5 February 1944 [redacted] NRL Report No. R-2229

FR-2229
Lab Memo 117-46

NAVY DEPARTMENT

Report on

Interpolation Charts for HF-DF Shipboard Calibration

[redacted]

[redacted]

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text 17 Tables 1 Plates 8

Authorization: BuShips ltr. (Conf.) 108(928-1) of 15 July 1943

Date of Investigation: 2 August 1943 to 15 October 1943

Task Group

M. K. Goldstein
M. J. Sheets
J. R. Atkinson

DECLASSIFIED by NRL Contract Declassification Team
Date: 3 AUG 2016
Reviewer's name(s): H. DO, P. HANNA
Declassification authority: NAVY DECLASS MANUAL, 11 DEC 2012, 08 SERIES

Prepared by: M. K. Goldstein
M. K. Goldstein

Mack J. Sheets
M. J. Sheets

Reviewed by: Warren B. Burgess
W. B. Burgess, Head, Measurements and Direction Finder Section

A. Hoyt Taylor
A. Hoyt Taylor, Superintendent, Radio Division

Approved by: J. L. Reinartz
J. L. Reinartz, Commander, USNR

A. H. VanKeuren
A. H. VanKeuren, Rear Admiral, USN

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by UNLIMITED only.

Distribution:
BuShips - 20
NR&SL - 1

DECLASSIFIED: By authority of 5000A January 1958
Entered by: E. Bliss Code 2027

DECLASSIFIED

SERIAL No. 39

5 February 1944 [redacted] NRL Report No. R-2229

DECLASSIFIED

NAVY DEPARTMENT Lab memo 117-46

Report on [redacted]

Interpolation Cha[redacted]
for
HF-DF Shipboard Calibration

Classification changed from Confidential
To Restricted
By authority Lab. memo. 117-46
File No. ---------- Dated 7-1-46

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text 17 Tables 1 Plates 8

Authorization: BuShips ltr. (Conf.) 108(928-1) of 15 July 1943

Date of Investigation: 2 August 1943 to 15 October 1943

Task Group

FR-2229

M. K. Goldstein
M. J. Sheets
J. R. Atkinson

Prepared by:

M. K. Goldstein
M. K. Goldstein

Mack J. Sheets
M. J. Sheets

Reviewed by:

Warren B. Burgess
W. B. Burgess, Head, Measurements and Direction Finder Section

A. Hoyt Taylor
A. Hoyt Taylor, Superintendent, Radio Division

Approved by:

J. L. Reinartz
J. L. Reinartz, Commander, USNR

A H VanKeuren
A. H. VanKeuren, Rear Admiral, USN

DECLASSIFIED

Distribution:
BuShips - 20
NR&SL - 1

[redacted]

DECLASSIFIED

TABLE OF CONTENTS

TABLES

PLATES

Reference Curves Through All Frequencies Calibrated

Comparison Between Curves Using Various Spacings of Calibration Frequencies and the Reference Curves

DECLASSIFIED

[redacted]

TABLE OF CONTENTS (Cont.)

PLATES (Cont.)

DECLASSIFIED

ABSTRACT

An investigation has been made to determine means for providing convenient and accurately corrected Naval shipboard direction finder bearings for any frequency within the h-f direction finder band without requiring more than a limited and feasible number of specific calibrations of the equipment.

Interpolation charts have been developed which simplify the plotting and application of direction finder calibration curves and furnish the desired corrected d-f bearings for the calibrated and for all other frequencies between those on which calibrations have been made. Means are discussed for choosing the optimum number and spacing of frequencies to be calibrated in terms of the probable interpolation accuracies that may be expected. A practical rapid calibration method is proposed to improve the efficiency and accuracy of making calibrations.

DECLASSIFIED

AUTHORIZATION

1. Work on this general problem was requested by the Bureau of Ships confidential letter 108(928-1) of July 15, 1943 to Naval Research Laboratory.

STATEMENT OF PROBLEM

2. The object of this investigation was:

(a) To investigate or develop means for providing corrected h-f Naval shipboard direction finder bearings for frequencies other than those actually calibrated.

(b) To accomplish (a) with a minimum of actual calibration frequencies or calibration time.

(c) To present the results of (a) in a manner that requires the least possible effort and skill on the part of the direction finder operator.

(d) To accomplish (a), (b) and (c) with optimum accuracy and minimum work in computing and plotting calibration data.

KNOWN FACTS BEARING ON THE PROBLEM

3. General High Frequency Shipboard Direction Finder Problem

Successful Naval shipboard hf-df operation has been recently achieved as a result of careful theoretical and experimental investigation of the effect of metallic objects and ship structures on direction finder performance (see bibliography (a) to (d)). While these investigations served to evaluate the various available locations for the hf-df collectors on Naval vessels, acceptable hf-df performance further required that definitely specified clearance areas be provided in the vicinity of the collector, and in addition, that the direction finder be calibrated for each frequency on which direction finder activity was anticipated. The importance of the latter was necessary in inverse proportion to the collector's clearance from the ship's metallic structures.

4. U.S. Navy Choice of Calibration Frequencies

Until recently, the Naval operating forces afloat found that approximately twenty five hf-df calibrations, requiring two to three days ship availability for calibrations of satisfactory quality, were adequate for their needs during the three to four month interval between recalibrations. Recalibrations are generally desirable in order to insure constancy of the deviation influence of the ship's structures.

DECLASSIFIED

In the case of recalibrations of the USS BEBAS made approximately within one month, considerable calibration instabilities were observed. More recently, however, forty or more hf-df calibrations have been found inadequate since enemy transmissions have been making very frequent shifts to new operating frequencies, indicating possible hf-df counter measures. Because it is not feasible at present to greatly increase the number of frequencies to be calibrated and since a large number of new enemy transmission frequencies are usually being encountered when the vessel is underway and when port calibration facilities cannot be employed, the operating forces are in urgent need of satisfactory means of obtaining corrected direction finder bearings for practically any frequency of transmission in the hf-df (e.g., 3-12 mc) band. At least one instance is known wherein the Commander of a Task Force deemed it necessary to break radio silence, in a probable combat area, in order to have one of the escort vessels of his convoy act as a target for calibrating an hf-df equipped Naval vessel on an important new enemy transmission frequency.

5. Proposed British Admiralty Choice of Calibration Frequencies.

The British experience in contending with the same frequency shifting, enemy transmission tactics is not too well known. Indications have been received that expedient practices (of unreported quality) have been used. For example, it is understood that at times the direction finder correction for the bearing on a new and uncalibrated transmitting frequency was obtained by using the correction of the nearest calibrated frequency. More recent British hf-df procedures apparently employ manual and comparatively awkward interpolations between calibrations, taken at one-half megacycle intervals. Specific instructions of the British in these particulars are contained in reference (f), an enclosure to references (d) and (e), from which the following is quoted:

"(a) (3 to 12 mcs) Curves of correction are to be obtained on frequencies selected (by the Calibrating Officers) from the list issued periodically by the Director of Signal Department, Admiralty. These frequencies are to be selected at approximately one-half megacycle intervals throughout this band.

"(b) Intermediate curves of correction are to be obtained by Calibrating Officers at one-quarter megacycle intervals in any regions where, due to rapid changes in the shape or magnitude of the curves obtained under (a) above, interpolation between the curves for any new intermediate frequency would appear to be unreliable. Additional swings should also be made on frequencies in the vicinity of those on which doubtful sense results are obtained so that the frequency range over which these results extend can be fairly accurately ascertained.

"(c)(Above 12 mcs) Curves of correction to be obtained on the actual frequencies indicated in the list.

"(d) Curves of correction are to be obtained for 2410 kcs and any other special frequencies in the British Naval Organization as directed by the C. in C."

As far as is known to the Laboratory no information is available as to the merit of the above practices.

ORIGINAL WORK DONE AT THIS LABORATORY

6. As a means for attaining the objectives listed in paragraph 2, the general problem was divided into three parts, and the following results accomplished:

(a) Using available (conventional) hf-df calibration data taken on the USS BEBAS (DE-10), Interpolation Charts have been developed which permit the obtainment of the corrected relative bearing for any frequency between actual calibrated frequencies. In addition, the interpolation chart method developed possesses the following pertinent advantages:

(1) The resulting accuracy is the greatest obtainable from the total actual calibration data available.

(2) The corrected bearing is given without requiring addition, or any other computation, by the direction finder operator (i.e., the method is rapid and involves minimum risk of error).

(3) Complete sense and blurring characteristics are incorporated for convenient use.

(4) The number of calibration charts is greatly reduced.

(5) The time and work required to prepare the interpolation charts is approximately two thirds that required for the conventional calibration charts which are now in use.

(b) The DAQ equipped USS BEBAS was employed in an experimental test to obtain the data used in developing the interpolation charts. Approximately 124 hf-df calibrations were made on specially selected frequencies in order to establish a highly accurate reference to which other selections of calibration frequencies could be compared.

(c) Comparison has been made showing the accuracy obtained with various methods of selecting the optimum number and spacings of calibration frequencies. This comparison includes the one-half megacycle calibration frequency spacings now being employed by the British, as reported in references (d), (e) and (f). *

(d) Rapid calibration methods are proposed that appear capable of materially improving current calibration speeds without affecting the calibration accuracy. Relatively simple auxillaries required for this purpose are described.

*References are given in Bibliography on page 13.

INTERPOLATION METHODS

7. Manual-Linear Interpolation

A logical and popular means for providing corrected hf-df bearings for Naval shipboard use for frequencies other than those actually calibrated consists of:

(a) The use of the conventional deviation curves of the two nearest calibrated frequencies.

(b) The performance of a linear frequency interpolation on the curves of (a), in order to obtain the correction for the desired uncalibrated frequency.*

(c) Adding this correction to the direction finder scale reading obtained on the uncalibrated frequency.

The above manual-linear interpolation method generally proves inconvenient, time consuming and subject to personal error when performed by the direction finder operator. There are indications that some direction finder operators prefer to avoid manual-linear interpolation, and utilize instead, the more expedient though less accurate method of directly obtaining a correction from the closest calibrated frequency. The large errors that may exist when applying such nearest calibrated corrections are shown in plates 4 and 5.

8. Smooth-Curve Interpolations

Probably the most accurate method for interpolating d-f corrections on frequencies between a given number of calibrated frequencies is to use a method of plotting corrections wherein smooth curves are drawn between the frequency points whose calibrations are known. In considering the various methods for plotting these desired smooth curves, it is apparent that of the three variables, namely, frequency, d-f scale reading, and deviation (or corrected d-f bearing), plotting frequency as an independent variable (e.g., abscissa) will best approach the desired smooth curve frequency interpolation. Further consideration shows that of the remaining choices for plotting the other two variables, using contours of constant d-f scale reading as an independent variable (e.g., contours) and corrected d-f relative bearing as the dependent variable (e.g., ordinates) permits linear frequency and d-f interpolations to be directly estimated by the d-f operator with high repeatable accuracies. Thus, the desired corrected relative

---

*A linear frequency interpolation for the deviation, dx, at frequency fx, when deviation d_1 and d_2 are known for the two calibrated frequencies f_1 and f_2, on either side of fx is directly given by;

$$dx = d_1 + (d_2 - d_1)\frac{(fx - f_1)}{(f_2 - f_1)}$$

Where f_1 is the lowest frequency and algebraic values of d_1 and d_2 are employed.

[redacted]

bearing on an uncalibrated frequency, can be rapidly and accurately obtained without requiring a single computation by the d-f operator. Plates 1 to 7 are examples of such plottings .

SENSE CHARACTERISTICS

9. In order to provide greater utilization of the d-f calibration data, the interpolation charts (see plates 6 and 7) directly incorporate complete sense characteristics on the contour curves. By this means, all of the sense data contained on the conventional calibration curve sheets are readily transferred to the interpolation charts. Additionally, contours are marked "Unreliable" whenever one calibrated bearing gives a reversed sense indication. These additional markings help to prevent the "sense" confusion formerly encountered by the d-f operator.

BLURRING CHARACTERISTICS

10. Blurring Characteristics For Estimating Bearing Reliability

It will be noted in plate 7 that some portions of the interpolation chart contain small letters, a, b, c, etc., on the contours. These letters are a convenient guide by which levels of bearing blurring (indistinct minimum on a manual null, FH3/DAR type, or pattern "pull in" on the automatic bearing indicator, DAQ type, direction finder) may be directly indicated. The following recommended reference letters correspond to levels of blurring such as may be read directly from the FH3/DAR manual or DAQ automatic bearing indicators:*

Manual Null (Arc of Blurring) Degrees	Blurring Reference	ABI Blurring (Pattern "Pull In") Percentage
a	5	10
b	10	20
c	15	30
d	20	40
e	25	50
f	30	60
g	40	70
h	50	80
i	70	90
j	90	100

* The figures in the second and third columns are to be used only with their letter references on the curves, and do not constitute a comparison of systems.

11. Blurring versus Bearing Fluctuation For Estimating Bearing Reliability

The bearing reliability estimates obtained from the use of d-f blurring characteristics by the U.S. Naval operating forces afloat has not been too

DECLASSIFIED

[redacted]

definitely established. It is understood from British experiences that considerable dependence is placed upon these blurring characteristics in order to permit of an estimate of bearing reliability related to the amount of sky wave components in the received transmission. An experienced d-f operator generally is able to make this estimate by noting the excess blurring in the bearing over and above the amount recorded during calibration. It is probably too early in the U.S. Naval operating experiences to definitely evaluate the full merit of such bearing reliability correlations. Fluctuations of the DAQ automatic bearing indicator bearings counteract to some extent the need for estimating bearing reliability by excesses of blurring. This counteraction is probably due to the more direct manner by which the d-f operators approximate amounts of sky wave components from the amount of fluctuation in the observed automatically indicated d-f bearing. Plate 7 shows the blurring characteristics incorporated on the interpolation charts in the event that future U.S. Naval operating experiences favor the use of excess blurring characteristics for evaluating bearing reliability. Should future Naval experiences show, however, that the amount of automatically indicated bearing fluctuations is adequate for estimating bearing reliabilities, the lettered blurring designations shown in plate 7 can be deleted in final charts.

CHART SIZE

12. In plates 1 to 6, inclusive, charts are shown having the approximate size of $8\frac{1}{2}$" by 11". In actual use these charts are convenient for handling and give an overall "repeatability" of interpolation that is of the order of 1° or better. To properly prepare these charts, it is convenient to plot using a scale in which abscissae and ordinates are two or more times the physical dimensions of those shown in plates 1 to 6. Plate 7 shows a chart for the complete azimuth, 0° to 360°, and for the most pertinent frequency range, i.e., 3.5 mcs to 10.5 mcs; it is a full size chart and has proven desirable in this form for the plotter as well as the d-f operator. The final size to be employed for the charts should, however, be further investigated to establish an optimum choice in view of the other practical factors that must be considered, i.e., size convenient for plotting, size convenient for use by the d-f operator, the facilities and time available for reducing from possibly large plotted dimensions to the final or application dimensions. It is possible that the increased use that may be given the interpolation charts may warrant the furnishing of necessary equipment auxiliaries that will permit improved chart arrangements suitable for efficient plotting and application use. Moreover, if extensive use of these charts is made, it is probable that several chart sizes may be desirable in order to more efficiently cover the azimuth and frequency bands.

CHOICE AND SPACING OF CALIBRATION FREQUENCIES

13. Need For Proper Spacing of Calibration Frequencies

Paragraph 4 has shown the urgent need for providing means for obtaining corrected d-f bearings for practically any frequency in the 3 mcs to 12 mcs band. Paragraph 5 discusses present British procedures for calibration at half megacycle intervals in the 3 mcs to 12 mcs band as a means for attaining such corrected bearings in this band. Presumably, the half

DECLASSIFIED

[redacted]

megacycle spacings are a compromise between: the time required to make the necessary number of calibrations and satisfactorily plot their results, the effort required for properly interpolating between calibration frequencies by the d-f operator, and the interpolation errors that can be tolerated.

14. Frequency Spacings For Reference Calibration Curves

Plates 4 and 5 indicate the accuracies that may be expected by use of smooth-curve interpolation methods when using various calibration frequency spacings. Plate 4, in particular, evaluates the errors that would be obtained when applying the smooth-curve interpolation method to frequency separations that were chosen without regard to interpolation procedures. For example, the solid curves in plate 4 are drawn through frequency and deviation points that were obtained using existing conventional hf-df calibrations, i.e., frequencies that were furnished to the Calibrating Officer by the office of the Anti-Submarine Warfare Command. These calibration frequencies are predicated entirely on official anticipation of enemy and other important transmissions on these frequencies for which d-f bearings will be required. The dotted curves of plate 4 are also drawn through the same points as those of the solid curve, but in addition a large number of extra calibrated frequencies are included. The extra points were carefully chosen to make the dotted curve the reference (or most accurate) calibration curve particularly since the extra points were chosen in the following manner:

Fre. Range Mc	Approx. Calibration Freq. Intervals	
	For Non-critical Freq.*	For Critical Freq.#
1.5 - 4	10%	$\pm\frac{1}{2}$% and $\pm 1\frac{1}{2}$%
4.0 - 10	5%	$\pm\frac{1}{2}$% " $\pm 1\frac{1}{2}$%
10 - 22	5%	$\pm\frac{1}{2}$% " $\pm 1\frac{1}{2}$%

* The smaller of the two closest integer frequencies were used.
# The critical frequencies were used as the necessary reference ffrequencies, the critical frequencies being determined from the charts; i.e., from the behavior of the contour-direction finder bearings for all calibration frequencies.

The deviations plotted in plates 4 and 5 represent the actual calibrations obtained on the USS BEBAS (DE-10), which was specifically calibrated on 124 frequencies in the 1.5 mcs to 22 mcs range for this purpose, during the week of July 26th at Casco Bay, Maine.

COMPARISON OF VARIOUS SELECTIONS OF CALIBRATION FREQUENCIES

15. Using the dotted curves as the reference (or true) calibrations, plate 5 shows the errors that would be obtained by use of the British proposed half megacycle method of selecting calibration frequencies. It is to be noted that irrespective of the method of selecting the spacings of calibration frequencies, all methods suffer to some extent from an

DECLASSIFIED

[redacted]

inadequate number of such calibration frequencies, particularly in the region of the critical frequencies. Paragraph 5(b) above shows that an attempt is being made to reduce the interpolation errors in the British method by including quarter megacycle spaced calibration frequencies in any region where rapid changes in the shape and magnitude of the deviation curves make the half megacycle spacings appear to be unreliable or where doubtful sense results are obtained. Table I compares the merit of the various methods for selecting spacings of the calibration frequencies in the currently most active hf-df frequency band.

DETERMINATION OF CRITICAL FREQUENCIES

16. It can be seen from plates 4 and 5 that in many cases it is practically impossible to determine the critical frequency regions when using half megacycle frequency spacings or when using the closer, though irregularly spaced special frequencies specified by the Anti-Submarine-Warfare office. Analyses of various methods of choosing frequencies including the extra frequencies discussed in paragraph 14 above indicate that a more reliable way of determining critical frequencies could be effected by having the calibration (target) vessel anchor "off the beam" at the regular (5/8 mile minimum) calibration distance, and run through the pertinent range of frequencies, using intervals of approximately one quarter megacycle. Frequency regions where deviations change rapidly with frequency can be observed readily and noted for later use as the critical frequency regions to be explored with closely spaced calibration frequencies. It has been found that the "off beam" azimuth method yields more pertinent critical frequencies than other known methods. This method of determining critical frequencies can be readily combined with the similar procedure used for determining the optimum sense capacitor adjustment of hf-df equipments, particularly in view of the large time saving that can be affected. This is possible because sense characteristics are generally taken over the frequency band before, during and after making the final sense adjustment, and because appreciable shifts in the sense check frequencies can be tolerated. No change in sense characteristics or adjustment should be experienced by using the "off beam" target position in lieu of the "off stern" position.

FACTORS TO BE CONSIDERED WHEN IMPROVING INTERPOLATION ACCURACIES

17. It is not known what importance is placed upon improving the interpolation accuracy of hf-df calibrations. The operating forces ashore and afloat are probably in the best position for specifying this importance and need for higher interpolation accuracy (of specified amount). They can more readily weigh the vessel availability and associated factors that would be required for the increased number of calibrations in view of the limitations of calibration facilities.

18. Limitations Imposed by Present Calibration Methods

[redacted]

The principal difficulty encountered when attempting to improve interpolation accuracy is the time limitation placed on making d-f calibrations. Present hf-df calibration methods can tolerate calibration speeds up to about 20 to 25 angular degrees per minute, for the required minimum calibration distance of 5/8 miles. This requires an average target boat speed between eleven and fourteen knots. Pelorus operators and data recording personnel generally introduce large errors when greater speeds are employed.

PROPOSED HIGH SPEED CALIBRATION METHOD

19. The Laboratory has long recommended high speed calibration procedures based on (a) military target sighting procedures such as may be employed to follow rapidly moving enemy craft (e.g., airplanes) and (b) automatic recording methods. Application of these procedures would allow a several fold increase in calibration speed without adversely affecting the calibration accuracy and in some cases actually improve such accuracy. If target vessel speeds of 33 or more knots are available, this would at least triple the existing calibration speed. Other possible arrangements may permit the vessel being calibrated to give the equivalent of high angular target speeds, e.g., using reversed screw rotations to approach spinning effect; or a combination of both methods, with opposite rotations, may be employed.

RAPID TARGET TRACKERS

20. While it is not within the scope of this report to evaluate the merits of the various radar, fire control and other types of high speed target trackers, the simpler portable types should not be overlooked, particularly when they may be especially suited for retention as part of the calibration crew's equipment.

RAPID D-F BEARING RECORDING

21. Many different arrangements can undoubtedly be devised for the rapid automatic recording d-f scale readings. One method proposed by Dr. M. K. Goldstein of this Laboratory is described in Appendix "B".

DISCUSSION OF RESULTS

22. As a solution to the problem of providing suitable hf-df bearing corrections for uncalibrated frequencies, a new and improved method for presenting hf-df calibrations is proposed which ~~possesses~~ the advantages listed in paragraph 6(a). Additionally, the merits of selection of various calibration frequency spacings are compared and means are suggested for approaching the best interpolation accuracy for the maximum numbers of calibrations (or time for calibration) that is permitted. Further, since it is shown that increased interpolation accuracy depends upon the number of calibrations made (as well as their spacing), high speed calibration procedures are proposed and include relatively simple auxiliaries reuired for this purpose.

[redacted]

CONCLUSIONS

23. It is concluded:

(a) That direct reading interpolation charts are more simple for calibration work than conventional calibration charts since no computations are involved during plotting or when used by the d-f operator.

(b) That interpolation charts give the corrected relative bearing for any uncalibrated frequency within range of the chart with the same ease as for calibrated frequencies. The additional accuracy and other advantages realized with these charts are listed in paragraph 6(a).

(c) That for the various interpolation methods known, interpolation accuracy depends upon the choice and number of calibrated frequencies.

(d) That the procedures used in preparing table I should be employed to obtain optimum interpolation accuracy for a given calibration time or number of calibration frequencies.

(e) That when a decision regarding the final choice and number of calibration frequencies is being made, the importance of increased interpolation accuracy versus the time and facilities available to effect the necessary increase in the number of calibrations should be carefully weighed.

(f) That the use of discreetly spaced calibration frequencies versus the use of calibrations made on specific anticipated enemy transmission frequencies should be carefully weighed when applying the conclusions of paragraphs (d) and (e) above, since overall d-f accuracies obtained on specifically calibrated frequencies are somewhat greater than those obtained by any interpolation methods.

(g) That high speed calibration methods, if developed, could be employed to at least halve the time required to make the conventional number of hf-df calibrations, without impairing calibration accuracy.

(h) That use of high speed calibration methods can permit an appreciable increase in the number of high quality d-f calibrations that can be made within the time allotted for a given number of conventionally made hf-df calibrations.

(i) That in view of conclusion (a), (b), (d) and (h), it is feasible for the d-f operator to obtain relatively high bearing accuracy on any uncalibrated enemy frequency in the hf-df band approaching that formerly possible only when a previous d-f calibration was available for the exact transmission frequency. This result can be realized in practice without any increase in calibration time; and the means employed should prove more convenient, more rapid and less subject to personal error when used by the d-f operator.

[redacted]

RECOMMENDATIONS

24. It is recommended:

(a) That interpolation charts be employed to supersede the existing hf-df deviation calibration charts.

(b) That interpolation charts be considered for mf-df and other ranges of d-f operation where deviation calibration charts are employed.

(c) That the choice and spacing of frequencies to be calibrated be made in accordance with paragraphs 23(d), (e) and (f).

(d) That a high speed calibration method discussed in paragraphs 18 to 21 be considered for development.

(e) That properly trained calibration crews be employed. They should be adequately staffed and equipped with a full complement of their own calibration auxiliaries in order to be capable of carrying out high speed as well as conventional speed hf-df calibrations on short notice and with minimum delays and assitance from the calibrated vessel's staff or other groups. The latter considerations will permit a greater number of calibrations for the assigned calibration time.

[redacted]

B I B L I O G R A P H Y

(a) "The Proximity Effect of a Metallic Fence on a Navy Model DT Direction Finder" - Naval Research Laboratory Report R-1890, dated June 19, 1943.

(b) "Secondary Radiation from Ship's Superstructure and Factors Controlling the Selection of the Most Suitable Position for High Frequency Direction Finder Aerials in Ships" - British Admiralty Report No. M400/4, December, 1941.

(c) "The Performance of the British FH-3 and the International Telephone & Radio Laboratories Crossed Loop Type High Frequency Direction Finders", aboard the U.S.S. CORRY (DD463). NRL Report R-1896, Dated June 20, 1942.

(d) "Calibration of Radio Direction Finder Type FH-3 in Destroyer Escorts Assigned to U.K. - VCNO Conf Ltr (SC) S67-9/EF13, Ser 0128802O, OP-20-E/dm, of Sept 17, 1943 to Comdeslant.

(e) Enclosure (a) to above reference (d) consisting of British Admiralty Secret Ltr D.S.D. (W) (S)/1209 of Sept 8, 1943 to VCNO.

(f) Enclosure (A) to above reference (e) consisting of British Admiralty Secret Ltr M-08114/43, S.W.I. of July 28, 1943.

[redacted]

Appendix A

1. While this report has been given only a confidential classification, attention is invited to the fact that certain of its contents and particularly the presentations in plates 1 to 6 inclusive might be considered as being of extreme practical value to an enemy. The presentations in the plates, while of considerable use in apprising the performance of high frequency direction finders in Naval vessels at a glance, by the same virtue would appear to be of considerable use to an enemy in showing the exact frequency at which the performance of high frequency direction finders, in the classes of vessels covered, thereby becomes highly erratic or entirely useless. Such information would permit an enemy to choose operating frequencies where high frequency direction finding for various classes of vessels would be impractical or inaccurate.

2. While it is true that such information could also be obtained from possession of calibration data of any direction finder, regardless of the manner of presentation, the presentations covered by this report and shown by plates 1 to 6 inclusive, is such as to make the characteristics stand out with great clarity and thereby attract attention.

3. It is believed desirable to reiterate the fact that the data submitted in the basic report are rigorously applicable only to vessels of the BEBAS class with installations of the Model DAQ collectors in a location identical with that employed in this vessel. For vessels of other classes or of the same class with a different type of installation, the specific data will differ from those shown although the technique of calibration and presentation should be described.

4. In this connection, it accordingly will be necessary during each prototype installation to determine the specific frequency distribution for the conduct of calibrations in order to permit the preparation of interpolation charts possessing the maximum usable accuracy. For certain classes of vessels, it is possible that sufficient calibration data are already available to permit of such a determination and a standardization of calibration frequencies. For installations in other classes of vessels, it will be necessary or at least highly desirable to conduct trial calibrations of a pilot installation at $\frac{1}{2}$ megacycle intervals with the signal approximately on one of the beams in order to obtain the required data. In this connection, it might be mentioned that in such cases, a somewhatsimilar frequency "run" is necessary in order to determine the proper adjustment of the sense capacitor in the loop head although present practices have been to conduct such "runs" with the signal astern. However, it is believed that beam bearings would be equally useful for the obtàinment of sense balancing data, so that on pilot calibrations, it would appear entirely feasible to conduct one calibration against frequency in $\frac{1}{4}$ megacycle increments with beam signals and obtain both sense balancing and calibration frequency

[redacted]

distribution data simultaneously. Such procedure would be invaluable, inasmuch as it would permit the obtainment of accurate sense data throughout the frequency band which might not become apparent on actual calibrations conducted at definite frequencies where sense reversals or indeterminate sense indications could exist between two of the calibrated frequencies and accordingly be passed unnoticed. It is the opinion of this Laboratory that the time thus required on the pilot installation will be amply justified by the saving of time of subsequent calibrations of many other vessels of the same class.

5. With respect to the employment of interpolation curves, it should be realized that, with any installation, there may be certain frequencies at which these curves will be of reduced value. However this is not a recrimination against the technique but is merely indicative of the fact that with any high frequency shipboard direction finder installation, certain regions exist in which stays, masts, stacks, conductors or other parts of the ship become resonant. In these regions the direction finder will either fail to function or will be extremely erratic in its operation or deviation. No method of calibration presentation will completely cope with this condition.

6. At several points in the basic report, mention is made of restricted frequency ranges, such as 3-10 megacycles or 3-12 megacycles, as well as quotations from a British report indicating similar frequency restrictions. This should not be interpreted as indicating that Interpolation Charts are not entirely useful throughout the entire frequency range of a Model DAQ equipment, or, in fact, the frequency range of any direction finder equipment, inasmuch as the Interpolation Chart procedure predicates a method of presentation rather than having any connection with direction finder performance. The basis for mentioning a frequency restriction, such as twelve megacycles, was connected entirely with the tactical employment of high frequency shipborne direction finder, it having been found that in general, enemy transmissions from submarines, or similar vessels are not frequently made on frequencies in excess of 12 megacycles. For this reason greater stress has been placed on the obtainment of the maximum calibration accuracy in the frequency bands 3-12 megacycles although it should be reiterated that Interpolation Charts would be equally useful at higher frequencies from a purely functional point of view.

7. With respect to footnote 6(c) of table 1, it is believed desirable to enlarge on the mechanics of determining the optimum number of frequencies to conduct calibrations on after a trial run with beam signals at $\frac{1}{4}$ megacycle intervals has been made. The process is one of trial and error inasmuch as it involves the variables of available calibration time and ultimate accuracy of the interpolation charts considered desirable of obtainment. In these premises, the following procedure is suggested:

DECLASSIFIED

[redacted]

(a) Plot the trial calibration curve of deviation versus frequency, following the serrations from point to point.

(b) Determine by consideration of the limitations of the specific calibration involved the number of different frequencies at which calibrations can be made. This will involve a certain amount of experience and the taking of cognizance of the various factors, such as the number of hours or days availability of the vessels, the relative speed at which the calibrating vessel can be run, the number and expertness of the calibration personnel, the available facilities, etc.

(c) If knowledge is available of certain specific enemy frequencies on which the equipment might be expected to be ultimately operated, first mark these frequencies on the trial calibration curve. By using these frequencies as definite calibration frequencies, the maximum accuracy in the operation of the equipment will be obtained at these points even though certain interpolation compromises must be made at other points.

(d) By inspection of the trial calibration curve mark other frequencies at which it would appear desirable to conduct calibrations in order to obtain the maximum accuracy from the interpolation charts. With a limitation on the number of calibrations that can be made, it is considered desirable to give the greatest weight, next to that given specific enemy frequencies, to those at or near the points of maximum deviation, so apportioned that a line connecting such points will most nearly approximate the trial deviation curve in this region. Better overall interpolation accuracy will be obtained by calibrating on frequencies in the region of those possessing the maximum changes in deviation rather than using frequencies where the deviation serrations are of a low order of magnitude.

(e) Count the number of calibration frequencies arrived at after the trial curve is thus marked. If this number is less than the number permitted by time and the other factors contingent thereon, go back to the trial calibration curve and pick additional frequencies near the points of the less severe serrations. If the number of frequencies determined by the first trial approximation exceed the number time and circumstances permit, go back to the trial calibration curve and eliminate those frequencies which would appear to afford the least compromise of ultimate interpolation accuracy.

DECLASSIFIED

APPENDIX "B"

1. Plate 8 indicates an arrangement of special equipment proposed by Dr. M. K. Goldstein of this Laboratory to permit of the obtainment of direction finder calibrations at high speed.

2. This suggested target tracker may take the form of a single portable pelorus capable of being mounted at least on the most pertinent Naval vessels, able to scan the horizon without encountering appreciable blind spots and possessing the following special auxiliaries:

(a) A suitable two-handled wheel (worm) drive arrangement to permit continuous and convenient tracking of rapidly moving targets (i.e., 60 or more degrees per minute).

(b) A comfortable seating arrangement to permit the operator to conveniently train the pelorus to follow his target and capable of rotating with the pelorus telescope or sighting mechanism.

(c) A suitable attachment for continuously "repeating back" the relative bearing of the pelorus to a recording device or capable of directly driving a suitable cylindrical chart on a 1:1 or other suitable angular displacement basis.

3. With this equipment the d-f operator when using the automatic indicator of a Model DAQ equipment needs only to key the marking relay whenever the d-f bearing has moved a given number of (say five) scale degrees. Additional "S-R", "S-U" and "B" markers can be provided as necessary to simultaneously permit recording of "Sense-Reversed", "Sense-Unreliable", and "Blurring" characteristics. If desired separate sense and blurring charts, run simultaneously with the deviation chart, may be employed with the "Deviation", "Sense", and "Blurring" characteristics transferred to a single chart at a later convenient time. Also, a rapid coded keying scheme may be employed for providing different identification from a single relay marker for the various bearing, sense, and blurring chacteristics desired.

[redacted]

TABLE 1

Comparison of Interpolation Accuracy for Different Methods of Spacing Calibration Frequencies in the Range 3.6 to 10.31 Mc.

Calibration Frequencies		Accuracy Obtained (1)		
Spacing based on:	No.	Av. Error (2) Degrees	Peak Errors (3) No.	Peak Errors (3) Degrees
Maximum Accuracy (for reference curve)	68			
ASW Frequencies (5)	22	1.9	1	18
(arbitrary spacing)			1	15
			1	14
			3	12
			1	11
NRL Proposed (6)	20	1.53	1	14
(with "off beam" test)			2	11
British Spacing (7)	18	1.8	1	15
(½ Mc. Spacing +4 extra)			1	14
			1	13
			3	12
			6	11
½ Mc Spacing (8)	14	2.07	1	15
(approximately)			4	14
			1	13
			3	12
			2	11
			2	10

Notes:

(1) Accuracies are based on errors noted in plate 5 between the reference calibration and the indicated calibration curve, the frequency band from 3.5 to 10.5 megacycles and the 0 to 90 degree quadrant being employed.

(2) Refers to an overall average of the individual contour average errors. The latter are obtained by planimetering the area between each reference calibration curve (contour) and the corresponding calibration method curve (contour) then dividing the measured area by their common (frequency) base line.

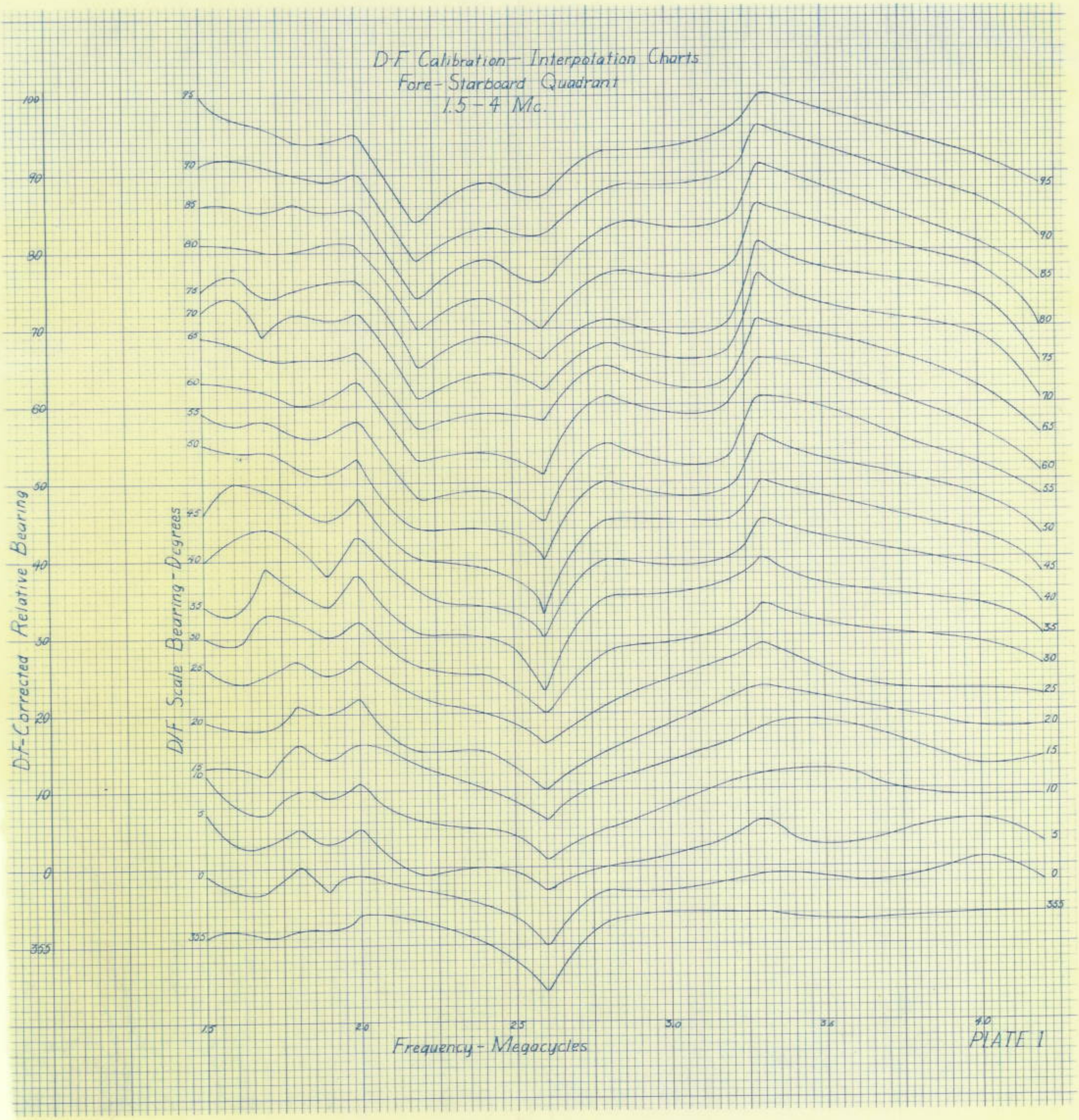
[redacted]

TABLE 1 (Cont.)

(3) Refers to peak errors of 10 degrees or more.
(4) The various methods of spacing the calibrations to obtain the reference curves is discussed in paragraphs 13 and 14 .
(5) The ASW spacing of calibration frequencies is based on a limited number of calibrations using exact transmitting frequencies. It therefore encounters critical frequencies only by pure chance.
(6) The above NRL proposed method is based on information obtained from a close frequency run with the target "off the beam" to determine the critical frequencies. Thus with nearly the same number of calibrations, the interpolation accuracy is considerably greater than that for either the ASW (random spacing) or the British method. The following procedure is employed for selecting the actual calibration frequencies used in the NRL method:

    (a) With target or transmitting source stationary, at approximately 90 or 270 degrees relative to ships' heading, note the d-f deviations obtained as the transmitting frequency is altered in steps of about 0.25 Mc.
    (b) Plot a deviation vs frequency curve, C_1, (i.e. true bearing being constant).
    (c) Superimpose a new deviation vs frequency curve, C_2, passing through an optimum number of deviation points of C_1, the latter being chosen to give the smallest number of calibration frequencies and minimum separation (difference) between C_2 and C_1 having due regard for the average separation as well as the peak separations.

(7) The British calibration points were chosen by the method given in paragraph (5). In addition to the $\frac{1}{2}$ megacycle separations specified, four additional calibrations were inserted as recommended; three because of sense conditions and one because adjacent curves were widely different.
(8) The $\frac{1}{2}$ megacycle spacing errors are listed in order to complete the accuracy comparison of the various methods.



D-F Calibration - Interpolation Charts
Fore-Starboard Quadrant
1.5 - 4 Mc.
D-F Corrected Relative Bearing
D/F Scale Bearing - Degrees
Frequency - Megacycles
PLATE I

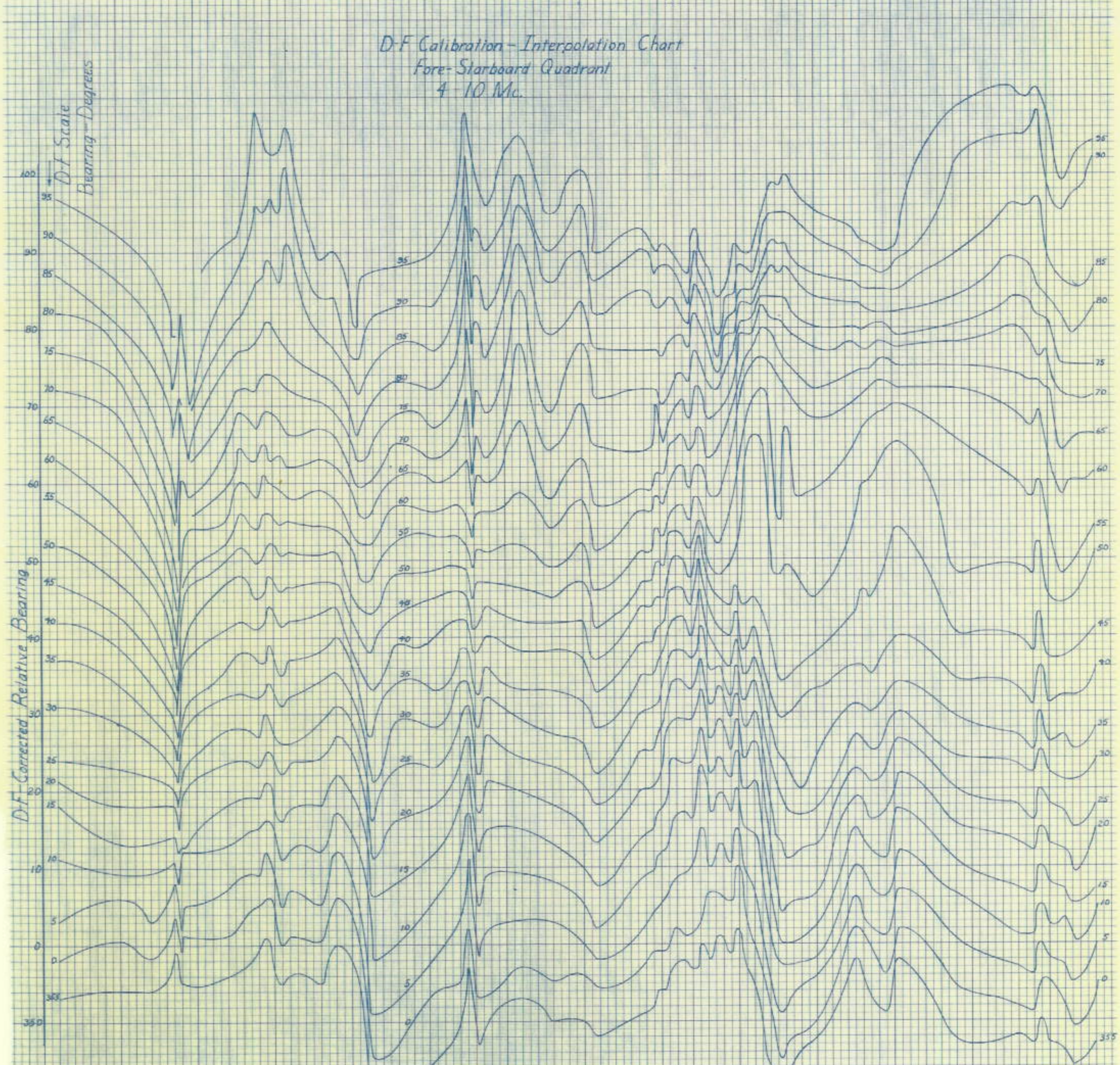

D-F Calibration - Interpolation Chart
Fore-Starboard Quadrant
4-10 Mc.
D-F Scale
Bearing - Degrees
D-F Corrected Relative Bearing
Frequency - Megacycles

PLATE 2

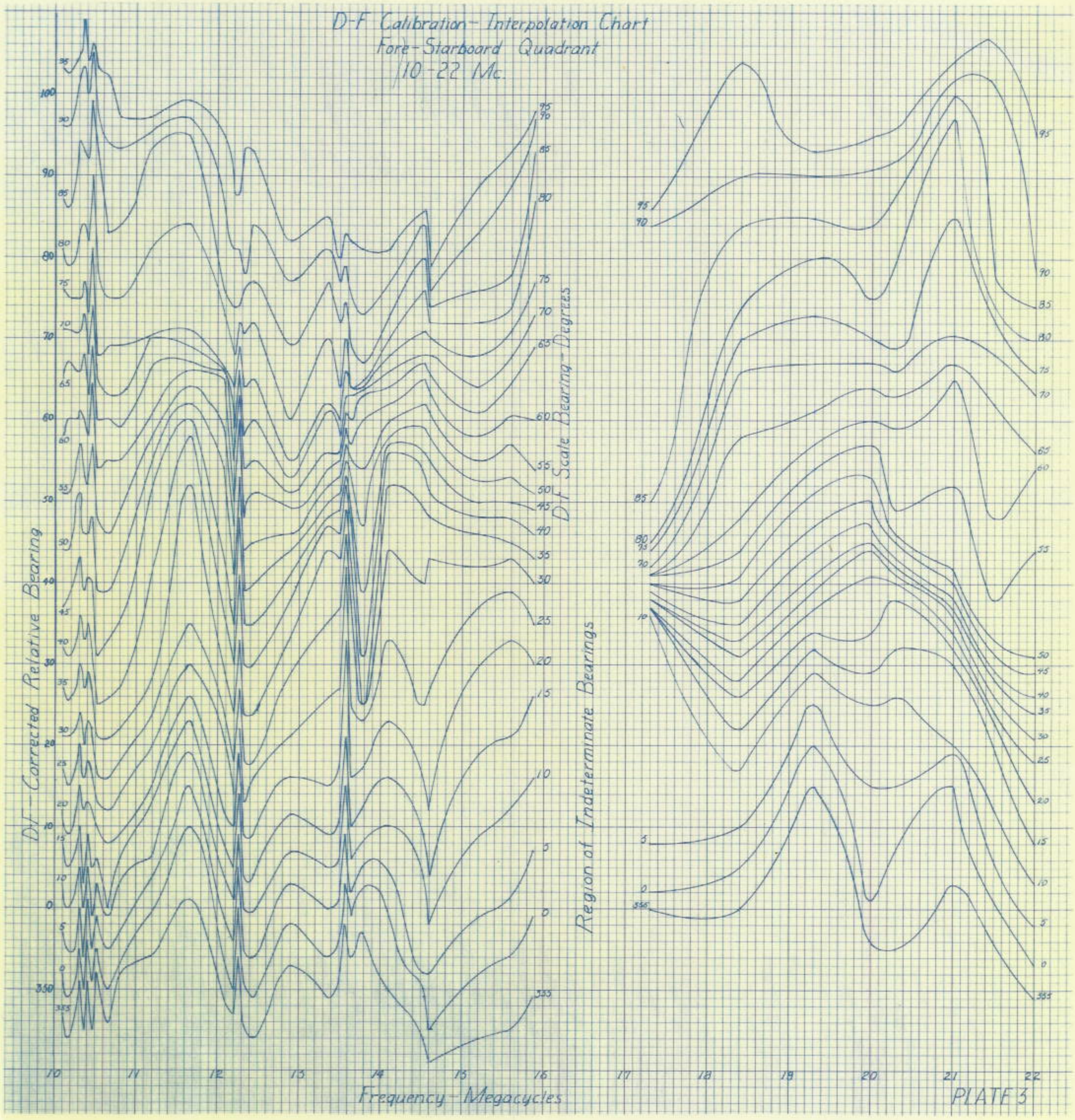
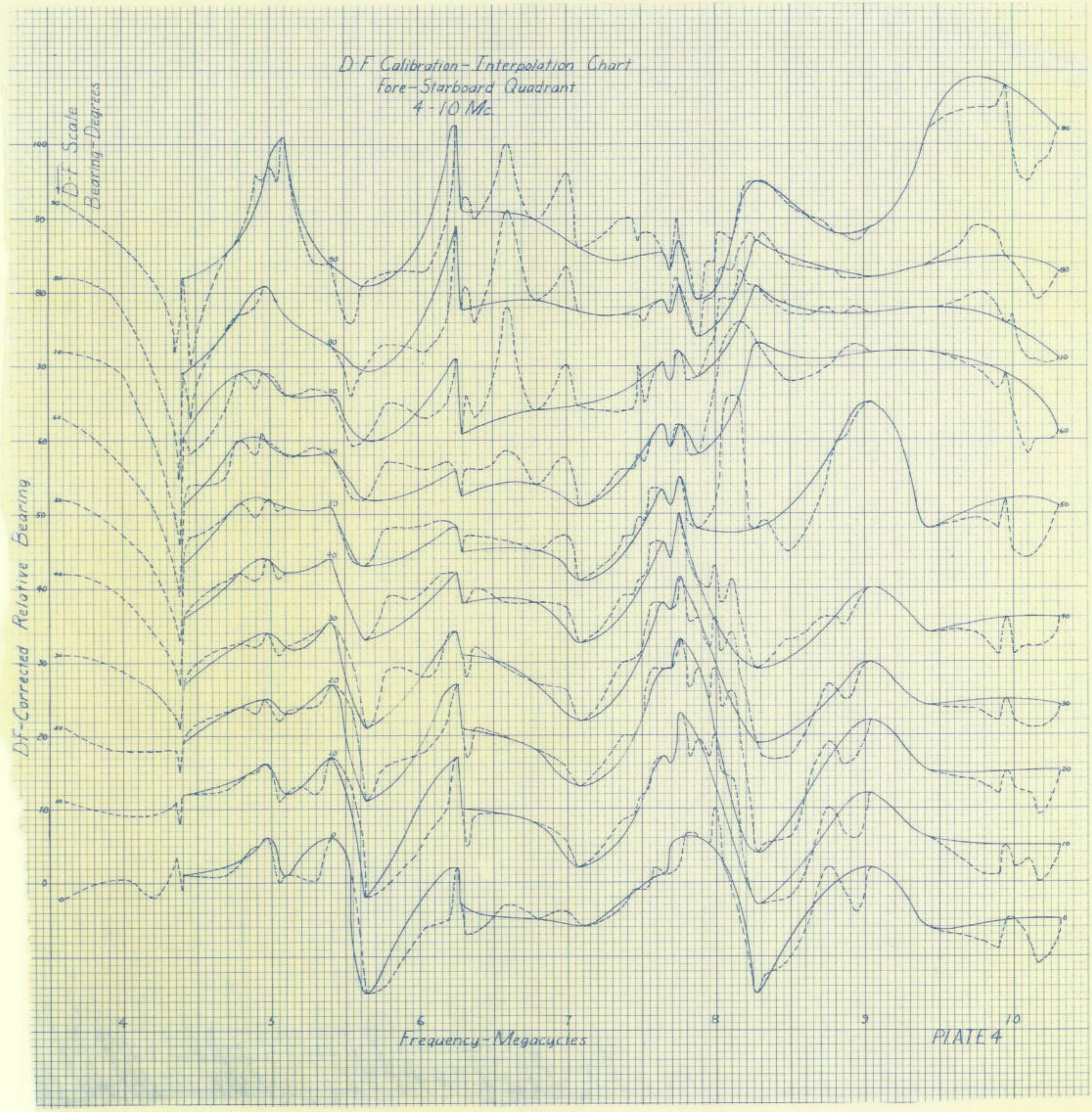
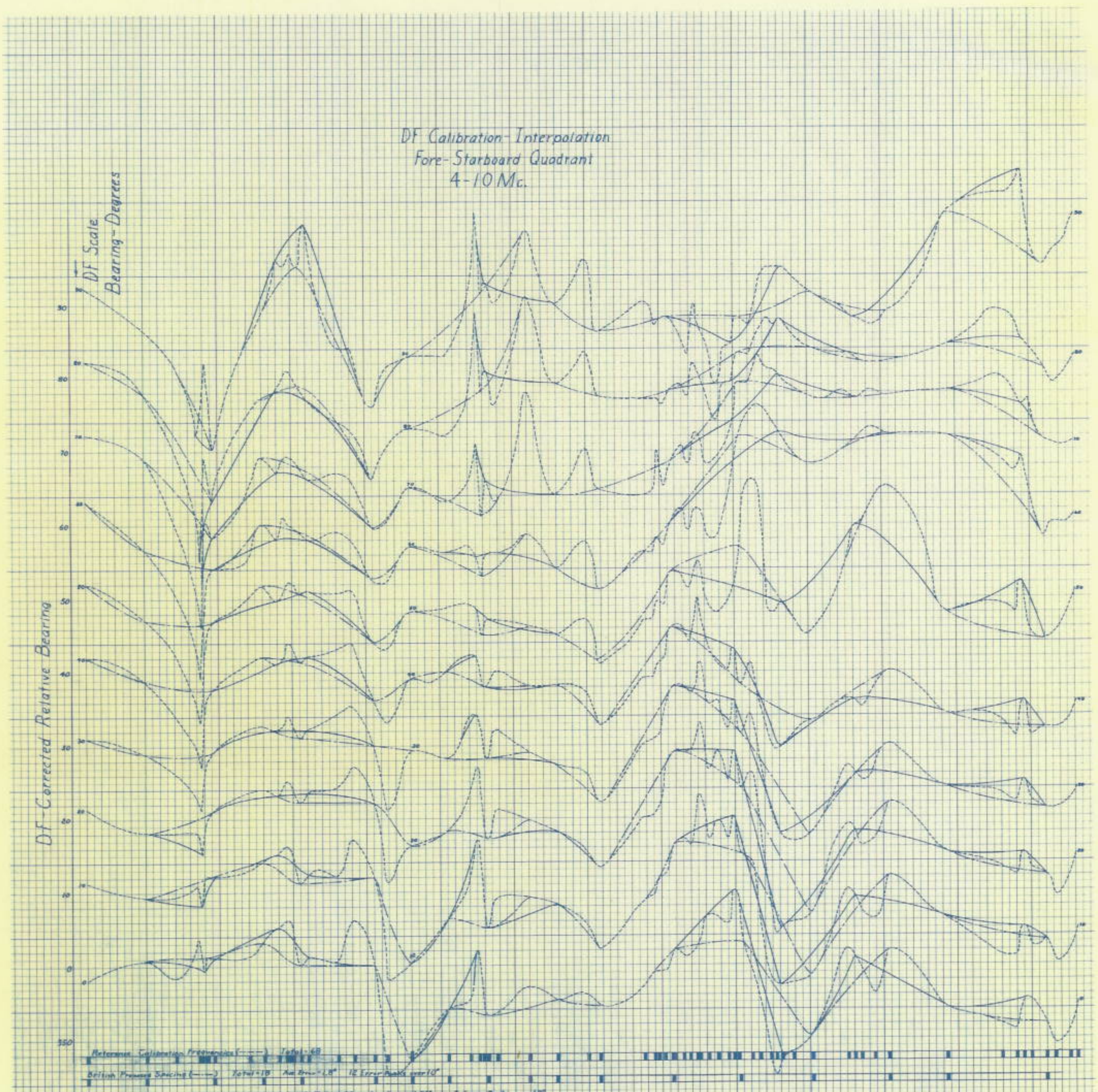


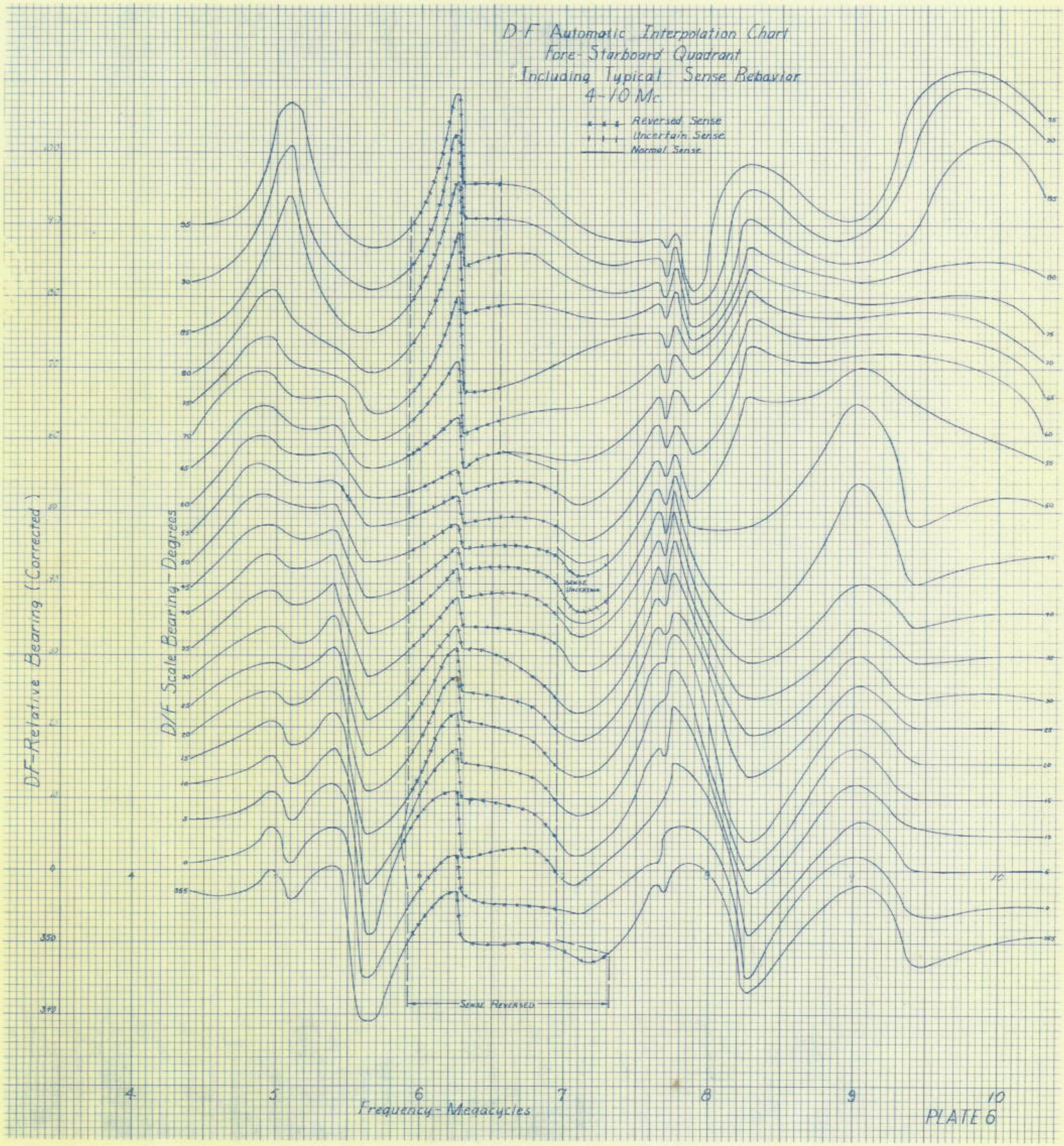
PLATE 3

DECLASSIFIED



DECLASSIFIED


DF Calibration - Interpolation
Fore-Starboard Quadrant
4-10 Mc.
DF Scale
Bearing - Degrees
DF Corrected Relative Bearing
Reference Calibration Frequencies (— — —) Total = 48
British Spacing (—·—) Total = 18 12 Error Peaks over 10°
NRL Proposed Spacing to Improve the Accuracy (——) Total = 20 3 Error Peaks over 10°
4
5
6
7
8
9
10
Frequency - Megacycles
PLATE 5


D-F Automatic Interpolation Chart
Fore-Starboard Quadrant
Including Typical Sense Behavior
4-10 Mc.
Reversed Sense
Uncertain Sense
Normal Sense
Sense Uncertain
Sense Reversed
DF-Relative Bearing (Corrected)
D/F Scale Bearing - Degrees
Frequency - Megacycles
4
5
6
7
8
9
10
350
340
PLATE 6

PROPOSED EQUIPMENT FOR HIGH SPEED D-F CALIBRATIONS

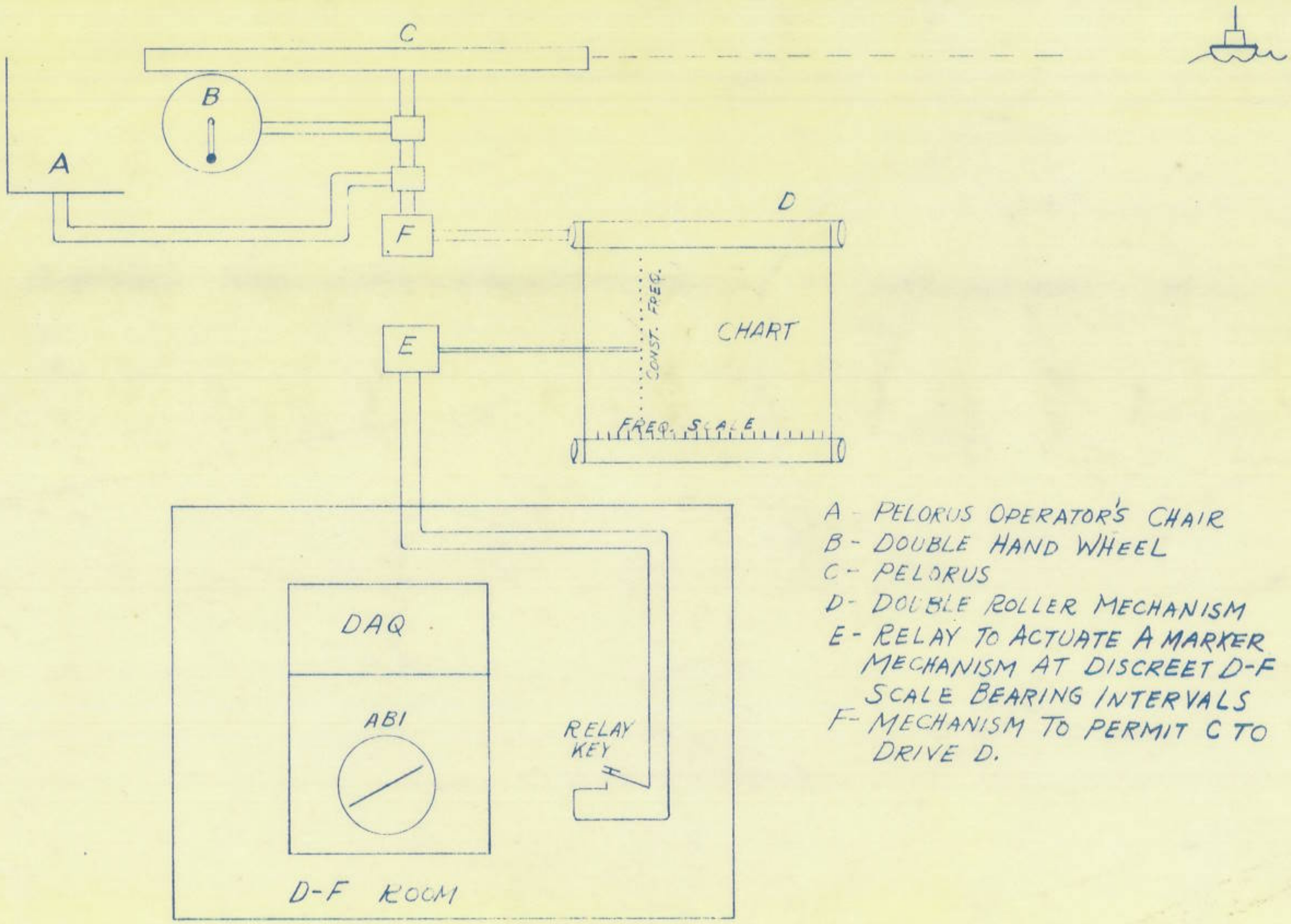


PLATE 5