effect of the buoys, are represented for the aspect 110° in figure 13. Data over the range interval 950-1550 yards have been included in these curves, and for comparison the recognition of the triplane target in the same range interval has been presented. Comparing the curves at 50% recognition, the bow and stern of the submarine have target strengths approximating that of the triplane target. The conning tower represents a stronger target, approximately 3 db greater than the triplane.

Recognition of the submarine as a whole

The observed recognition of the submarine is complicated by the physical size of the target. At 1000 yards, the submarine subtends an angle of 5.7° , part of which is incorporated into the observation of total extent. Before the target strength of the submarine can be derived from the data, a correction for the physical extent must be applied.

When the echoes from the separate parts of the submarine can be differentiated, it has been found that each part demonstrates the characteristics of a point target. A discussion of the combined effect of several point targets is presented in reference 7 where it is shown that the recognition of a multiple point target as a whole is a well defined function of the recognition of the several parts.

The reference (7) discusses the effect of the angular separation of several point targets upon the observed extent of the submarine and the conclusion of the observations agrees with that predicted from theory. In effect, the submarine as a whole shows that the characteristics which would be expected of a multiple point target, consisting of three individual targets separated by a distance equal to half the length of the submarine. It is therefore possible to combine the recognition curves of the several parts of the submarine in such a way that the complication of its physical extent is eliminated.

The recognition curve of the total submarine is obtained by combining the several recognition curves in figure 13 according to the method described in the cited reference. The contribution of the bow and stern results in a target approximately 1 db stronger than the conning tower alone. The target strength data at this aspect (110°) are given in Table II.

Table II

Target strengths of "USS BAYA" at aspect 110° compared to six-foot triplane at random aspect. Range interval 950-1550 yards

Target	Target strength db	Equivalent sphere diam.(feet)
Triplane	7.3	28
Bow	6.7	26
Center	10.6	41
Stern	7.3	28
Total submarine	11.4	45

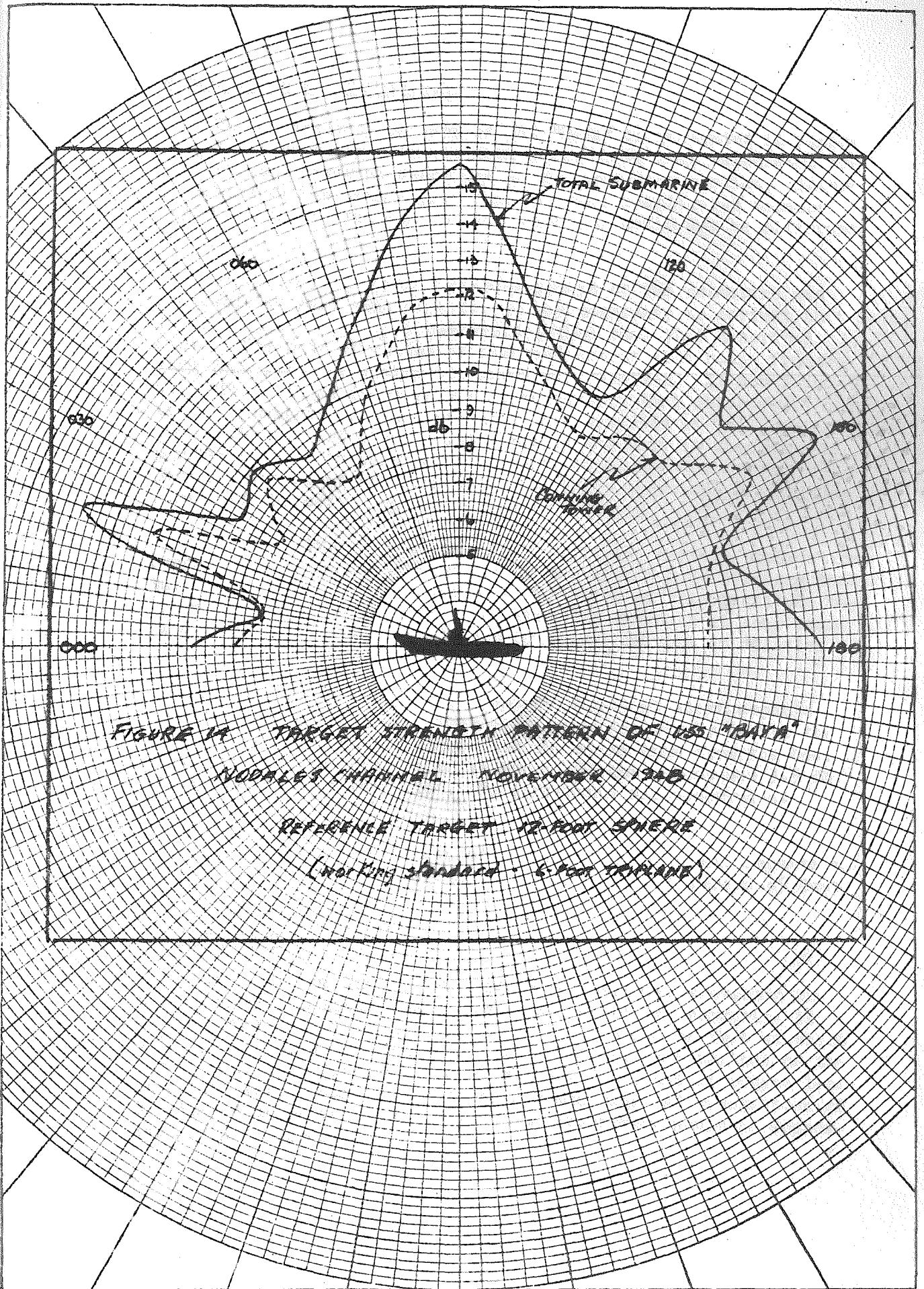


FIGURE 14 TARGET STRENGTH PATTERN OF USS "BATA"
 NODALES CHANNEL NOVEMBER 1940
 REFERENCE TARGET 12 FOOT SPHERE
 (WORKING STANDARD - 6 FEET TORUS)

Submarine target directivity

The directivity pattern of USS "Baya" is presented in figure 14. The target strengths at each aspect have been calculated from recognition curves as described in the preceding section. Interpretation of the beam aspect data has been complicated because separate echoing surfaces of the submarine could not be differentiated.

Since only the total observed extent of the submarine was available at near beam aspects, it was necessary to correct that data for physical extent by a different method than that described above. The rate of change of observed extent with range from beyond 2000 yards to within 600 yards was examined. It was found that this rate of increase was approximately that which would occur if three targets of equal strength were situated at the conning tower, and at the bow and stern. Interpreting the data in this manner permitted the correction of the observations for the effect of physical extent at the aspects 080° - 100° , where the recognition curves of the several parts were not available.

The beam data were particularly variable, certain observations suggesting a possible strength of 23 db, almost 8 db stronger than that represented for the average. Variation of this magnitude may be real, for it is to be expected that the strength at near beam aspects would be sensibly altered by slight changes in relative bearing.

The submarine presents a stronger target at stern aspects than forward of the beam. This difference is largely due to the greater contribution of echoes from the stern than from the bow. On the average the difference in stern and bow echoes was 3.5 db at aspects greater than 110° . No difference was observed at aspects less than 070° .

The mean target strength of the submarine over all aspects was 11.5 db. This strength is equivalent to that of a sphere 45 feet in diameter.

Maximum range

The 2500 yard limit of the 144 range recorder prevented the observation of maximum range of recognition of the submarine in Nodales channel. By definition, this range would be that at which 50% recognition would occur when the transducer was trained on the target bearing. Extrapolation of the data obtained at ranges less than 2000 yards, suggests that the maximum range of recognition of USS "Baya" under the conditions of the experiment would be approximately 3000 yards.

Reliability of data

The data upon which the foregoing estimates are based are subject to various sources of error. The mean target strengths can be relied upon (with 95% confidence) to within ± 2.5 db. This includes the reliability of the triplane and sphere comparisons.

The submarine target directivity pattern is not subject to the errors involved in referring the observations to a standard target. However, the fewer number of observation at each aspect and the correction for the buoys imply a 95% confidence band of approximately $+ 2.0$ db. The directivity pattern near beam aspect is less reliable. The data suggest that a 95% confidence interval of ± 3 db is applicable for this region.

SUMMARY

The target strength of a stationary Fleet submarine was observed by the Recognition method, using short (8 ms) pulse lengths at 22 KC. Slight, but variable, upward refraction and marked image interference from a relatively smooth sea surface were present. Reverberation was not a complicating factor. A ten-foot sphere and a six-foot triplane were used as secondary and working standards.

The mean target strength at all aspects was 11.5 ± 2.5 db, referred to a sphere 12 feet in diameter. The target strength varied from 8.2 ± 2.0 db broad off the bow to 15.6 ± 3 db abeam. Target strengths were greater on the quarter than on the bow.

The principle echoing surface was at or near the conning tower and most of the target strength (9.8 ± 2.5 db) of the submarine was associated with this region. Stern and bow echoes were significant. Echoes from the stern were on the average 3.0 db stronger than echoes from the bow at aspects on the quarter.

Stern and bow echoes contributed 1.7 db to the total strength. This contribution increased to over 3 db at or near beam aspects.

The mean strength of the submarine was equivalent to that of a sphere 45 feet in diameter and provided a maximum range of approximately 3000 yards in Nodales channel.

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