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Report on

RADAR CROSS SECTION OF SHIP TARGETS, III

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ABSTRACT

The numerical values of the radar cross sections of combat ships presented in an earlier report are supplemented by measured values on ships of other types. The measurements are examined to determine the way in which they vary with frequency for a ship of given type and aspect. It is found that the far-zone radar cross sections increase roughly with the fourth or fifth power of the frequency.

Abnormal propagation conditions have been observed to increase the far-zone radar cross section by 10 decibels.

The reflections from the antennas of air-search radars have been measured on some of the larger ships. Because of its elevated position, the reflections from the antenna in its broadside aspect predominate when the ship is partially below the horizon, although not at closer ranges.

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1. INTRODUCTION

1-1. The work reported here has been conducted under the authorization of NRL Problem S411R-S, and is a continuation of the work previously reported in NRL Report R-2232.

1-2. In two previous NRL reports bearing the same title as the present report, the analysis and measurement of radar reflections from ship targets have been presented. The first report, No. RA-3A-213A (hereafter to be referred to as Report I), presented a simplified analysis which led to definitions of the radar cross section of ship targets. The second report, No. R-2232 (hereafter to be referred to as Report II), presented data derived from measurements on a number of combat ships. These data were found to be in accord with the definitions of radar cross section given in Report I.

1-3. In Report I it was found that the variation of received signal with range could be divided into two zones, called the near and far zones, and an appropriate radar cross section defined for each zone. These definitions are:

Far Zone:

$$(1) \quad \sigma_f = 4\pi R^2 \left(\frac{R}{h_1}\right)^4 \cdot \frac{W_r}{W_o}$$

Near Zone:

$$(2) \quad \sigma_n = 4\pi R^2 \frac{W_r}{W_o}$$

where

R = Range

h_1 = Height of radar antenna

W_r = Power density received at radar antenna

W_o = Free-space power density at target

1-4. The measurements of radar cross section were made by comparing the echo from the ship with the echo from targets of calculable radar cross section. These targets and the technique used in the measurements were described in Report II.

1-5. Since the measurements collected in Report II were made, data on further types of combat ships have been obtained and are presented here, together with the previous data. These data have been examined to determine the way in which the radar cross section of a ship varies with frequency.

2. METHODS OF MEASUREMENT

2-1. The method of determining the values of radar cross sections of ships remains substantially the same as described in Report II. In the standard target system and radar antenna locations, several changes have been made to improve the accuracy of the measurements.

2-2. The beam of the 3000 Mc SG radar was previously partially obstructed in the radial runs down Chesapeake Bay. This was overcome by moving the antenna to a new location, in which an unobstructed view is obtained over all the sectors normally used for these measurements.

2-3. The one-foot square corner reflector (at a range of 3900 yards) used as the SHF standard target for the measurements of Report II was raised to 22 feet above mean water level, so that it would be situated at the maximum of the second lobe for the 3000 Mc radars. The second maximum was chosen for reasons of mechanical convenience. At its new height, this reflector is at the first maximum for the Mark 12 radar.

2-4. A three-foot triangular corner reflector was installed on a mount of negligible reflection at a range of 9700 yards from the radars, and at a height of 17.5 feet above the mean water level, which is nearly at the first maximum for the 3000 Mc radars. The chief uses of this target were to provide a check for the calculated radar cross section of the one-foot square corner reflector, and to provide an indication of propagation conditions.

2-5. The ratio of echo powers to be expected from the corner reflectors at 9700 and 3900 yards can be calculated very readily under standard propagation conditions, and so can be compared with measured ratios as a check on the calculated radar cross sections of these targets. On days when propagation conditions were considered "normal", the measured power ratio was sufficiently close to the calculated value to place confidence in the use of the one-foot corner at 3900 yards range as a standard. On days when propagation conditions were not normal, the echo from the three-foot corner at 9700 yards varied relative to the one at 3900 yards, this variation amounting to as much as 15 decibels.

2-6. A further indication of propagation conditions was provided by Sharps Island Lighthouse, on which a two-corner reflector had been installed at the height of the first field intensity maximum for the 3000 Mc radars. Propagation conditions were considered "not normal" when the echo from the lighthouse faded badly. On these days, some fading of the lighthouse echo was noticeable on all the radar frequencies. The weather on such days was typically fair, often slightly hazy, and almost dead calm. When such conditions were encountered during the ship measurements, several repeats of each type of ship run were requested. Even though the received echo might vary somewhat erratically with range on a given run for a given frequency, when all the runs for a given aspect were considered together, the composite curve of echo power vs. range turned out to be fairly regular in many cases.

3. DATA OBTAINED

3-1. Radar Cross Section Measurements.

3-1-1. Since Report II, measurements of radar cross sections have been made on the heavy cruiser Quincy, the light cruiser Miami, the submarine Cathelot, the Essex class carrier Franklin, the escort carrier Croatan, and the minesweeper Implicit. Measurements were made at frequencies of 200, 400, 560, 700, 970, and 3060 Mc/s, except in some instances when equipment failure developed. The values of far-zone and near-zone radar cross sections obtained are given in Tables I and II, respectively. Also included in these tables are the values for the ships given in Report II, in order that all values to date may be available together. The least range to which a given value of σ_f may be applied can be obtained from Table III.

3-2. Variation of Radar Cross Section with Frequency.

3-2-1. It is important to know how the values of far-zone radar cross section vary with frequency. This question was discussed in Report I, and it was deduced that σ_f should increase as the fifth or sixth power of the frequency, depending on the shape of the target horizontally. This conclusion was based on the assumption that all portions of the ship are illuminated in phase vertically.

3-2-2. A discussion of this point may hept to clarify the phenomena involved. The values of σ_f would be expected to increase at least as the fourth power of the frequency, since in the far zone (effective top of the ship below the maximum of the lowest lobe of the radar) the field intensity received from a small portion of the target is proportional to the square of its height in wavelengths; the received power thus is proportional to the fourth power of the height in wavelengths, or to the fourth power of the frequency. If the reflections from all portions of the target are phased at random, then we should find σ_f to increase as the fourth power of the frequency.*

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* We have been informed by Mr. T. S. Kuhn of the Radio Research Laboratory, Harvard University, that he has carried through an analysis of ship reflections along the lines of Report I, but under the assumption that the scattering from the various parts of the target is purely random. He obtains results similar to those in Report I insofar as the existence of the far and near zones is concerned, but the variation of radar cross section with frequency is not the same. It is important to note that the suitability of the definitions of σ_f and σ_n given by (1) and (2) is not impaired.

In such a case, however, there would be no directivity to the scattering from the target other than approximately a cosine variation; in other words, for completely random scattering the radar cross section should be proportional to the projected area of the target.

3-2-3. It is known from observation that the radar scattering pattern of a ship has many lobes, the number of lobes and their sharpness increasing with the frequency. The existence of scattering patterns of this type is due to the existence of coherent phase relations between the various portions of the target, rather than phase relations which are purely random. Whenever such directivity exists, the maximums of the lobes are reinforced by the depletion of energy from the remaining directions of space, most of the energy being concentrated in the lobes. Since this concentration usually increases as the frequency increases, the effect is to augment the increase of the radar cross section with frequency. If the concentration is only in one plane, either horizontally or vertically, then the value of σ_f will increase as the fifth power of the frequency; if concentration takes place in both horizontal and vertical planes, then σ_f will increase as the sixth power of the frequency.

3-2-4. In comparing the trend of σ_f with frequency as determined from experimental data with theoretical expectations, one very significant point should be kept clearly in mind. Since the measurements leading to σ_f were made by observing pip heights on an A-scope, the probability that the full pip heights were missed somewhat by the operator has to be considered. Since the fading of the pip definitely becomes more and more rapid as the frequency of the radar is increased, it is quite probable that the values reported may be below the theoretical maximums, increasingly so for higher frequencies. Thus the values of σ_f may not be entirely appropriate for comparison with theory. The values reported, however, should correspond to the pip heights of tactical importance.

3-2-5. The values of σ_f given in Table I have been examined to determine their variations with frequency. This has been done by plotting the values for each aspect on log-log graph paper, and fitting a line of integral power (fourth, fifth, or sixth power, whichever gave the best fit) to the points. The bow, stern, and broadside aspects for each type of ship have been plotted on a single sheet, with a few exceptions where this would lead to confusion. Plates 1-14 show the results for the entire series of combat ships covered to date.

3-2-6. Of the 36 lines fitted to the data, 22 fit best to a fourth power slope, and 14 to a fifth power.

3-2-7. If we use the smoothed values of σ_f as given by the straight lines fitted to the plots, we can formulate the relationship as:

$$\sigma_f = K \cdot f^s$$

where s is the slope (4, 5, or 6), and f is the frequency in megacycles per second. The values of K and s obtained from Plates 1-14 are tabulated in Table IV.

3-2-8. Most of the plots of σ_f versus frequency have one point more than 3 db off the fitted straight line, many have two points, and one or two have three points off the curve by more than 3 db. The 400 Mc/s measurement is most frequently "out of line." This is probably due chiefly to set difficulties. This particular radar has consistently been afflicted with a jittery sweep of the A scope, making it difficult to make accurate readings. Furthermore, until recently, a pulsed signal generator was not available for this set, so that gain dial settings, calibrated by a c-w signal generator before or after (or both) the ship run had to be used. It was found in some cases that the gain dial calibration curve changed considerably between calibrations before and after a run, so that a considerable error could result in the value of σ deduced. Furthermore, the absence of a pulsed signal generator made it impossible to evaluate the effect of TR recovery on the standard target echo. This could inject a further error of about 2 or 3 decibels. It is considered, therefore, that the earlier 400 Mc/s measurements are not reliable.

3-2-9. The considerable scattering of the measured values from a straight-line slope is worthy of consideration. An immediate consequence is that the estimation of values of radar cross section at other frequencies can be made only roughly. This is equivalent to saying that the simple theoretical analysis used does not represent the situation well enough.

3-2-10. An explanation of the cause of these deviations from a smooth frequency trend is not difficult to find. In addition to the hull, many parts of the superstructure present surfaces whose dimensions are large relative to the wavelength. In the far zone, reflections from these elevated parts of the ship are enhanced because of their heights, so that the reflection from a surface such as the flat side of a gun turret may be comparable with that from the hull. Since the distance to such an elevated part of the ship differs slightly from the distance to the hull, a phase difference between the corresponding reflected components results. If this difference in distance amounts to a quarter of a wavelength (or an odd multiple of a quarter-wavelength), the reflected components in question are in phase opposition. However, if the difference in distance is a half-wavelength (or a multiple thereof), the components add in phase. Consequently, for a given structure, such a mechanism will result in values of radar cross section which oscillate or "scatter" with frequency about a smooth value. The extent of this scattering depends on the relative amplitudes of the reflections from individual parts of the ship's structure, as well as the number of such individual reflecting surfaces. It is probably a hopeless task to attempt to assess the extent of these fluctuations by means other than experimental measurement.

3-2-11. One case in which the above phenomenon clearly applied was that of the CVL. At 200 Mc/s, the port broadside reflection was greater than the starboard broadside reflection by 5 decibels. At 700 Mc/s, however, the starboard reflection was the greater, although by only 1 decibel. This effect, no doubt, was due to the island structure.

3-3. Effect of Propagation Conditions.

3-3-1. It was mentioned in paragraph 35 of Report II that, on one occasion, abnormal conditions of propagation yielded values of σ_f about 10 times those obtained during normal or "standard" conditions. This phenomenon was confirmed during some of the runs made on several other ships. The amount of increase occasioned by the particular degree of refraction present varied, but was of the order of 10 decibels. Wherever this phenomenon was clearly recognized, the values of radar cross section corresponding to normal conditions were selected. Since no systematic low-level meteorological data were available, it was not possible to evaluate definitely the extent of abnormal propagation conditions. Consequently, some of the values tabulated may deviate somewhat from the values which correspond to standard conditions.

3-4. Effect of Air-Search Radar Antenna.

3-4-1. It was noticed in some earlier measurements that on certain frequencies the echo from the rotating air-search radar antenna of certain large ships could be followed to several thousand yards greater range than the ship echo itself. When this antenna is rotated in normal search operation, the echo from it "flashes" up on the A-scope of the observing radar when the antenna is broadside to the radar. Measurements were made of this flashing echo from the SK antenna of the CL and the CVE. The ship was measured with and without the maximum influence of the SK antenna by making certain of the ship runs with the SK antenna trained constantly on the measuring radars, and by making certain other runs with the antenna rotating at a constant rate.

3-4-2. The effect of the SK antenna varied with frequency, as expected. For 3000 Mc/s, the SK antenna was visible at greater ranges than the ship proper, but the operator had to watch intently to catch the "flash" as the narrow reflected beam swept around. If the operator were not expecting the flash or if the SG radar used in making the measurements at this frequency had been searching, it is almost certain that the flash would not have been observed. For the lower frequencies the beam reflected from the SK antenna was broader, of course, and it was possible to measure the signal more readily.

3-4-3. The results of these measurements have been expressed in terms of a far-zone radar cross section, and are presented in Table V. From Table I, it can be seen that the values of σ_f for the SK antenna are not as large as those for the ship itself in broadside aspect. Thus, well within the horizon, where very little of the ship is screened by the curvature of the earth, the broadside echoes from the ship will predominate. Only at extreme ranges, where the lower part of the ship is below the horizon, will the SK antenna give the stronger echo, and then only when it is broadside to the radar.

4. CONCLUSIONS AND RECOMMENDATIONS

4-1. Conclusions.

4-1-1. The results of the measurements that have been made show quite definitely the existence of the far and near zones.

4-1-2. The variation of far-zone radar cross section with frequency is not smooth. The best integer exponent of frequency was found to be either 4 or 5.

4-1-3. Abnormal propagation conditions increase the values of far-zone radar cross section. This increase has been observed to be of the order of 10 decibels.

4-1-4. The SK antenna, when broadside to the observing radar, gives large reflections, which predominate when the ship is partially below the horizon, although not at closer ranges.

4-2. Recommendations.

4-2-1. It is recommended that additional ships be made available at the Chesapeake Bay Annex for radar cross section measurements. These should include several ships of each class, in order that more representative average values for each class may be determined, as well as to allow measurements to be made under various degrees of atmospheric refraction.

TABLE I

Values of σ_T in Square Meters

Ship	Aspect	200	400	560	700	970	3060
		Frequency in Mc/s					
AM-246 Implicit	Bow	$6.0\cdot10^{10}$	$6.6\cdot10^{11}$	$1.1\cdot10^{13}$	$6.2\cdot10^{12}$	$1.1\cdot10^{14}$	$2.3\cdot10^{15}$
	Stern	$4.4\cdot10^{10}$	$2.6\cdot10^{12}$	$1.6\cdot10^{12}$	$4.5\cdot10^{12}$	$1.7\cdot10^{13}$	$1.1\cdot10^{15}$
	Br's'd	$6.0\cdot10^{10}$	$1.1\cdot10^{13}$	$2.2\cdot10^{13}$	$3.8\cdot10^{13}$		$7.1\cdot10^{15}$
BB-26 New York	Bow	$1.4\cdot10^{12}$	$3.3\cdot10^{14}$		$4.8\cdot10^{15}$		$1.0\cdot10^{16}$
	Stern	$2.5\cdot10^{12}$			$1.2\cdot10^{15}$		
	Br's'd	$1.9\cdot10^{13}$	$5.1\cdot10^{14}$	$3.3\cdot10^{15}$	$5.7\cdot10^{13}$		$6.1\cdot10^{17}$
CA-71 Quincy	Bow	$1.8\cdot10^{12}$	$3.9\cdot10^{15}$	$4.3\cdot10^{14}$	$1.7\cdot10^{15}$	$9.3\cdot10^{14}$	$9.2\cdot10^{16}$
	Stern	$5.7\cdot10^{12}$	$5.3\cdot10^{15}$	$4.3\cdot10^{14}$	$1.5\cdot10^{15}$	$7.9\cdot10^{14}$	$3.2\cdot10^{17}$
	Br's'd	$7.5\cdot10^{12}$	$3.9\cdot10^{15}$	$2.2\cdot10^{15}$	$1.4\cdot10^{16}$	$3.2\cdot10^{16}$	$5.5\cdot10^{17}$
CL-89 Miami	Bow	$1.4\cdot10^{11}$	$4.0\cdot10^{14}$	$2.0\cdot10^{13}$	$3.2\cdot10^{14}$	$3.4\cdot10^{14}$	$4.1\cdot10^{16}$
	Stern	$1.9\cdot10^{11}$	$9.1\cdot10^{13}$	$1.1\cdot10^{13}$	$6.4\cdot10^{13}$	$1.4\cdot10^{14}$	$1.7\cdot10^{16}$
	Br's'd	$1.1\cdot10^{13}$		$2.3\cdot10^{15}$	$3.6\cdot10^{15}$	$1.4\cdot10^{16}$	$3.0\cdot10^{17}$
CV-13 Franklin	Bow	$5.6\cdot10^{12}$	$4.6\cdot10^{13}$	$8.7\cdot10^{13}$	$7.1\cdot10^{14}$	$1.4\cdot10^{15}$	$4.1\cdot10^{16}$
	Stern	$1.1\cdot10^{12}$	$4.6\cdot10^{14}$	$4.3\cdot10^{14}$	$5.6\cdot10^{14}$	$1.7\cdot10^{15}$	$5.3\cdot10^{16}$
	Br's'd	$5.7\cdot10^{13}$	$3.6\cdot10^{15}$	$5.4\cdot10^{15}$	$3.2\cdot10^{16}$		$1.3\cdot10^{18}$
CVE-25 Croatan	Bow			$9.1\cdot10^{13}$	$1.1\cdot10^{14}$	$6.3\cdot10^{14}$	$4.6\cdot10^{16}$
	Stern	$3.7\cdot10^{11}$		$7.1\cdot10^{13}$	$1.1\cdot10^{14}$	$7.9\cdot10^{14}$	$5.8\cdot10^{16}$
	Br's'd			$2.6\cdot10^{15}$	$1.4\cdot10^{16}$	$2.2\cdot10^{16}$	$1.4\cdot10^{18}$
CVL-30 San Jacinto	Bow	$1.3\cdot10^{11}$	$1.6\cdot10^{14}$	$5.4\cdot10^{13}$	$5.5\cdot10^{13}$	$5.6\cdot10^{14}$	$2.8\cdot10^{16}$
	Stern	$5.5\cdot10^{11}$	$4.3\cdot10^{13}$	$7.9\cdot10^{13}$	$5.5\cdot10^{13}$	$4.2\cdot10^{14}$	$7.7\cdot10^{15}$
	Br's'd	$6.1\cdot10^{12}$	$1.2\cdot10^{16}$	$1.8\cdot10^{15}$	$3.4\cdot10^{15}$	$2.8\cdot10^{15}$	$7.5\cdot10^{16}$
DD-496 McCook	Bow	$2.4\cdot10^{11}$	$3.3\cdot10^{12}$		$2.9\cdot10^{12}$		$5.4\cdot10^{16}$
	Stern	$5.8\cdot10^{10}$			$2.2\cdot10^{13}$		$1.3\cdot10^{17}$
	Br's'd	$5.7\cdot10^{11}$	$2.9\cdot10^{13}$	$7.5\cdot10^{13}$	$6.9\cdot10^{13}$		$1.3\cdot10^{18}$
DE-322 Newell	Bow	$3.7\cdot10^{10}$	$9.2\cdot10^{11}$		$1.4\cdot10^{13}$		$8.5\cdot10^{16}$
	Stern	$1.9\cdot10^{11}$	$9.2\cdot10^{11}$		$5.1\cdot10^{12}$		$5.4\cdot10^{16}$
	Br's'd	$6.6\cdot10^{11}$	$1.1\cdot10^{13}$	$1.5\cdot10^{14}$	$2.9\cdot10^{13}$		$1.5\cdot10^{18}$
LCT	Bow	$1.2\cdot10^{8}$			$6.6\cdot10^{9}$		
	Stern	$2.1\cdot10^{8}$			$6.6\cdot10^{9}$		
	Br's'd	$4.3\cdot10^{8}$			$7.4\cdot10^{10}$		
LST	Bow	$4.2\cdot10^{10}$			$2.0\cdot10^{12}$		$1.7\cdot10^{15}$
	Stern	$2.6\cdot10^{10}$			$5.2\cdot10^{12}$		$1.3\cdot10^{15}$
	Br's'd	$9.4\cdot10^{10}$			$1.0\cdot10^{14}$		$1.5\cdot10^{17}$

TABLE I (continued)

Ship	Aspect	200	400	560	700	970	3060
SS-180	Bow		$7.4\cdot10^{10}$	$3.0\cdot10^{10}$	$5.3\cdot10^{10}$	$5.5\cdot10^{11}$	$4.4\cdot10^{13}$
Catchelot	Stern		$6.9\cdot10^{10}$	$2.2\cdot10^{10}$	$1.8\cdot10^{10}$	$3.9\cdot10^{11}$	$2.1\cdot10^{14}$
Surfaced	Br's'd		$1.2\cdot10^{11}$	$2.0\cdot10^{11}$	$8.7\cdot10^{11}$	$2.0\cdot10^{12}$	
SS-180	Bow	$4.6\cdot10^{7}$	$1.2\cdot10^{10}$	$3.0\cdot10^{10}$	$1.0\cdot10^{11}$	$3.7\cdot10^{11}$	$9.9\cdot10^{13}$
Catchelot	Stern	$8.9\cdot10^{7}$	$7.3\cdot10^{10}$	$2.2\cdot10^{10}$	$6.5\cdot10^{10}$	$3.7\cdot10^{11}$	$4.6\cdot10^{13}$
Awash	Br's'd	$1.3\cdot10^{8}$	$1.8\cdot10^{11}$	$2.0\cdot10^{11}$	$3.5\cdot10^{11}$	$6.3\cdot10^{11}$	$1.4\cdot10^{14}$

TABLE II

Values of σ_n in Square Meters

Frequency in Mc/s

Ship	Aspect	400	700	970	3060
AM-246	Bow	$1.7\cdot10^{3}$	$6.6\cdot10^{3}$	$2.0\cdot10^{4}$	
Implicit	Stern	$6.3\cdot10^{3}$	$1.6\cdot10^{4}$	$1.6\cdot10^{4}$	$4.8\cdot10^{4}$
	Br's'd	$1.3\cdot10^{4}$	$8.3\cdot10^{4}$	$5.4\cdot10^{5}$	$9.4\cdot10^{5}$
CA-71	Bow	$7.1\cdot10^{4}$		$6.5\cdot10^{4}$	$1.1\cdot10^{6}$
Quincy	Stern	$6.3\cdot10^{4}$		$5.5\cdot10^{4}$	
	Br's'd				$1.7\cdot10^{8}$
CL-89	Bow	$1.1\cdot10^{3}$	$8.5\cdot10^{4}$		
Miami	Stern		$3.4\cdot10^{4}$	$1.6\cdot10^{5}$	
	Br's'd	$7.0\cdot10^{3}$	$2.4\cdot10^{6}$	$3.3\cdot10^{6}$	$1.3\cdot10^{7}$
CVE-25	Bow				
Croatan	Stern				
	Br's'd				$6.8\cdot10^{5}$
CVL-30	Bow	$7.2\cdot10^{4}$	$3.0\cdot10^{4}$		$1.3\cdot10^{6}$
San Jacinto	Stern	$1.0\cdot10^{4}$	$2.9\cdot10^{4}$		~~$9.4\cdot10^{5}$~~
	Br's'd	$1.2\cdot10^{6}$	$8.5\cdot10^{6}$		$9.4\cdot10^{6}$
LST	Bow				$2.1\cdot10^{4}$
	Stern				$2.4\cdot10^{4}$
	Br's'd				$1.2\cdot10^{7}$
SS-180	Bow	$7.1\cdot10^{1}$		$2.0\cdot10^{3}$	
Catchelot	Stern	8.0			
Surfaced	Br's'd	$1.2\cdot10^{2}$			$5.4\cdot10^{5}$

TABLE III

Least Range (in yards) to which Values of σ_T may be Applied

Ship	Aspect	200	400	560	700	970	3060
		FREQUENCY IN MC/S					
AM-246 Implicit	Bow	3,500*	5,000*	5,000*	6,700	6,000*	11,000*
	Stern	2,000	5,200*	3,500	5,100	8,000*	16,000*
	Br's'd	3,000*	6,200*		5,700	11,000*	13,500*
BB New York	Bow	<5,000	<8,000	<8,000	<8,000		9,000
	Stern	<5,000	5,000	8,000	8,000		10,000
	Br's'd	<5,000	5,000	7,000*	8,000		
CA-71 Quincy	Bow	5,000	18,500*		10,000*	18,000*	22,000*
	Stern	7,000	19,000*		11,000*	14,500*	19,000*
	Br's'd	6,000	15,000*	6,000	6,000	9,500*	14,000*
CL-89 Miami	Bow	3,500	17,000*	6,000*	8,500*	11,000*	
	Stern	3,000	10,000*		7,500*	12,000*	
	Br's'd	3,000	23,000*	8,000	7,500*	9,500*	17,500*
CV-13 Franklin	Bow	12,000	11,000		12,500	11,500	
	Stern	12,000	8,500		12,500	11,000	14,000*
	Br's'd	7,500	8,500	7,500	7,500		
CVE-25 Croatan	Bow			7,000	7,000	7,000	18,000*
	Stern	7,500		10,000	10,000	10,000*	14,000*
	Br's'd				8,000*	10,000*	15,000*
CVL-30	Bow	<5,000	8,300*		8,000*	12,000*	13,000*
	Stern	<5,000	9,600*		8,000*	13,000*	15,000*
	Br's'd	<5,000	12,000*	[illegible]	6,000*	13,000*	14,000*
DD	Bow	<5,000	5,000	3,500			15,000?*
	Stern	<5,000	5,000	3,500			15,000?*
	Br's'd	<5,000	5,000	3,500			15,000?*
DE	Bow	<5,000	5,000	3,500			15,000?*
	Stern	<5,000	5,000	3,500			15,000?*
	Br's'd	<5,000	5,000	3,500			15,000?*
LCT	Bow	<5,000			3,500		
	Stern	<5,000			3,000		
	Br's'd	<5,000			4,000		

TABLE III (continued)

Ship	Aspect	FREQUENCY IN MC/S: 200	400	560	700	970	3060
LST	Bow	<5,000			6,000*		
	Stern	<5,000			6,000		
	Br's'd	<5,000			6,000		
SS-180 Surfaced	Bow		5,500*	4,000	4,000*	4,500*	10,000*
	Stern		8,000*		5,000	5,000*	10,000*
	Br's'd		3,500	3,000	3,000	7,000	10,000*
SS-180 Awash	Bow	2,500	4,000*	4,000	5,000	4,000*	10,000*
	Stern	2,500			5,000		10,000*
	Br's'd	2,500	4,500*	3,000	3,000	3,000*	21,000*

* Denotes that curve actually broke away from inverse 8th power. The ranges without asterisk denote only the extent of the measurements.

TABLE IV

Values of s and K in formula: $\sigma_f = K \cdot f^s$

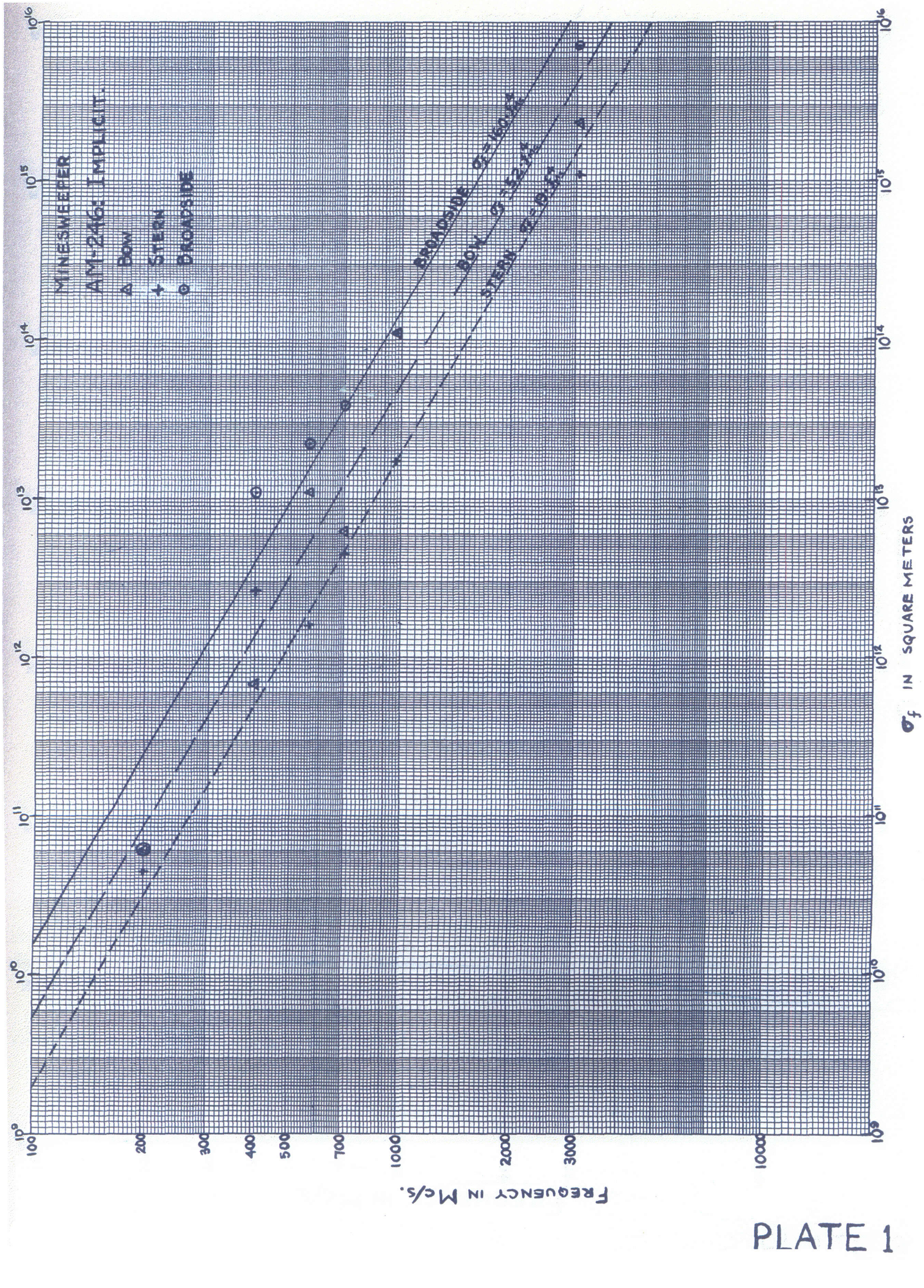
Ship	ASPECT: Bow s	Bow K	Stern s	Stern K	Broadside s	Broadside K
AM-246	4	52.	4	19.	4	$1.6 \cdot 10^2$
BB-26	4	$2.4 \cdot 10^3$	4	$2.4 \cdot 10^3$	4	$1.6 \cdot 10^4$
CA-71	4	$2.7 \cdot 10^3$	4	$4.4 \cdot 10^3$	4	$1.2 \cdot 10^4$
CL-89	5	0.52	4	$1.8 \cdot 10^2$	4	10^4
CV-13	4	$2.1 \cdot 10^3$	4	$1.6 \cdot 10^3$	4	$6 \cdot 10^4$
CVE-25	4	$5.7 \cdot 10^2$	4	$5.7 \cdot 10^2$	4	$2.7 \cdot 10^4$
CVL-30	4	$3.2 \cdot 10^2$	4	$3.2 \cdot 10^2$	4	$5 \cdot 10^3$
DD-496	5	0.25	5	0.25	5	2.5
DE-322	5	0.14	5	0.14	5	2.5
LCT	4	0.05	4	0.06	4	0.3
LST	4	18.	4	18.	5	0.5
SS-180 (surfaced)	5	$4.4 \cdot 10^{-4}$	5	$7 \cdot 10^{-4}$	5	$4 \cdot 10^{-3}$
SS-180 (awash)	5	$5 \cdot 10^{-4}$	5	$3.6 \cdot 10^{-4}$	5	10^{-3}

TABLE V

Values of σ_f in Square Meters

Bow Aspect with SK Antenna Aimed Forward

Ship	200	400	560	700	970	3060
CL-89	$2.1 \cdot 10^{12}$	$9.1 \cdot 10^{14}$	$5.8 \cdot 10^{13}$	$6.7 \cdot 10^{14}$	$5.4 \cdot 10^{15}$	
CVE-25			$2.9 \cdot 10^{15}$	$2.1 \cdot 10^{15}$		



MINESWEEPER
AM-246: IMPLICIT.
Δ BOW
+ STERN
⊙ BROADSIDE
BROADSIDE $\sigma_f = 160 f_{Mc}^4$
BOW $\sigma_f = 52 f_{Mc}^4$
STERN $\sigma_f = 19 f_{Mc}^4$
σ_f IN SQUARE METERS
FREQUENCY IN Mc/s.

PLATE 1

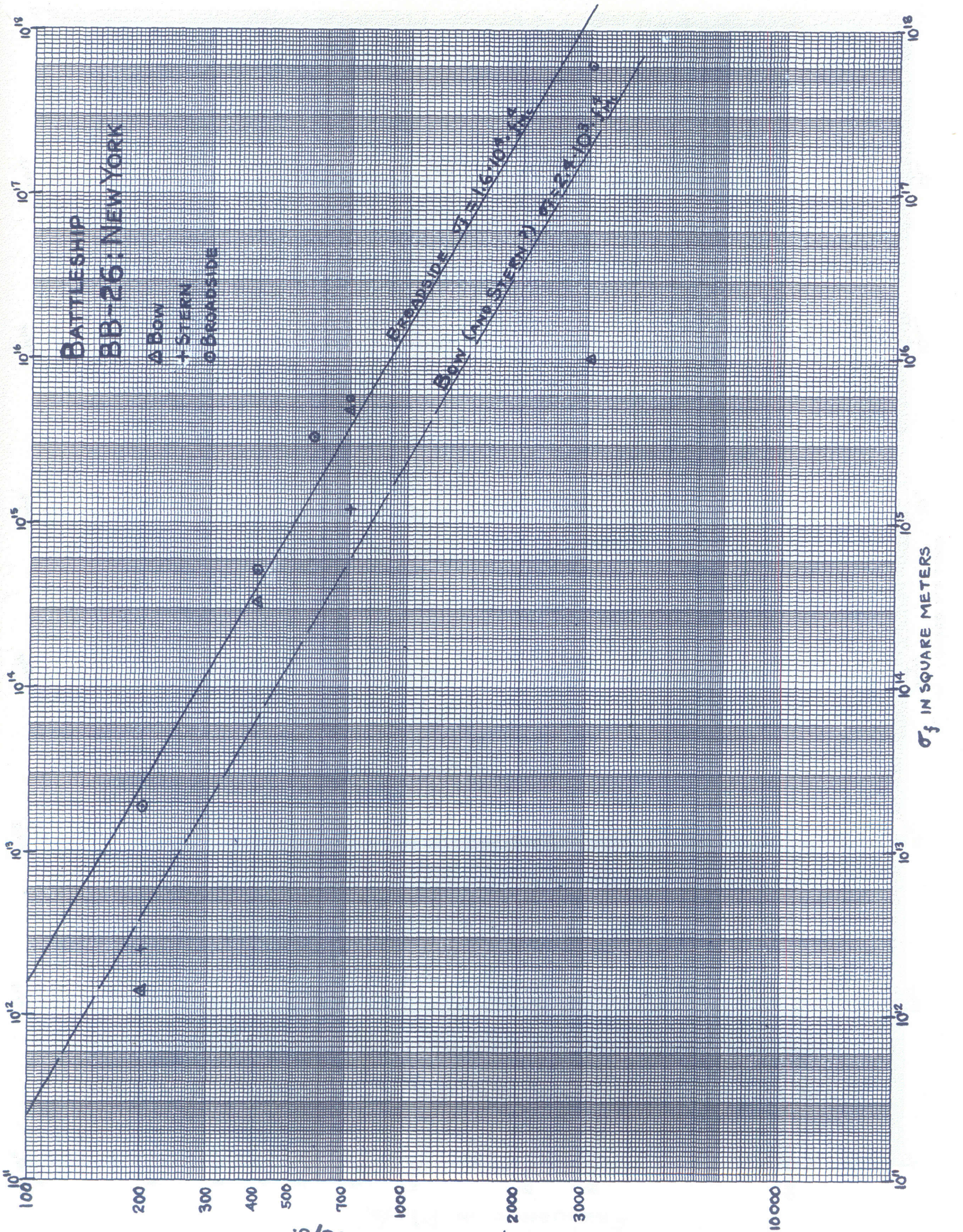

BATTLESHIP
BB-26: NEW YORK
Δ BOW
+ STERN
⊙ BROADSIDE
BROADSIDE
BOW (AND STERN)
FREQUENCY IN Mc/S.
σ_f IN SQUARE METERS
100
200
300
400
500
700
1000
2000
3000
10000
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18

PLATE 2

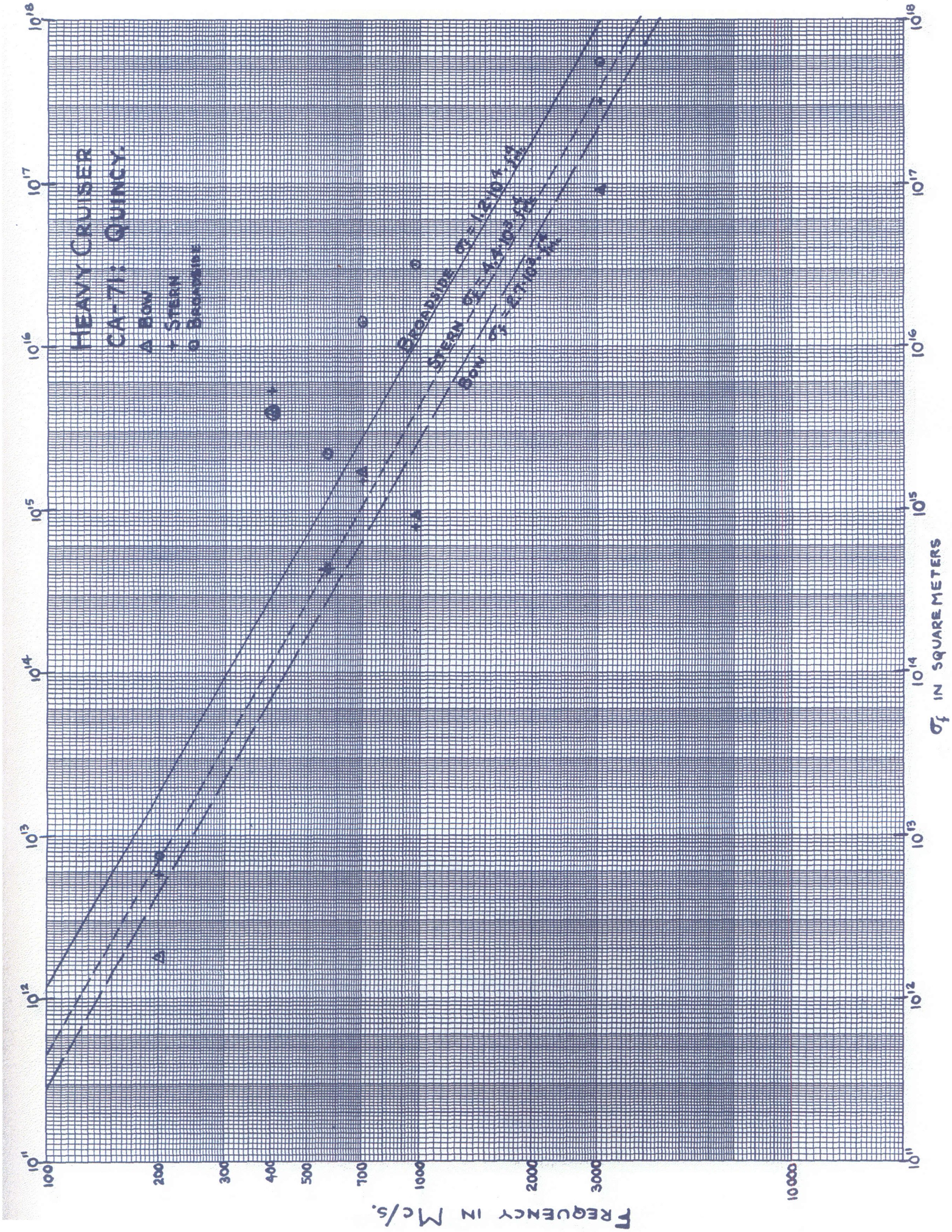

HEAVY CRUISER
CA-71: QUINCY.
Δ BOW
+ STERN
o BROADSIDE
BROADSIDE σf = 1.2·10^4·f^4
STERN σf = 4.4·10^3·f^4
BOW σf = 2.7·10^3·f^4
FREQUENCY IN Mc/s.
σf IN SQUARE METERS
100
200
300
400
500
700
1000
2000
3000
10000
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18

PLATE 3.

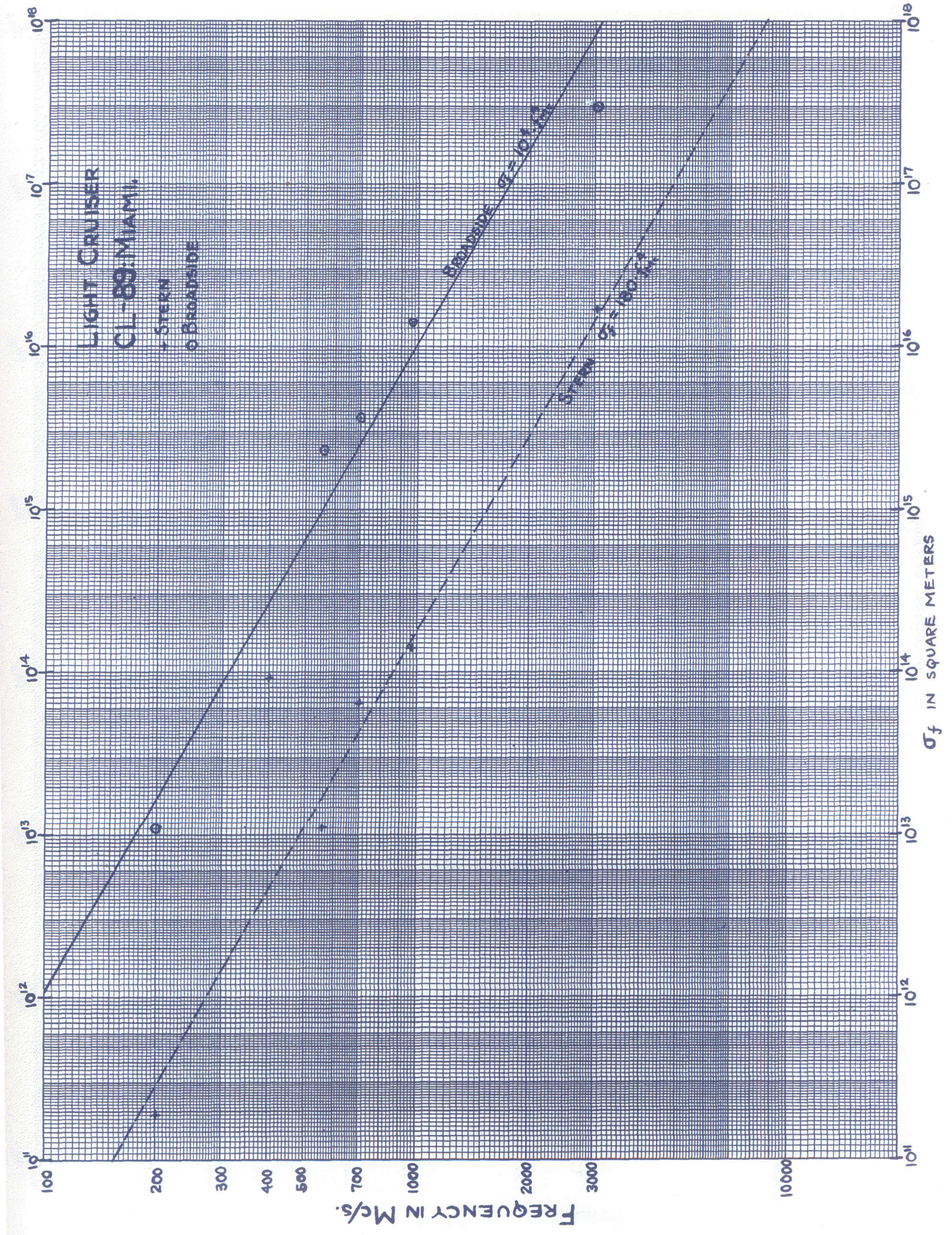

LIGHT CRUISER
CL-89 MIAMI
+ STERN
o BROADSIDE
BROADSIDE σf = 10^4 f^4 Mc
STERN σf = 180 f^4 Mc
σf IN SQUARE METERS
FREQUENCY IN Mc/s.
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18
100
200
300
400
500
600
700
1000
2000
3000
10000

PLATE 4

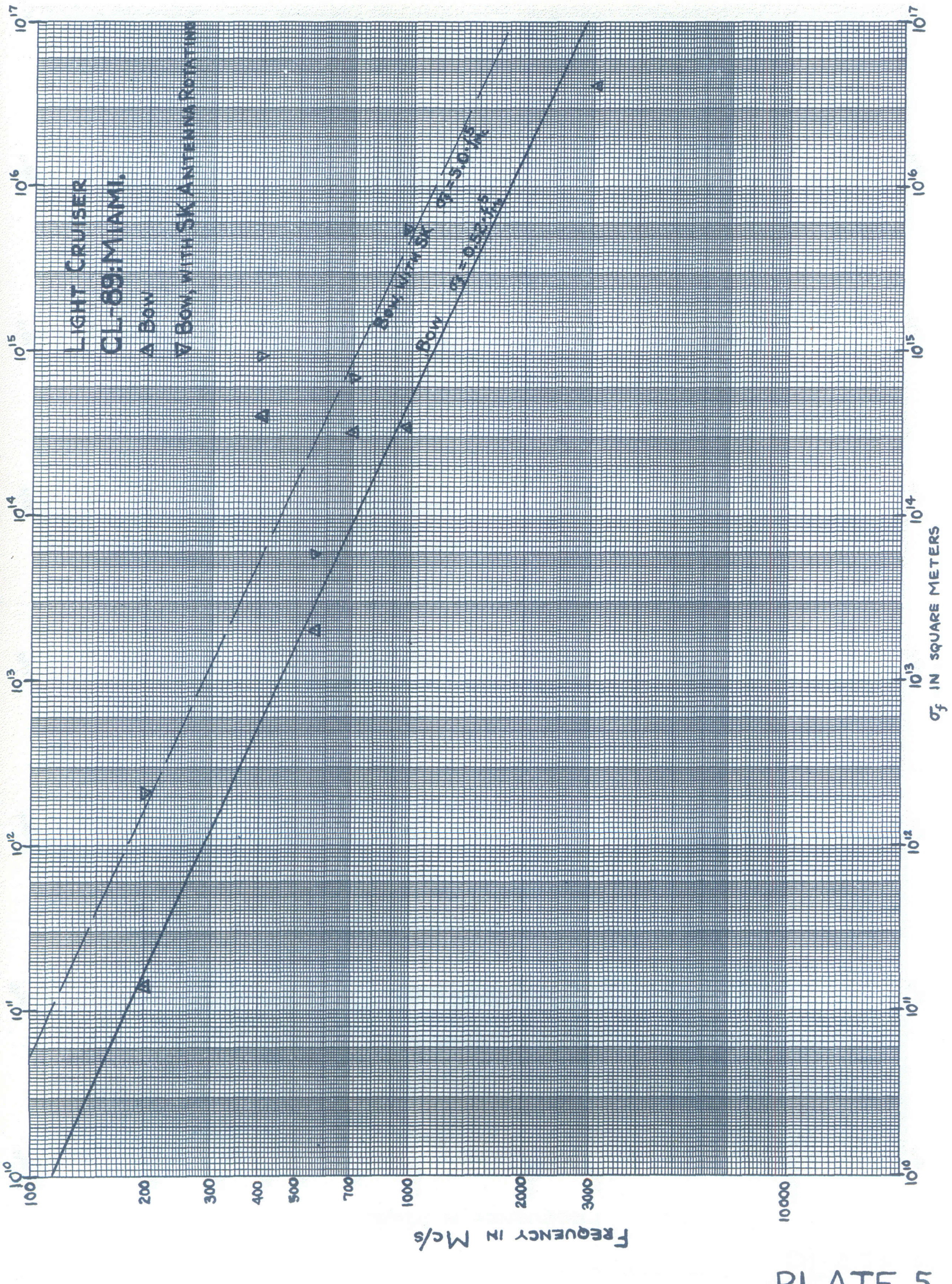

LIGHT CRUISER
CL-89: MIAMI.
Δ BOW
∇ BOW, WITH SK ANTENNA ROTATING
BOW WITH SK
BOW
FREQUENCY IN Mc/s
σf IN SQUARE METERS
100
200
300
400
500
700
1000
2000
3000
10000
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17

PLATE 5

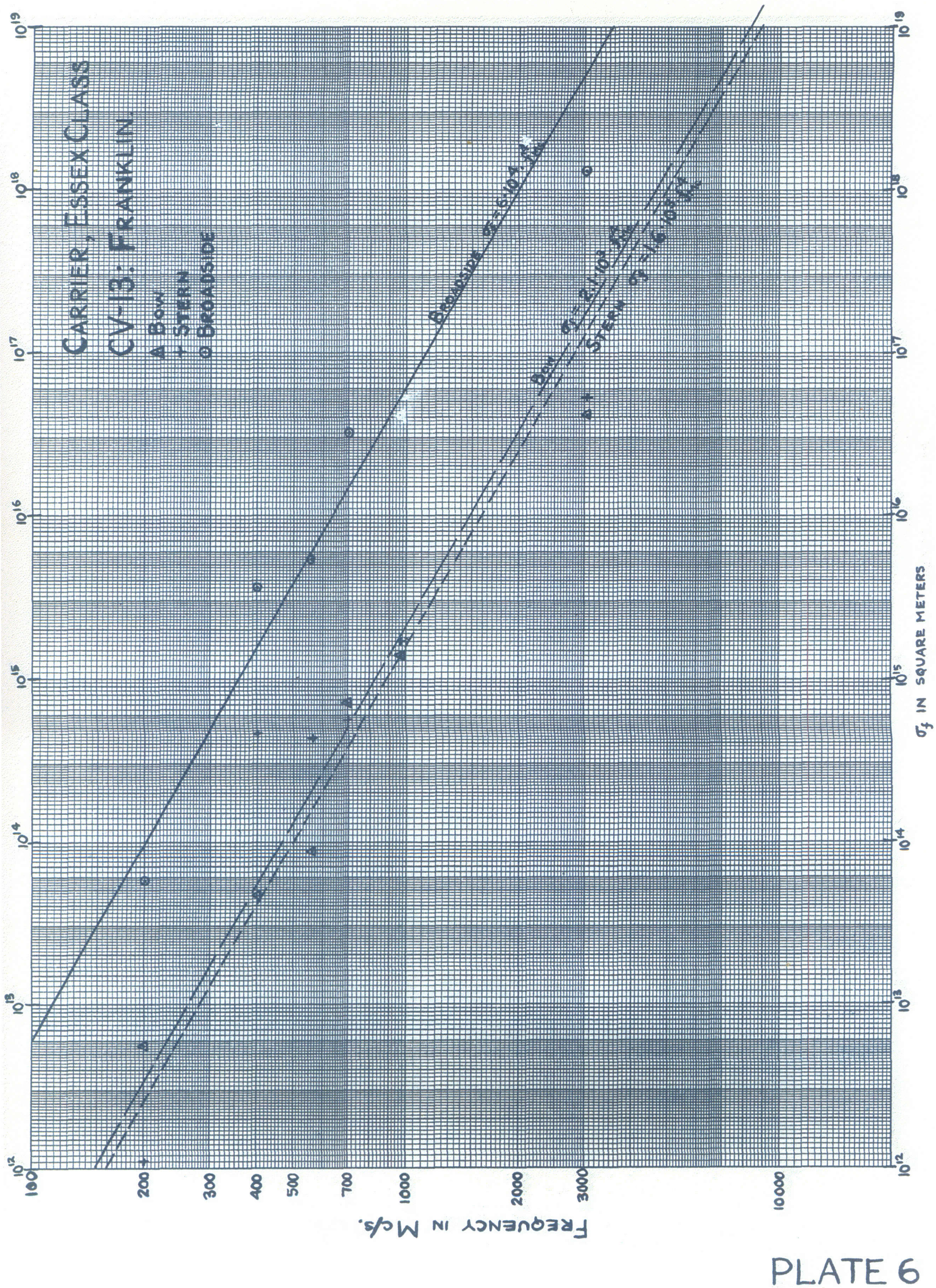

CARRIER, ESSEX CLASS
CV-13: FRANKLIN
Δ BOW
+ STERN
O BROADSIDE
BROADSIDE $\sigma_f = 6 \cdot 10^4 \cdot f^4$
BOW $\sigma_f = 2.1 \cdot 10^3 \cdot f^4$
STERN $\sigma_f = 1.6 \cdot 10^3 \cdot f^4$
σ_f IN SQUARE METERS
FREQUENCY IN Mc/s.
100
200
300
400
500
700
1000
2000
3000
10000
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}

PLATE 6

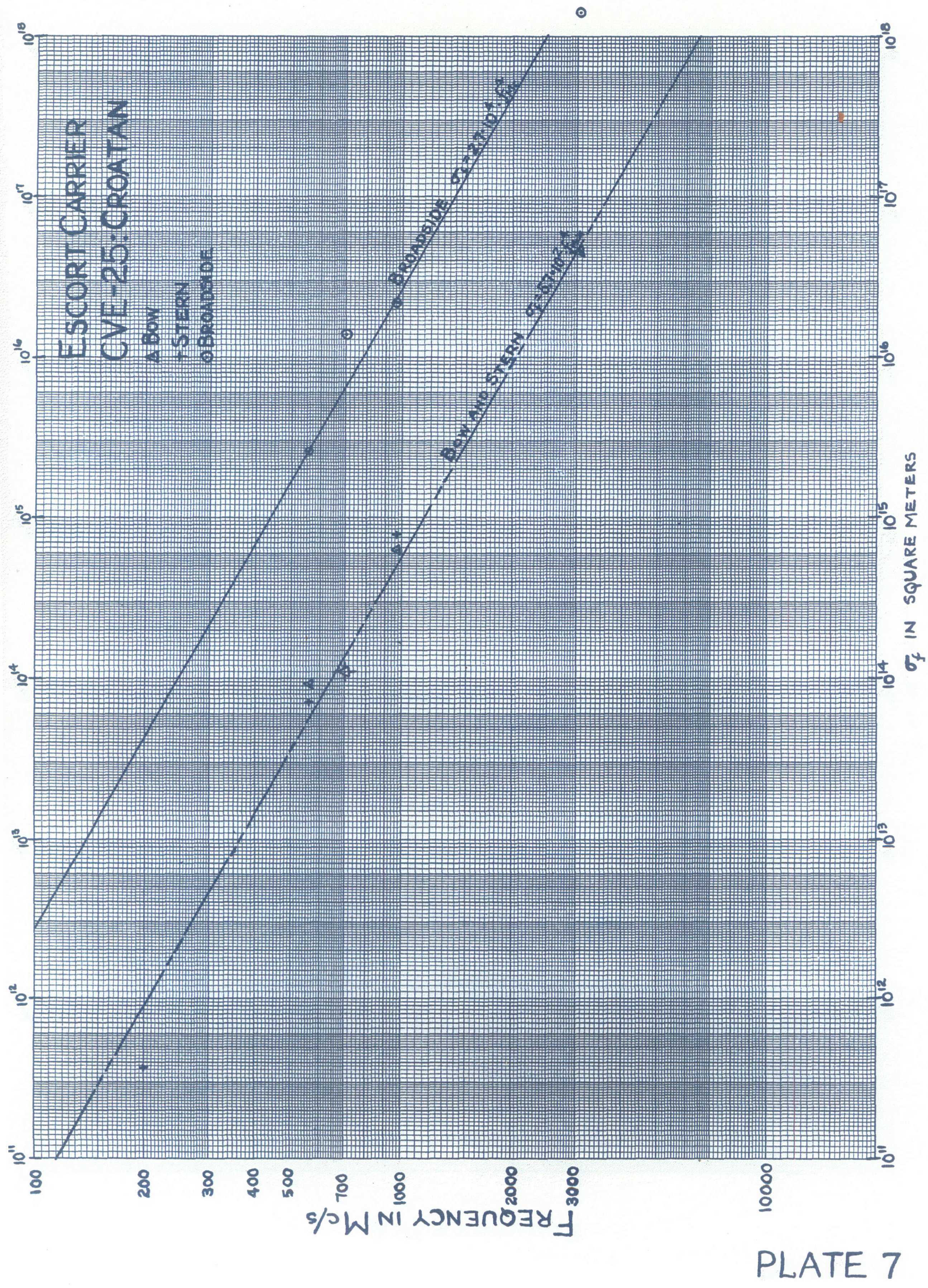

ESCORT CARRIER
CVE-25-CROATAN
Δ BOW
+ STERN
⊙ BROADSIDE
BROADSIDE
BOW AND STERN
FREQUENCY IN Mc/s
100
200
300
400
500
700
1000
2000
3000
10000
σ_f IN SQUARE METERS
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}

PLATE 7

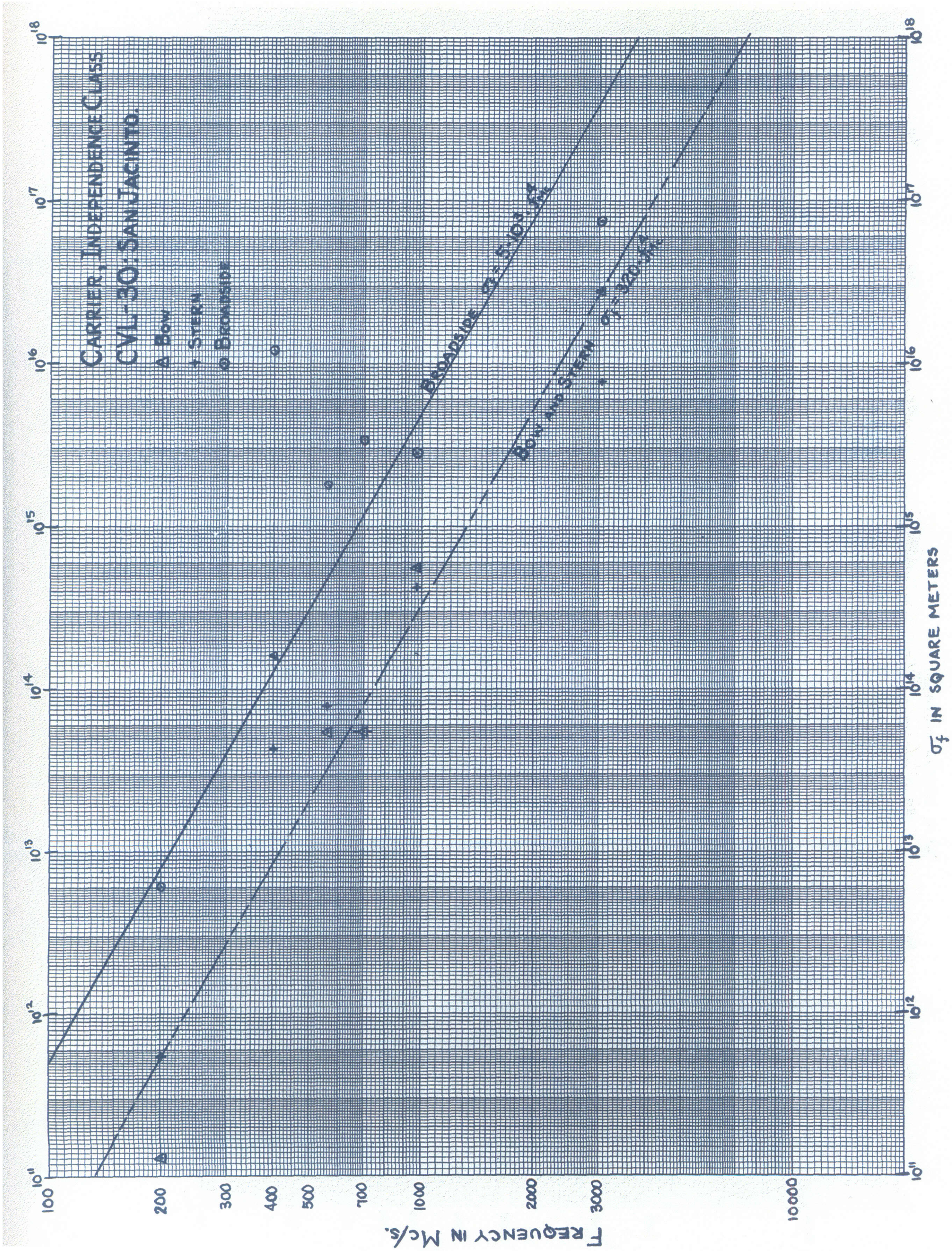
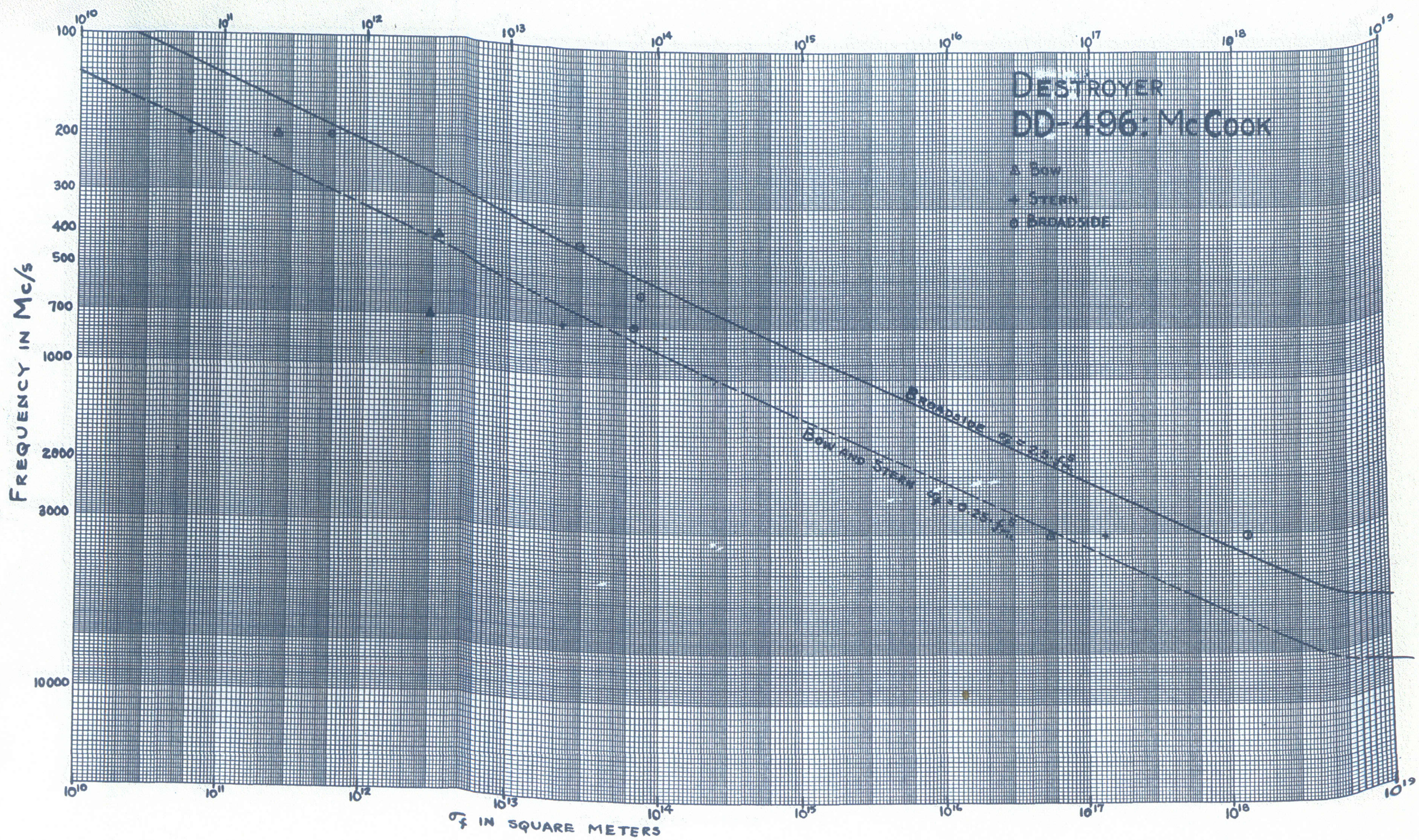
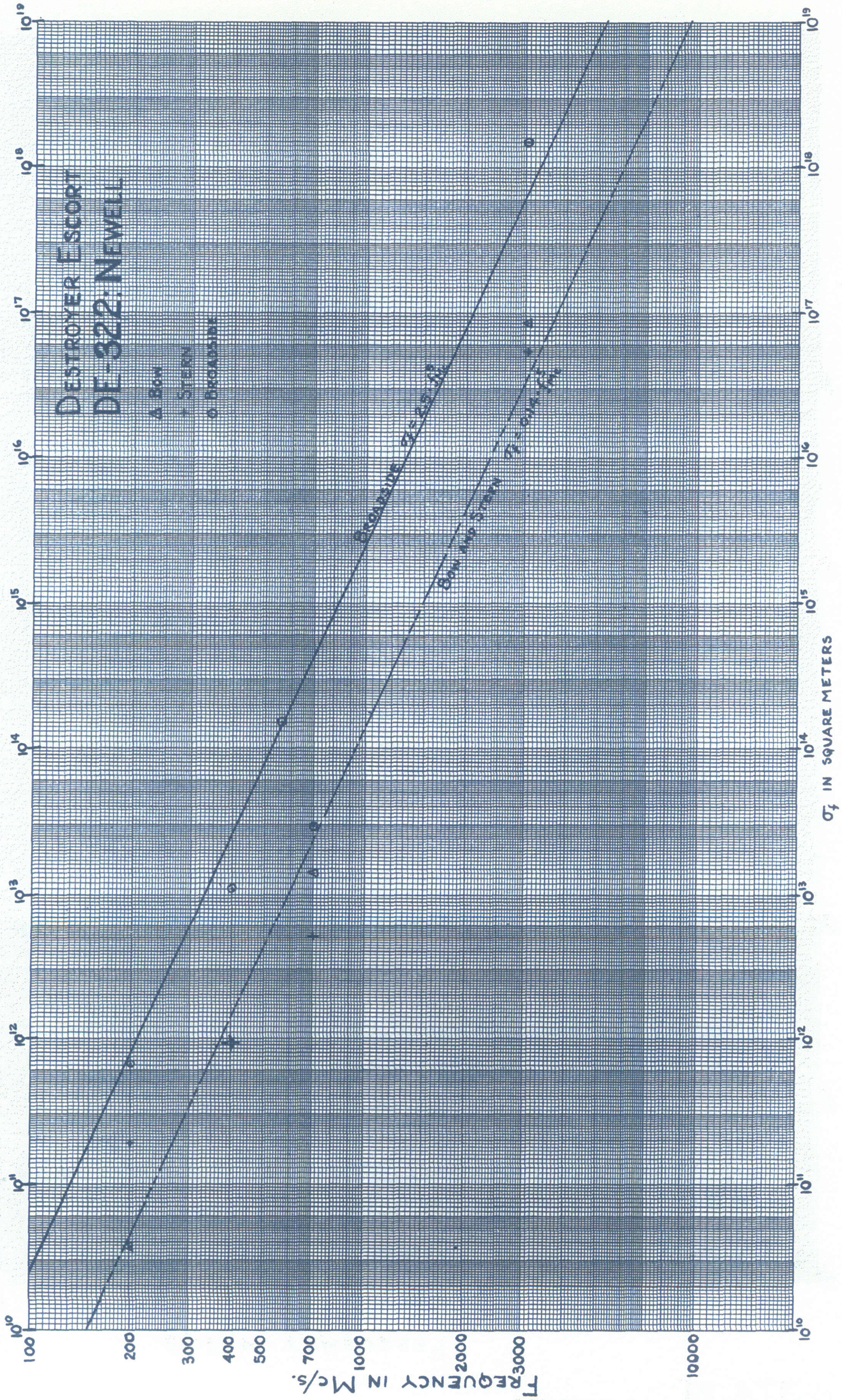

Carrier, Independence Class
CVL-30: San Jacinto.
△ Bow
+ Stern
⊙ Broadside
Broadside $\sigma_f = 5 \cdot 10^8 \cdot f_{Mc}^4$
Bow and Stern $\sigma_f = 320 \cdot f_{Mc}^4$
σ_f in square meters
Frequency in Mc/s.
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
100
200
300
400
500
700
1000
2000
3000
10000

PLATE 8



DESTROYER
DD-496: McCOOK
Δ BOW
+ STERN
o BROADSIDE
BROADSIDE $\sigma_t = 2.5 f_{mc}^{2.5}$
BOW AND STERN $\sigma_t = 0.25 f_{mc}^{2.5}$
FREQUENCY IN Mc/s
100
200
300
400
500
700
1000
2000
3000
10000
σ_t IN SQUARE METERS
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}

PLATE 9



Destroyer Escort
DE-322: Newell
Δ Bow
+ Stern
o Broadside
Broadside
Bow and Stern
Frequency in Mc/s.
σ_f in square meters
100
200
300
400
500
700
1000
2000
3000
10000
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18
10^19

PLATE 10

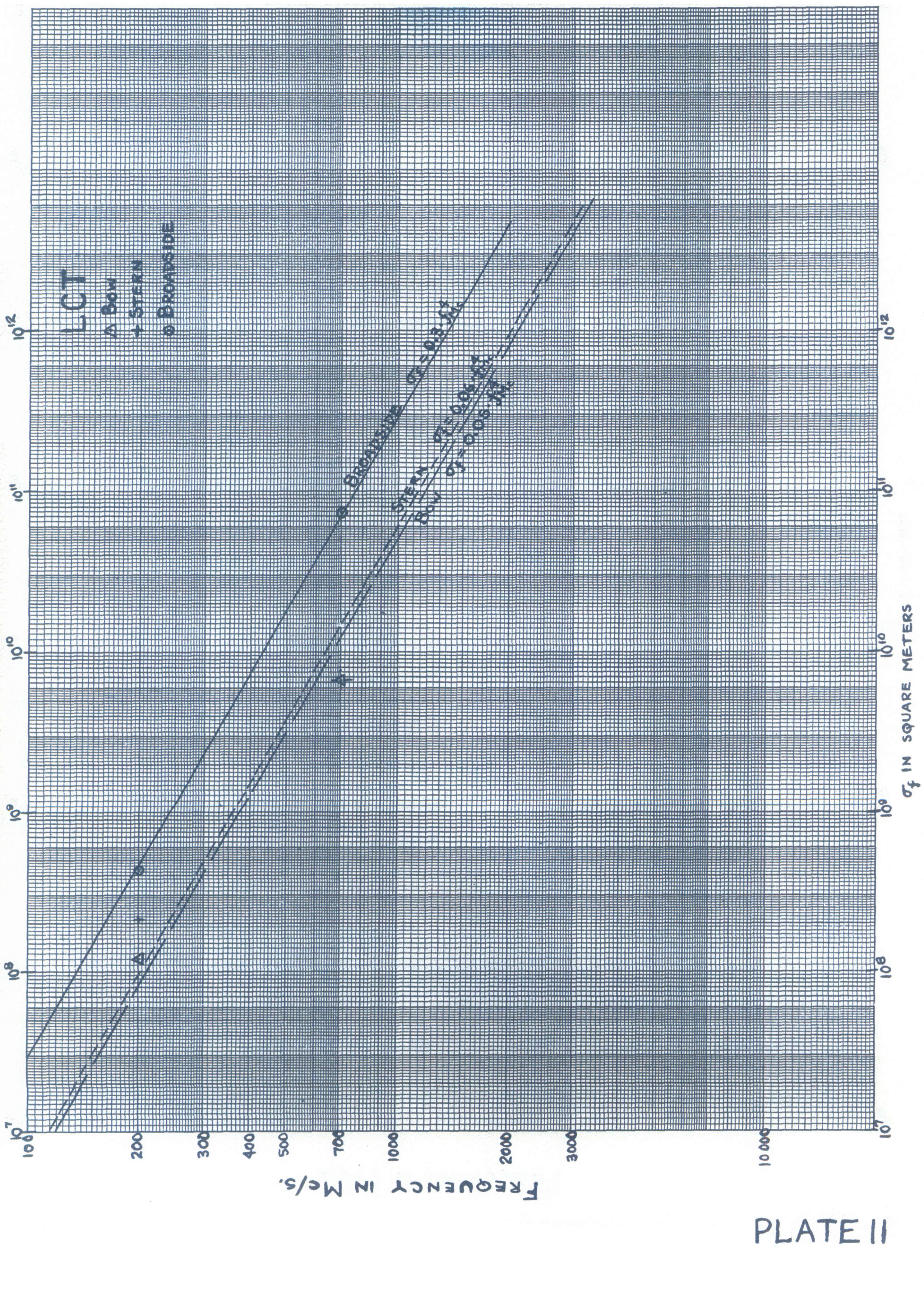

LCT
Δ BOW
+ STERN
○ BROADSIDE
BROADSIDE
STERN
BOW
FREQUENCY IN Mc/S.
σ_f IN SQUARE METERS

PLATE II

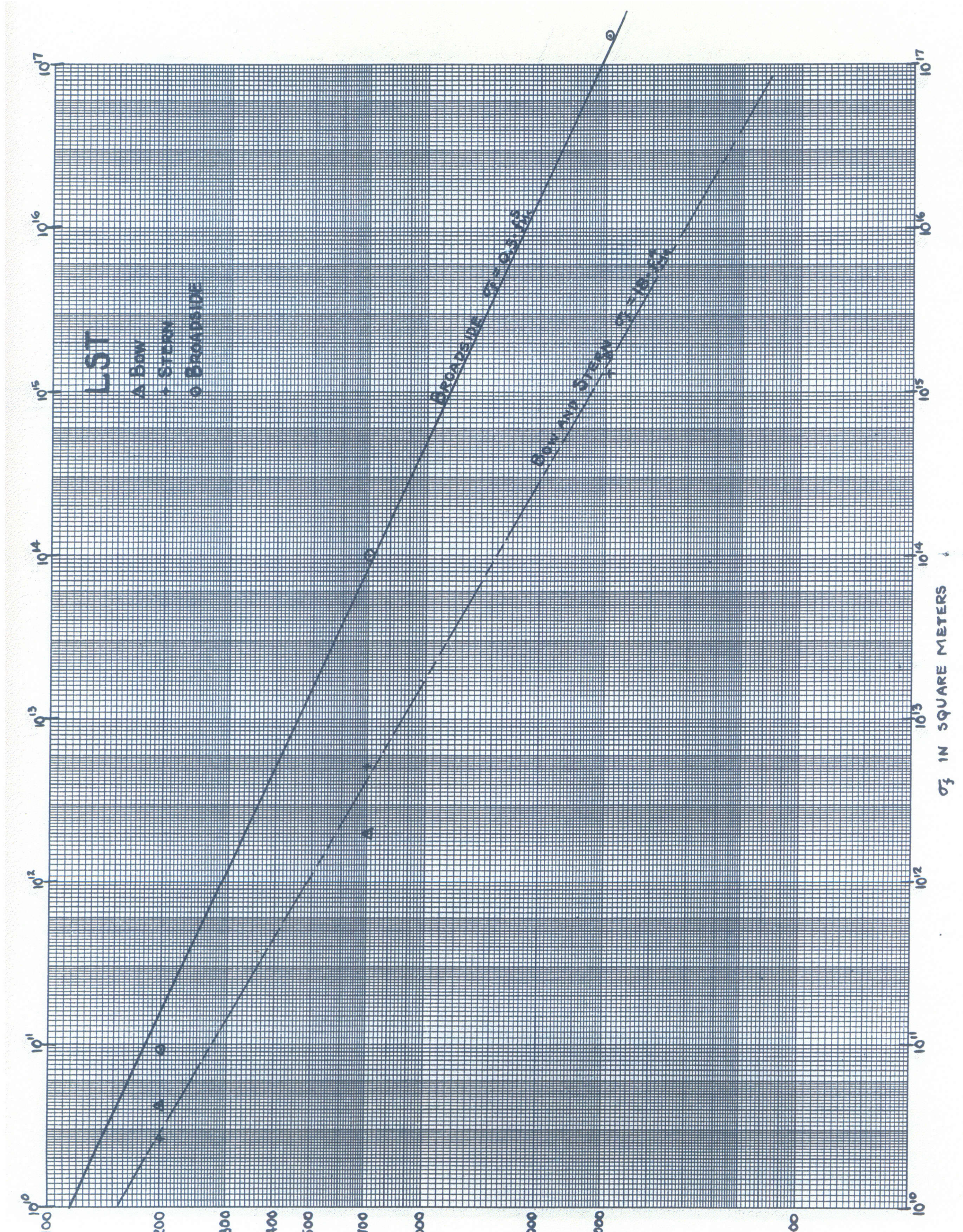

LST
Δ Bow
+ Stern
⊙ Broadside
Broadside
Bow and Stern
σ_f in square meters
Frequency in Mc/s.
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17
100
200
300
400
500
700
1000
2000
3000
10000

PLATE 12

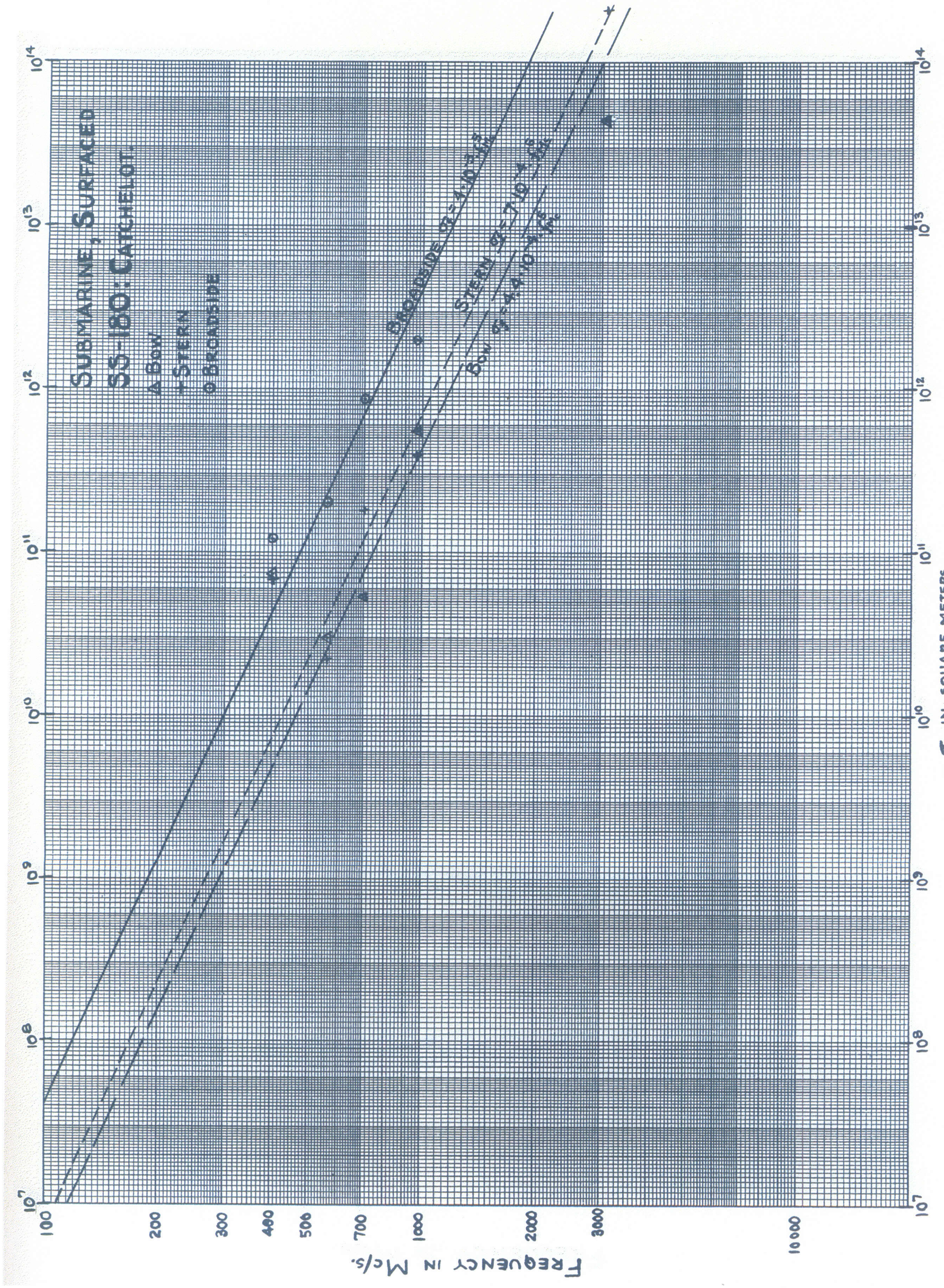
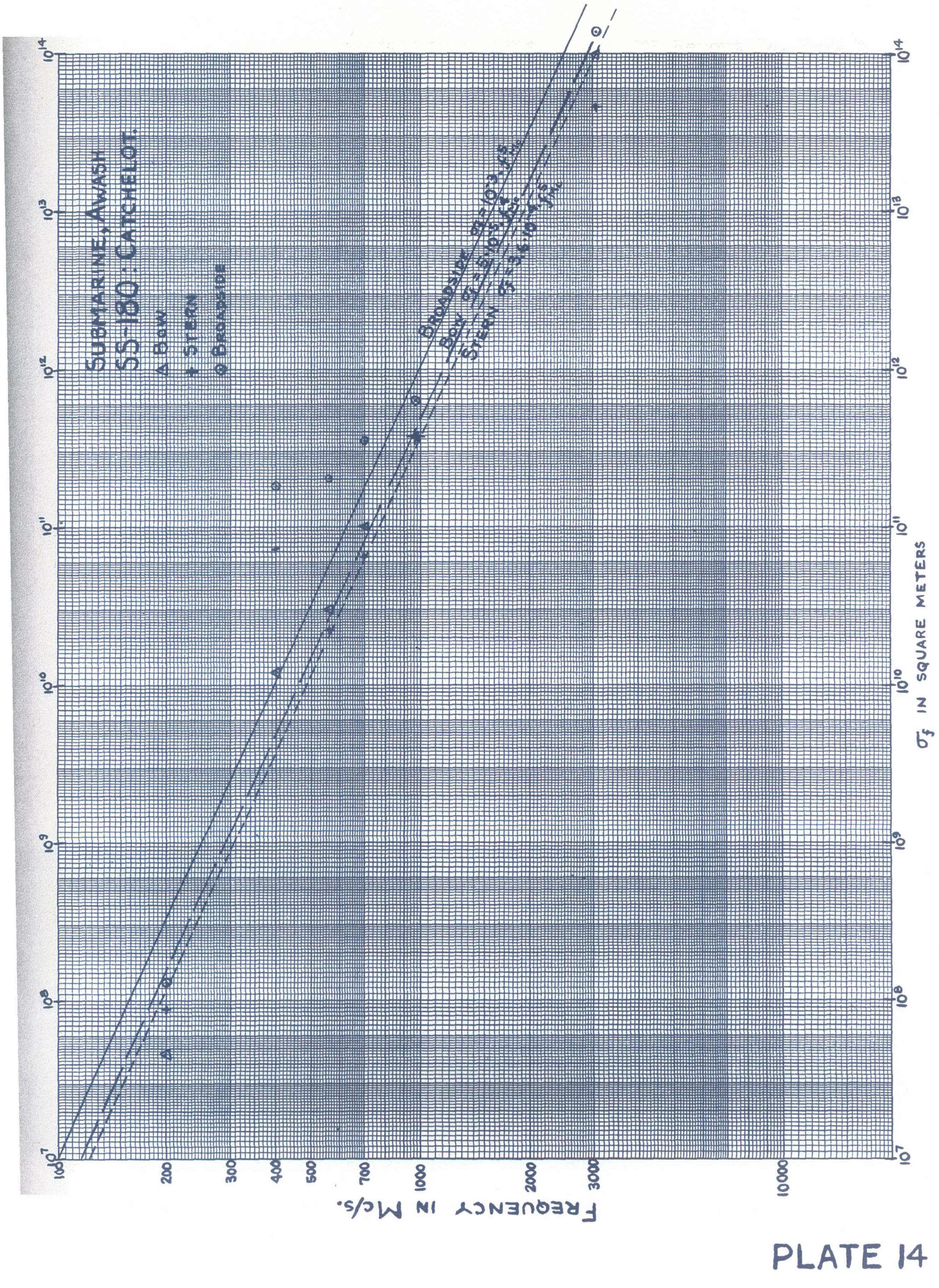

SUBMARINE, SURFACED
SS-180: CATCHELOT.
Δ BOW
+ STERN
○ BROADSIDE
BROADSIDE
STERN
BOW
FREQUENCY IN Mc/s.
σf IN SQUARE METERS
100
200
300
400
500
700
1000
2000
3000
10000

PLATE 13



SUBMARINE, AWASH
SS-180: CATCHELOT.
Δ BOW
+ STERN
⊙ BROADSIDE
BROADSIDE $\sigma_f = 10^{-3} \cdot f^5_{Mc}$
BOW $\sigma_f = 5 \cdot 10^{-4} \cdot f^5_{Mc}$
STERN $\sigma_f = 3.6 \cdot 10^{-4} \cdot f^5_{Mc}$
σ_f IN SQUARE METERS
FREQUENCY IN Mc/s.
100
200
300
400
500
700
1000
2000
3000
10000
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}

PLATE 14

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