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REPORT No. S-1610

DATE 19 April 1940

SUBJECT

Comparative Tests of QC, JK, and JL Listening Gear on U.S.S. SEALION.

BY

NAVAL RESEARCH LABORATORY

FR-1610

BELLEVUE, D. C.

U. S. GOVERNMENT PRINTING OFFICE 4—7456

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19 April 1940 [redacted] NRL Report No. S-1610

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NAVY DEPARTMENT

Report

on

Comparative Tests of

QC, JK, and JL Listening Gear on U.S.S. SEALION

DECLASSIFIED

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

Number of Pages: Text - 6 Tables - 8 Plates - 5

Authorization: BuEng. ltr. C-S68 (12-12-R4) of 27 January 1939.

Date of Tests: 15 and 24 January 1940.

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Distribution: BuEng.-BuC&R (10)
U.S.S. SEMMES (1)

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ABSTRACT

On 15 and 24 January 1940 comprehensive comparative tests were made of the sound gear on the U.S.S. SEALION while listening to the propeller noise from the U.S.S. SEMMES as target.

The equipment consisted of a keel mounted, rochell salt JK projector, a keel mounted combination JK and magnetostriction QC projector, a number of QC units (all-directional) mounted around the conning tower, all operated at a frequency of 24 kilocycles, and a JL equipment consisting of a series of hull mounted magnetophones on lines each side of the bow operating at audio frequencies through an electrical compensator and amplifiers.

The essential problem was to distinguish the target noise through a background of local noise. The major factors are the apparatus, the operating conditions, the water conditions, and the listeners. The test routine provided for simultaneous comparisons of the different equipments, under a wide variety of operating and water conditions and with different listeners, to permit an evaluation of the apparatus under known or controlled conditions for the three other factors.

The quantity and consistency of the data on the SEALION warrant the following conclusions:

(a) The keel mounted QC and JK supersonic equipments on the SEALION were definitely and consistently superior to the JL sonic equipment for listening to propeller noise under all operating and water conditions covered by these tests. This superiority consisted in lower background noise, higher signal/noise ratio, more accurate bearings, longer ranges in both deep and shallow water, more reliable operation and less training required for the operator. This conclusion is substantiated by numerous other tests made by the SEMMES during the past six years.

(b) The background of local noise for the QC and JK keel mounted units on the SEALION was increased by less than 6 decibels in going from minimum to maximum submerged speed. The absolute noise levels and the rise in level due to increased speed were approximately the same on the JK and QC units.

(c) The JK was consistently superior to the QC for listening to propeller noise. The signal intensity averaged 15 decibels higher for the same noise level, and the maximum range averaged 40 per cent greater.

(d) The all-directional units (QC units on conning tower) had such a high background noise level on the SEALION that no target propeller noises were heard.

(e) The loss coefficients for propeller noise were of the same order as for direct supersonic signals of the same frequency and under the same water conditions.

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(f) The intensity of the propeller noise from a target at constant speed and range was substantially independent of the relative bearing from the SEALION except in the sector from 160° to 200°.

(g) Measurement of the intensity of the propeller noise is at best an inaccurate indication of the range and may be misleading unless the constancy of the sound source and of the water conditions are known.

(h) The maximum ranges attained while listening to the SEMMES at 15 knots varied from 2,000 yards to 10,000 yards under the different operating and water conditions during these tests. No estimate of the "reliable" listening range can be made unless the water conditions are known.

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INTRODUCTION

1. During the cruise of the U.S.S. SEMMES and U.S.S. SEALION to San Juan, St. Thomas, and Guantanamo in January 1940, two days were devoted to comparative tests of the QC, JK, JL and all-directional QC (conning tower mounted units) for listening to the SEMMES' propellers in two different areas. Comparisons were made in deep water (over 1,000 fathoms), in shallow water (20 to 30 fathoms), while lying-to with minimum auxiliaries operating, lying-to charging batteries, underway on the surface at speeds from 5 to 12 knots, underway at periscope depth at speeds from 2.5 knots to 7.5 knots, and at different speeds of the SEMMES as target. Comparisons are made on the basis of relative intensity at the same range, relative maximum range, relative accuracy of bearings compared with the periscope bearings, and relative loss coefficients in decibels per thousand yards.

2. The listeners were two men from the SEMMES and the sound men on the SEALION. They might be rated as experienced but not highly expert. To average out the personnel factor the operators were rotated on the different equipments in the different tests.

3. Two general types of runs were made. In the "out-and-in" type, the SEMMES ran away from the SEALION until no longer heard by any listener, then reversed course and ran toward the SEALION until picked up by all listeners. The SEMMES course was curved to give a changing bearing to the SEALION and to prevent shadowing the propellers by the hull or the wake of the SEMMES. In the "circle" type of run, the SEMMES circled the SEALION at specified ranges and speeds. The ranges were not constant but the decibel values used in plotting the curves were adjusted to the specified range by a correction factor calculated from the experimental data of the particular test.

4. The deep and shallow water comparisons were made in the Virgin Islands area about 40 miles northeast of St. Thomas where a large shoal area at 15 to 30 fathoms is only a few miles from an open ocean area of 2,000 fathoms and where water conditions should be uniform in both deep and shallow areas. The temperature-depth curve taken in deep water at 2235 on 15 January, Curve 1, Plate 1, shows less than 0.2°F. variation from 1 to 20 fathoms, but has an inversion of 0.4° between 20 and 25 fathoms. A 10 to 20 knot northeast wind all day prevented the building up of a gradient near the surface. However, the wind decreased from 20 knots when the tests began at 1300 to 10 knots at 2100 when they finished and this undoubtedly changed the listening conditions somewhat. A submerged run was made only in deep water as it was not considered safe to dive in the shallow water area.

MAXIMUM RANGE DATA

5. A summary of the data on the deep and shallow water tests is shown in Table 1, and comparisons of deep and shallow, surface and submerged, lying-to and underway tests are shown in Table 2. In obtaining the maximum range in each case, the time-range-bearing record

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obtained by periscope readings was compared with time-intensity-bearing record obtained by each listener. The criterion for maximum range was that the sound bearing should be within $\pm 5^\circ$ of the periscope bearings, that the intensity level should be definitely above the average background noise level, and that the listener could definitely recognize the noise of the SEMMES propellers. In the original data the JL readings are frequently marked weak or bearing uncertain. A zero means that no recognizable propeller noise was heard.

6. A study of Table 1 shows a general increase in maximum range with time on all units under all conditions. This is probably due to the fact that the wind decreased from 20 knots at the beginning of the tests to 10 knots at the end, thus improving the surface water conditions, reducing the background of water noise and the pitch or roll of the ship, and also that the listeners improved with practice. In the last two columns, the ratios of the maximum ranges are given for each run during which the conditions would be identical, thus eliminating the effects of the improvements noted above. This shows that the JK averaged 41% greater range than the QC and the JL about 60% less than the QC or 30% of the JK. It should be noted that these ratios are in ranges and not intensities. At no time did the JL equal the JK.

7. In Table 2 are given other ratios calculated from the data of Table 1, all expressed in terms of the maximum ranges obtained under the conditions specified.

8. The deep/shallow ratios average about 2.0 for the JK and QC. There are three known factors involved in this comparison: the apparatus, the water conditions, and the listeners. The water conditions are known to have improved between the times of the shallow and deep tests, and the listeners probably improved with practice, thus tending to increase the ratio. Positive quantitative conclusions about the equipment are questionable in this case, especially as the JL is also better in deep water.

9. The submerged/surface ratios indicate that on the SEALION neither the water noise nor the air-borne noise from the engines is a serious handicap for keel mounted JK and QC units at speeds up to 8 knots, as the ranges are about the same as for running at slower speeds on motors with less vibration and air-borne noises.

10. In the lying-to and charging vs. running at 8 knots and charging ratios, the averages are less than 1.0 for the JK and QC but 1.37 for the JL. This may be interpreted in terms of the listening conditions and background of noise. While lying-to there is considerable roll and yaw to the ship making it impossible to hold a conically beamed projector like the QC or JK constantly on the target and this reduces the average intensity. The vibration and air-borne noise are low, although there is considerable irregular water noise. The JL being focused in a horizontal plane only is not much affected by the roll, but is improved by the low noise background. When underway into the wind and sea, the roll is largely eliminated and the pitch has no

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effect on the JK and QC, but with the JL the pitch of the ship causes the water to run in and out of the vents in the superstructure just above the magnetophones and raises the background noise level above the signal level.

ACCURACY OF SETTING BEARINGS

11. Table 3 shows the difference between the bearings recorded by each listener against time and the record of periscope bearings against time. These errors seem larger than previous experience would indicate. It is probable that the settings were actually more accurate than the record indicates. The bearings were changing 5° or more per minute so an error in timing and recording would appear as an error in bearing. The 1° less error for the QC than for the JK is not considered significant as it was eliminated and both were improved in later tests by listening at lower levels. The intensity level on the JK was 10 to 20 decibels above the QC and generally too high for accurate setting of the bearing during these tests.

LOSS COEFFICIENTS

12. The range-intensity curves for 15 January were plotted for each type of gear on each run and where the data were sufficient to determine a slope for the curve, the results are given in Table 4 for the JK and Table 5 for QC. The loss coefficient α is defined as the average decibel loss per thousand yards between the ranges given. Some typical range-intensity curves are shown on Plate 2. From both the tables and the curves it will be seen that the loss coefficients have a wide spread but they have been arranged in three fairly homogeneous groups, 500 to 1500 yards, 1,000 to 4,000 yards, and 5,000 to 9,000 yards, and the averages calculated for each group. There was no means of measuring the intensity on the JL in this test so it is not included in this comparison. The average loss coefficient $\alpha = 4.75$ for 1,000 to 4,000 yards compares favorably with an average value of $\alpha = 6.0$ for a 24 kilocycle direct cw signal obtained during a two months period at Guantanamo in 1938 under various water conditions. The conditions of these tests on 15 January 1940 are considered good and should give a less than average loss coefficient.

STUDY OF SOUND PATTERNS AROUND SEALION

13. This test was made on 24 January in deep water off Guantanamo Bay entrance. The temperature-depth curves are shown on Plate 1. This was a calm morning preceded by three days of calm weather, so the 0735 curve is irregular but the 0.3°F. inversion at about 7 fathoms would tend to keep the sound in the layer above this level and give good intensity on a projector at 50 feet depth. By 1055 a rather steep positive gradient had developed in the first 5 fathoms but this is not seriously unfavorable for listening to propeller noise under the conditions of test.

14. The SEMMES' speed was 15 knots throughout the tests. In runs 1 and 3 she "circled" the SEALION at 1,500 yards and in run 2 the

average radius was 2,700 yards. Since it was impossible to keep the range exactly as specified the decibel readings on the curves were adjusted to the average range. The readings of intensity on the JK and QC are directly comparable since the amplifiers are the same type, the same frequency of 24 kilocycles was used on both, and the zero decibel level had the same arbitrary value. The differences therefore are in the projectors. The JL gave audio frequencies and the sensitivity level is unknown, so the zero decibel level is not comparable to the QC or JK, but the slope of a range-intensity curve is comparable since it is independent of the level.

15. Plates 3 and 4 show the sound pattern for the JK and QC at 1500 and 2700 yards respectively with the SEALION at about 2.5 knots. In Plate 5 the SEALION'S speed was 7.5 knots and the range 1500 yards. The 1500 yard curves are fairly symmetrical except around 180°. The listeners were usually able to recognize the SEMMES through the SEALION'S propellers, but the output meter had no discrimination and measured the total noise. The 2700 yard run gave fairly constant values for the JK but the QC curve is flat at the bow. The reason is not obvious and may well be experimental error. Comparison of the six curves shows no consistent distortion on any particular bearing. The readings average 15.0 decibels higher on the JK than on the QC for the three runs. The noise levels were low at approximately zero decibels for both at speeds up to 8 knots submerged.

LOSS COEFFICIENTS FOR PROPELLER NOISE

16. The data of 24 January furnish an excellent basis for calculating the loss coefficients for propeller noise. First an approximate loss coefficient is determined and this is used to adjust each range-intensity reading to the average values of 1500 and 2700 yards for runs 1 and 2, respectively. The averages are then calculated for each. The difference in intensity divided by the difference in range gives the loss coefficient α. The results are shown in Table 6.

17. The value of 7.0 ± 0.3 for the JK is considered the more reliable as the abnormal flattening of the QC curve at 2700 yards makes the average intensity low, the difference in intensities at the two ranges greater, and therefore α larger than normal.

18. Given the intensity at a known range, the loss coefficient, α, and the noise level, it is possible to calculate the theoretical maximum range, that is, the range at which the signal would be reduced to the noise level. Thus from Table 6 for the JK at 1500 yards the intensity was 40.6 decibels, $\alpha = 7.0$ and the noise level was 0 decibels. The maximum range =

$$1500 + \frac{40.6 - 0}{7.0} \times 1000 = 7300 \text{ yards.}$$

Similarly for the QC the maximum range is found to be 5300 yards. The ratio of maximum ranges, JK/QC = 1.38. This checks remarkably well with the average of 1.41 found on 15 January.

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EFFECT OF SEALION'S SPEED ON MEASUREMENTS

19. During runs 1 and 2 the SEALION operated at minimum submerged speed to keep the local background noise as low as possible. During run 3 she made 7.5 knots. The comparison of runs 1 and 3, both at 1500 yards, is shown in Table 7. The data show that the higher speed had no effect on the JK or QC but that it raised the noise level on the JL above the signal level so that no readings were obtained. The noise level was raised less than 6 decibels for the QC and JK and was therefore 20 to 30 decibels below the signal. The background noise had no effect on the total noise because, for example, a noise level of 6 decibels added to a signal of 26 decibels gives a total of 26.05 decibels.

20. The listeners from the SEMMES, who had had previous experience with the deck mounted JK on the S-20, frequently commented on the great reduction in background noise for the keel mounted JK on the SEALION.

ALL DIRECTIONAL UNITS - QC UNITS MOUNTED ON CONNING TOWER

21. These units were designed primarily for reception during supersonic intercommunication, but attempts were made to pick up propeller noise during these tests. The results were entirely negative. The background noise was so high that the SEMMES propellers were not heard at any time even at ranges as short as 1000 yards and at minimum submerged speed. These units are therefore of no practical value for listening to propeller noise. They are mounted in an inherently noisy location and an increase in sensitivity would not improve the signal/noise ratio.

ESTIMATION OF RANGE FROM INTENSITY MEASUREMENTS

22. The data of 24 January may be used to calculate the accuracy with which the range may be estimated from a series of intensity measurements. The average intensities for each run were found and each individual reading was subtracted from the average to give its deviation from the mean. The average deviation from the mean was then calculated. Since a few large deviations might affect the average quite materially, the median deviation was also found. The median deviation is that value for which there are as many readings above it as below it without regard to the magnitude of the difference. From the average deviation the equivalent error in range can be calculated from the observed value of α . Thus for 2.6 decibels average deviation from the mean intensity and α = 7.0 decibels per kiloyard, the average error in range will be 2.6/7.0 x 1000 = 370 yards. Since the deviations are averaged without regard to sign, the error in range may be either plus or minus. These calculations are summarized in Table 8. The data show that the median error in estimating the range from a single reading of intensity is more than ± 300 yards; that is, it is just as probable that the error will be greater than ±300 yards as it is that it will be less. The average error is ±400 yards. It should be remembered that this uncertainty is calculated from 175 readings taken under approximately ideal conditions of constant target speed and range,

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uniform changes in bearing, good listeners and excellent water conditions. If the target had been running on a zig-zag course, at variable speeds, or if the temperature gradients had been unknown and variable, the uncertainty would have been complete.

CONCLUSIONS

23. The keel mounted QC and JK supersonic equipments on the SEALION were definitely and consistently superior to the JL sonic equipment for listening to propeller noise under all operating and in water conditions covered by these tests. This superiority consisted lower background noise, higher signal/noise ratio, more accurate bearings, longer ranges in both deep and shallow water, more reliable operation and less training required for the operator. This conclusion is substantiated by numerous other tests made by the SEMMES during the past six years.

24. The background of local noise for the QC and JK keel mounted units on the SEALION was increased by less than 6 decibels in going from minimum to maximum submerged speed. The absolute noise levels and the rise in level due to increased speed were approximately the same on the JK and QC units.

25. The JK was consistently superior to the QC for listening to propeller noise. The signal intensity averaged 15 decibels higher for the same noise level and the maximum range averaged 40 per cent greater.

26. The all-directional units (QC units on conning tower) had such a high background noise level on the SEALION that no target propeller noises were heard.

27. The loss coefficients for propeller noise were of the same order as for direct supersonic signals of the same frequency and under the same water conditions.

28. The intensity of the propeller noise from a target at constant speed and range was substantially independent of the relative bearing from the SEALION except in the sector from 160° to 200°.

29. Measurement of the intensity of the propeller noise is at best an inaccurate indication of the range and may be misleading unless the constancy of the sound source and of the water conditions are known.

30. The maximum ranges attained while listening to the SEMMES at 15 knots varied from 2000 yards to 10,000 yards under the different operating and water conditions during these tests. No estimate of the "reliable" listening range can be made unless the water conditions are known.

[redacted]

TABLE 1

SHALLOW WATER TESTS

SEALION listening at 24 kilocycles on QC and JK and audio frequencies on JL. SEMMES at 15 knots in 15 to 30 fathoms.

	SEMMES	SEALION	Maximum Range			Maximum Range Ratio	
Run	Course	Condition	QC	JK	JL	JK/QC	JL/QC
1-A	Out	Lying-to and charging batteries.	1900	2900	0	1.55	0
-B	In	do	1900	3800	0	2.00	0
2-A	Out	do	-	1700	0	-	0
-B	In	do	1900	1900	0	1.00	0
3-A	Out	do	1700	2700	0	1.60	0
-B	In	do	2500	2900	2200	1.15	0.90
4-A	Out	Lying-to with all engines stopped.	2200	3700	2200	1.70	1.00
-B	In	do	3400	3900	1600	1.15	0.45
5-A	Out	8 knots and charging.	2700	3100	0	1.15	0
-B	In	do	2200	2200	1600	1.00	0.75
	Mean - - - - - - -		2300	2900	700	1.35	0.30

DEEP WATER TESTS

SEALION listening on 24 kilocycles on QC and JK and audio frequencies on JL. SEMMES target at 15 knots in 2000 fathoms.

	SEMMES	SEALION	Maximum Range			Maximum Range Ratio	
Run	Course	Condition	QC	JK	JL	JK/QC	JL/QC
6-A	Out	Running periscope depth.	6700	10000	5600	1.50	0.85
-B	In	do	3800	8700	5600	2.30	1.45
7-A	Out	Lying-to charging.	3600	4500	0	1.25	0
-B	In	do	4300	5000	3600	1.15	0.85
8-A	Out	8 knots charging.	5800	8600	0	1.50	0
-B	In	do	4000	4800	0	1.20	0
	Mean - - - - - - -		4700	6900	2400	1.50	0.50

[redacted]

TABLE 2

RATIOS OF MAXIMUM RANGES

Condition	Deep/Shallow Ratios QC	JK	JL
Lying-to charging batteries	2.05	1.85	1.64
Running at 8 knots and charging	2.00	2.52	-
Condition	**Submerged/Surface Ratios**		
Submerged - periscope depth - 5 knots Surface - charging - 8 knots	1.07	1.40	-
Condition	**Lying-to/Running 8 Knots Ratios**		
Shallow water	0.81	1.0	1.37
Deep water	0.81	0.71	-

TABLE 3

ERRORS OF BEARINGS IN DEGREES

Averages of 5 to 15 reading on each run.

Run	QC	JK	JL
1-A	5	5	-
-B	1.5	3	-
2-A	-	7.5	-
-B	3	1.5	-
3-A	3.5	2	-
-B	3	4.5	14
4-A	6	6	13
-B	5	7.5	-
5-A	2.5	7	-
-B	4	4	13
6-A	-	3	1
-B	2.5	2	8
7-A	4	4	-
-B	3.5	7.5	0
8-A	1.5	2	-
-B	2	3	-
Average	3.3°	4.3°	8.0°

[redacted]

TABLE 4

LOSS COEFFICIENTS FOR PROPELLER NOISE ON JK

$$\alpha = (db_1 - db_2)/(R_2 - R_1)$$

Run	R_1	R_2	Db_1	Db_2	α 500 to 1500	α 1000 to 4000	α 5000 to 9000
2-B	500	1500	39.5	26.0	15.5		
3-A	1000	2000	20.5	17.0		3.5	
-B	1000	2000	26.5	22.0		4.5	
4-A_1	500	1500	42.0	29.0	13.0		
-A_2	1500	3500	29.0	18.0		5.5	
-B	1000	3000	43.5	31.0		6.2	
5-B	500	1500	75.0	54.0	21.0		
6-A	5000	9000	16.7	5.0			2.9
6-B_1	500	1500	53.0	36.0	17.0		
-B_2	1500	3500	36.0	24.0		6.0	
-B_3	6000	9000	11.0	3.5			2.5
8-A_1	1000	5000	21.0	2.0		4.8	
-A_2	5000	9000	-1.0	-1.0			0.0
-B	1000	5000	14.0	-4.8		4.7	
Average - - - - - - - - - - - - - - - -					16.5	5.0	1.0

TABLE 5

LOSS COEFFICIENT FOR PROPELLER NOISE ON QC

Run	R_1	R_2	Db_1	Db_2	α 500 to 1500	α 1000 to 4000	α 5000 to 9000
2-B	500	1500	36.0	20.5	16.5		
4-A	500	1500	35.0	17.0	18.0		
-B	1000	3000	30.0	20.0		5.0	
5-A	500	1500	41.0	28.0	13.0		
-B	500	1500	43.0	33.0	10.0		
7-B	1000	4000	23.0	11.0		4.0	
8-A	1000	5000	28.0	10.0		4.5	
-B	1500	4000	22.0	11.0		4.4	
Average - - - - - - - - - - - - - - - -					14.4	4.5	None

[redacted]

TABLE 6

LOSS COEFFICIENTS FOR PROPELLER NOISE

Deep Water - Guantanamo Bay Area

Average Range	No. Readings	Average Db JK	No. Readings	Average Db QC	No. Readings	Average Db JL	No. Readings
1500	37	40.6	59	26.4	43	21.2	39
2700	13	32.2	24	16.9	14	23.1	7
α = Db/Kyd		7.0 ± 0.3		7.9 ± 0.5		-1.8	

Noise level = 0 db.

TABLE 7

EFFECT OF SEALION SPEED ON PROPELLER NOISE MEASUREMENTS

SEALION Speed	Average Range	No. Readings	Avg. Db JK	No. Readings	Avg. Db QC	No. Readings	Avg. Db JL	No. Readings
2.5	1500	37	40.6	59	26.4	43	21.2	39
7.5	1500	13	41.2	20	25.6	15	-	0
	Diff.		+0.6		-0.8		-	

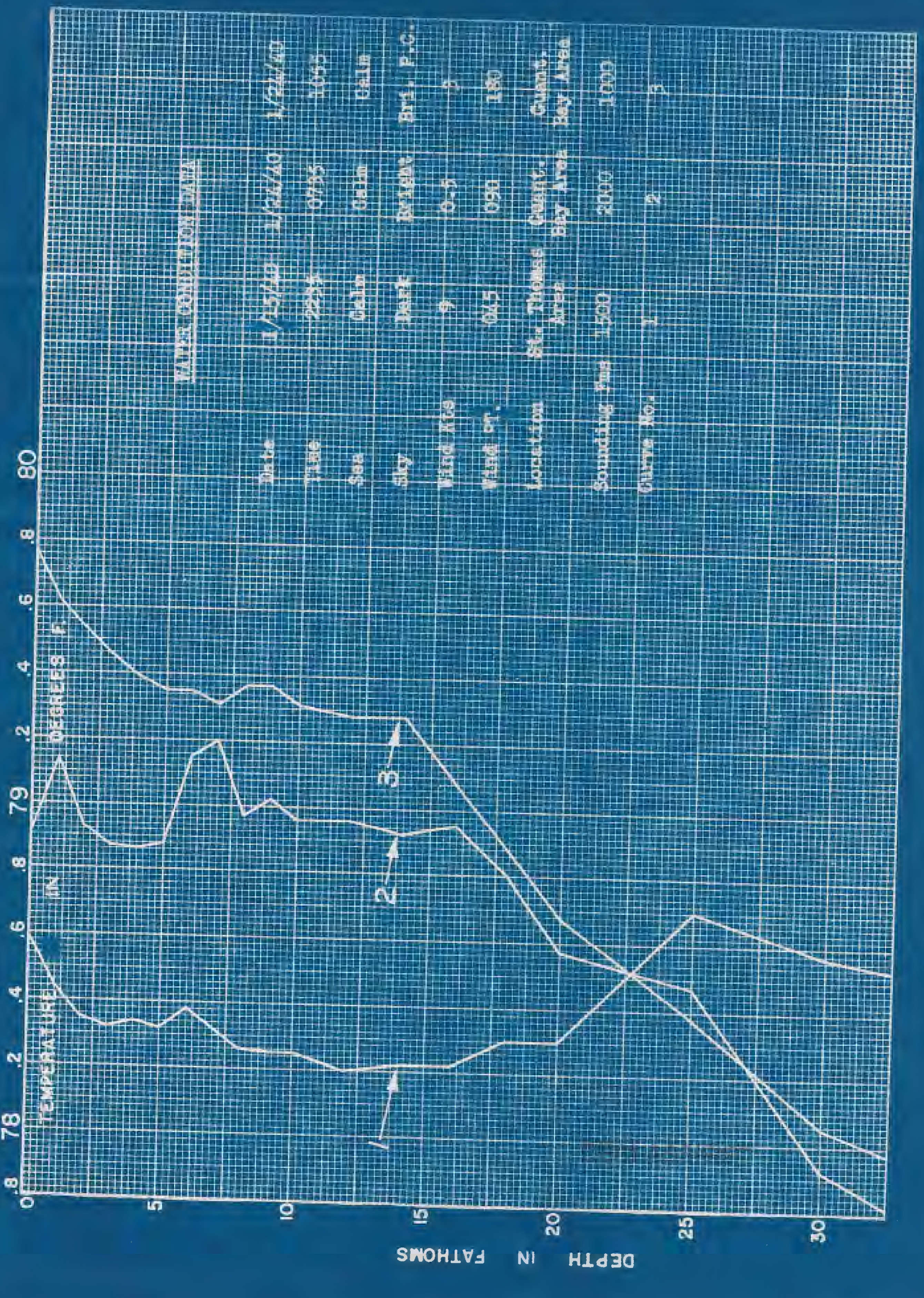
TABLE 8

ACCURACY OF INTENSITY READING AS MEASURE OF RANGE

Based on data of 24 January 1940

Projector	Deviation from Mean			Equivalent Error in Range	
	Average	Median	No. Readings	Average	Median
JK	2.6 db.	2.2 db.	103	±370 yd.	±310 yd.
QC	3.5	3.1	72	±440	±390

[redacted]



N. R. L. 34A

PLATE I

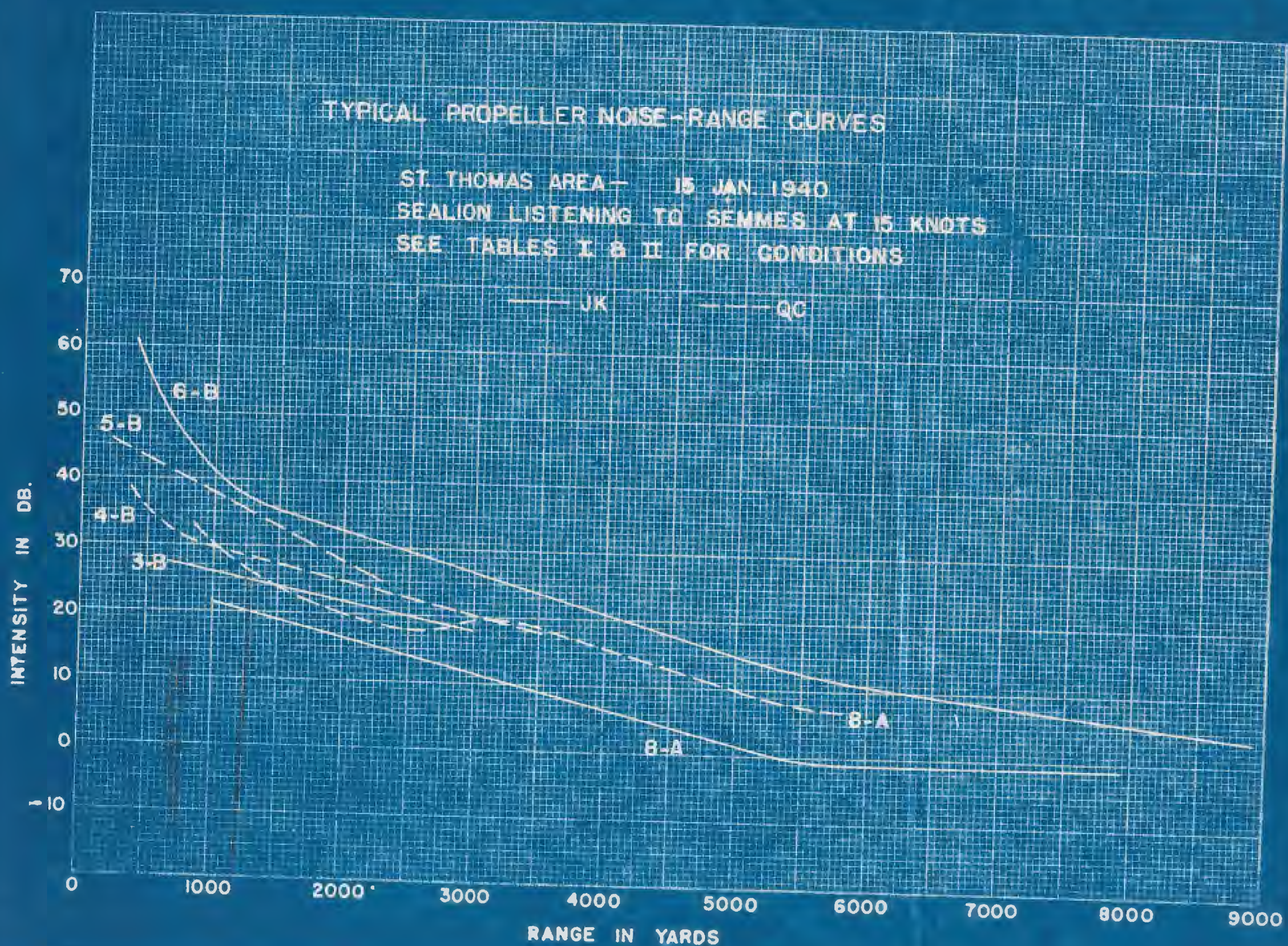
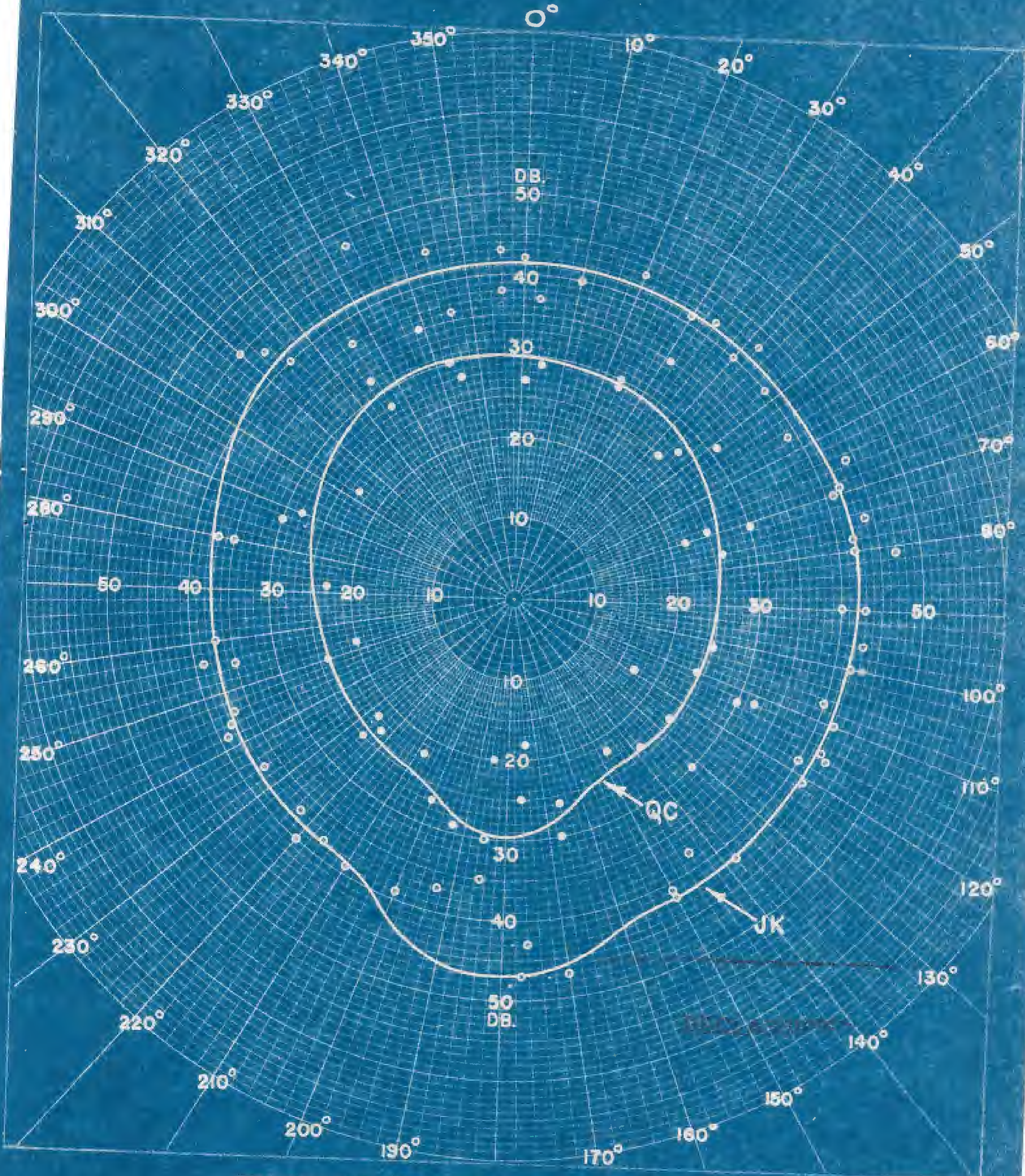
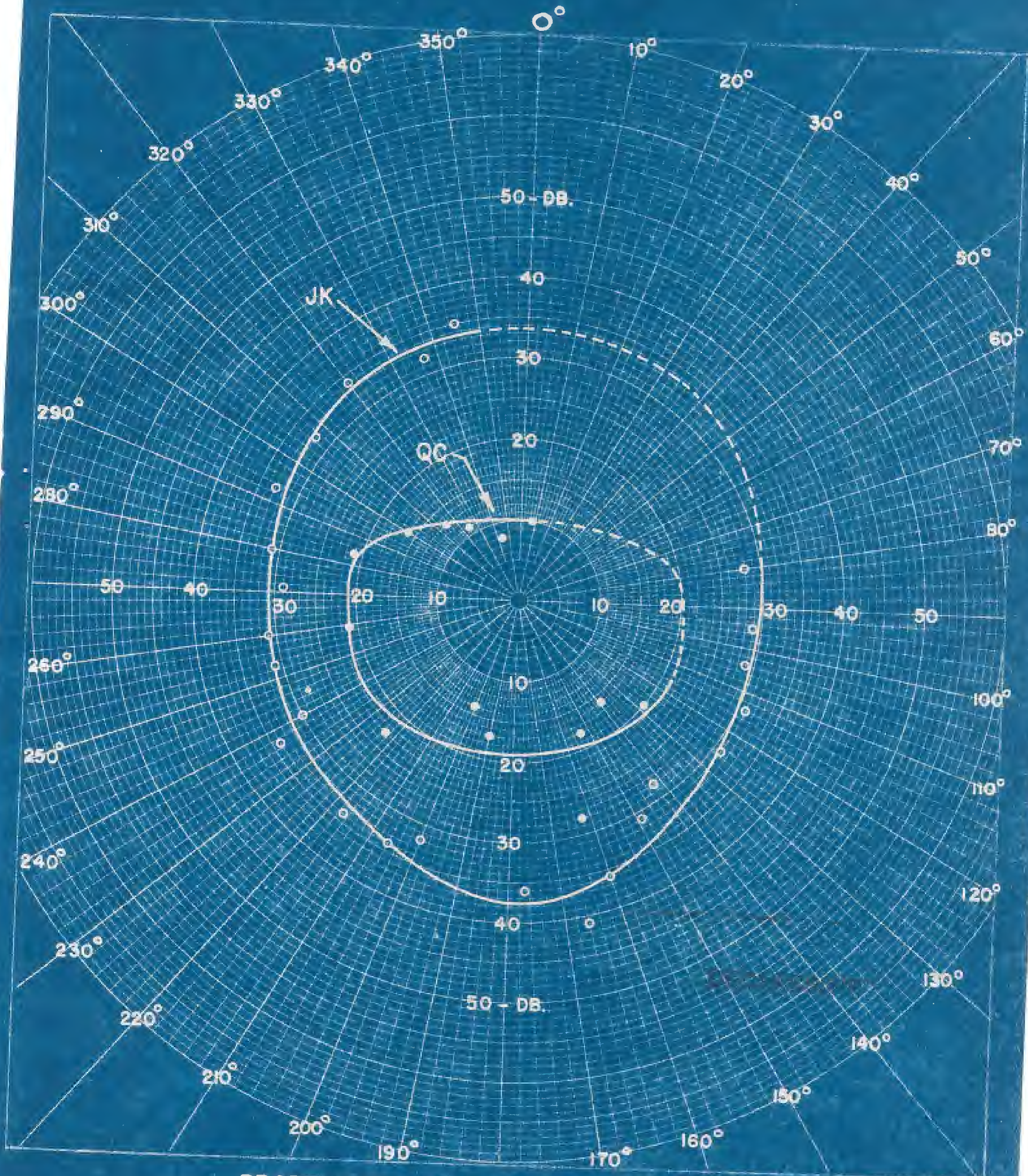

TYPICAL PROPELLER NOISE-RANGE CURVES
ST. THOMAS AREA— 15 JAN. 1940
SEALION LISTENING TO SEMMES AT 15 KNOTS
SEE TABLES I & II FOR CONDITIONS
JK
QC
6-B
5-B
4-B
3-B
8-A
8-A
INTENSITY IN DB.
70
60
50
40
30
20
10
0
-10
RANGE IN YARDS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

PLATE 2



PROPELLER NOISE - BEARING CURVES
GUANTANAMO BAY AREA -- 24 JAN. 1940
SEMMES AT 15 KTS. -- SEALION AT 2.5 KTS. -- RANGE 1500 YDS.

PLATE 3

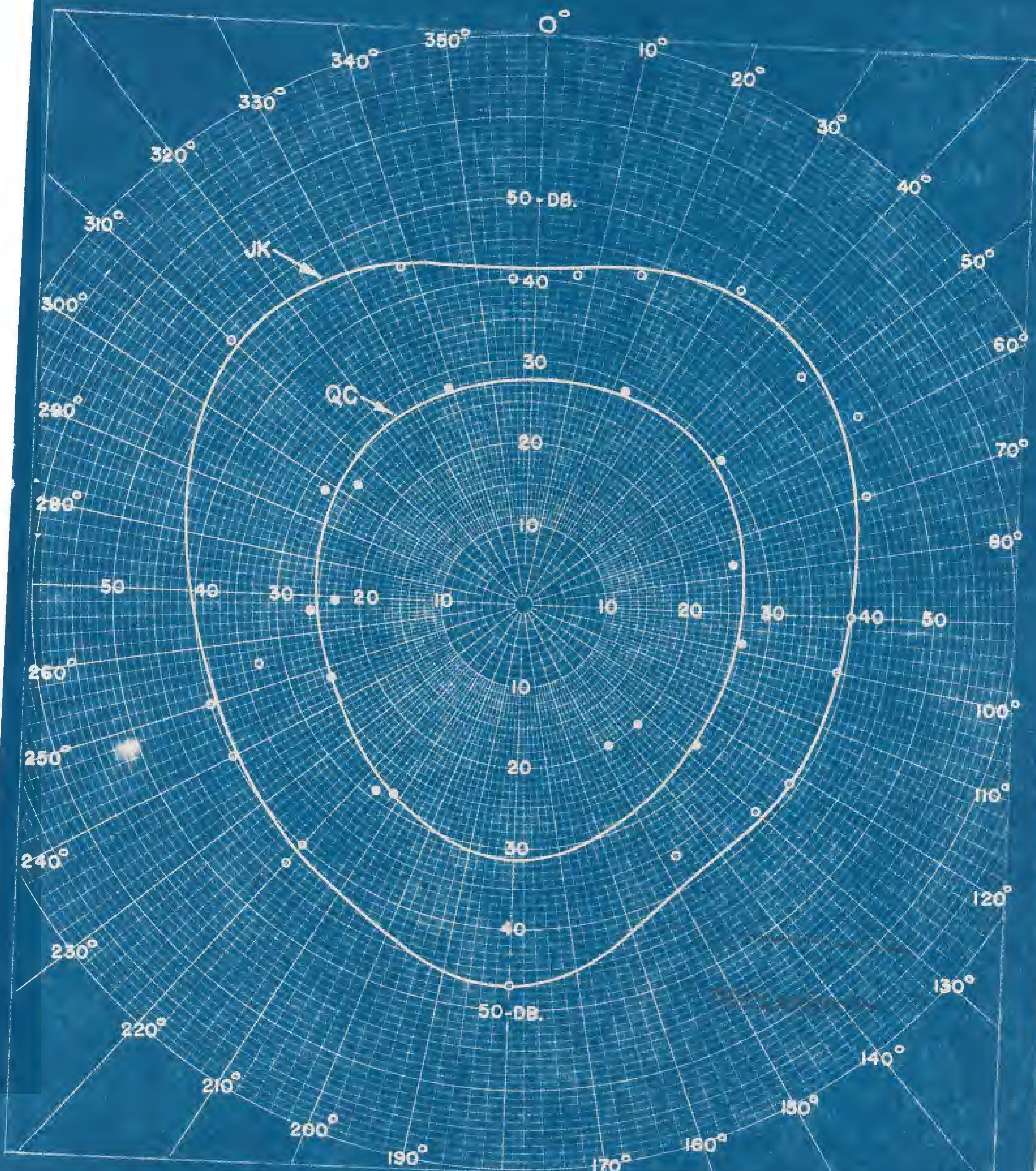


PROPELLER NOISE - BEARING CURVES

GUANTANAMO BAY AREA - - - 24 JAN. 1940

SEMMES AT 15 KNTS. - - SEALION AT 2.5 KNTS. - - RANGE 2700 YDS.

PLATE 4



PROPELLER NOISE - BEARING CURVES

GUANTANAMO BAY AREA -- 24 JAN. 1940

SEMMES AT 15 KNTS. -- SEALION AT 7.5 KNTS. -- RANGE 1500 YDS.

PLATE 5