NRL Report 7510

Radar Cross Section of the HMS Arethusa at Grazing Incidence

[Unclassified Title]

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December 13, 1972

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ABSTRACT

The radar cross section (RCS) of the HMS Arethusa has been measured at grazing incidence for frequencies of 1300, 2800, and 9225 MHz. The measurements are for horizontal polarization at 1300 and 2800 MHz and for both horizontal and vertical polarizations at 9225 MHz. The measurements were performed using the NRL dynamic measurement radar at the Chesapeake Bay Division of NRL as the ship proceeded in circular orbits around a point approximately 9500 yards from the radar. Cross-section values were plotted as a function of ship's aspect in the form of polar profiles including the 20, 50, and 80 percentile values of the RCS distribution functions, which were determined for 2-degree azimuth increments. Recording instrumentation aboard the ship permitted azimuth aspect determination to the order of 0.2 degree.

PROBLEM STATUS

This is a final report on this ship measurement. Measurements on additional ship classes will continue.

AUTHORIZATION

NRL Problem R06-44
Project S3315

Manuscript submitted October 18, 1972.

RADAR CROSS SECTION OF THE HMS ARETHUSA AT GRAZING INCIDENCE

INTRODUCTION

The radar-cross-section (RCS) values of the British frigate HMS Arethusa have been determined at grazing incidence using the NRL dynamic measurement radar [1,2]. The values cover a 360-degree azimuth aspect interval in 2-degree increments and are the 20, 50, and 80 percentiles of the RCS distribution functions from each of the 2-degree increments. The measurements were made using horizontal polarization on transmission and reception at frequencies of 1300 MHz, 2800 MHz, and 9225 MHz. In addition, vertical polarization on transmission and reception was used at 9225 MHz. The measurements were performed October 28, 1969, following a visit of the Arethusa to Washington, D.C.

RADAR SYSTEM

The system used for the measurement was the NRL dynamic measurement radar which consisted of three similar pulsed radars operating from a common pedestal. Table 1 lists some of the basic system characteristics. The receiver systems use no AGC and operate with an instantaneous dynamic range of 40 dB. The dynamic range is further increased by use of remotely controlled RF attenuators in each receiver channel which switch in 10-dB increments, providing an additional signal positioning capability of either 10 or 20 dB. These attenuators effectively position the 40-dB dynamic range to most adequately contain the return signal. In addition RF attenuators normally used to provide an automatic range compensation were set to a fixed value to ensure that the received signal would not saturate the receiver. This necessitated a range compensation during the data reduction.

Table 1
Basic System Characteristics

Parameter	L Band	S Band	X Band
Frequency	1300 MHz	2800 MHz	9225 MHz
Peak radiated power	250 kW	250 kW	250 kW
Pulse width	1 μsec	1 μsec	1 μsec
Pulse rate	500 pps	500 pps	500 pps
Beamwidth (E by H plane)	7.5° × 6°	3.5° × 3°	3° × 3°
Transmitted polarization	H, V	H, V	RC,LC,H,V
Received polarization	Same as transmitted	Same as transmitted	Simultaneous reception of RC,LC,H,V

The target was tracked manually in train and elevation from an optical tracker which is slaved to the pedestal drive. Range tracking is automatic.

DATA ACQUISITION

Data were taken as the ship orbited in a 1000-yard-diameter circle around a point approximately 9500 yards from the radar site. The radar is about 100 feet above the water; thus the average angle of incidence was 0.2 degree. At the selected speed of 6 knots the azimuth aspect angle changed at the rate of approximately 0.5 degree per second.

To accurately determine the azimuth aspect angle, the ship's heading was continuously recorded during the data runs by use of a synchro-to-digital converter connected to the ship's gyrocompass. The digital output of the converter was combined with the output of a WWV-synchronized time-code generator and recorded on tape. A similarly time-coded tape at the radar site contained the radar range and the train and elevation angles. Thus, by time alignment of the tapes in a computer combined with suitable programming, the azimuth aspect angle could be determined to an accuracy of ±0.2 degree. If the gyrocompass is determined to have an offset, the aspect angle is adjusted as required.

Primary data recordings of the reflectivity data are accomplished by stretching the pulse amplitude to be recorded and quantizing this amplitude to ten bits for recording on a 16-track digital recorder. These amplitudes are recorded at a rate of 500 pulses per second for each of the three radar channels. In addition the range, train and elevation angles, step attenuator values, run number, and timing information are recorded on the same tape. Other data recorded at the site are the WWV time code, range, and train and elevation angles on a computer-formatted tape, pulse-to-pulse video on 35-mm film, field of view on 16-mm boresight film, the detected stretched video on a chart recording, and a simultaneous voice commentary from all operator stations. The film recordings, chart recordings, and voice recordings are used in the analysis for judging the quality of the recorded data.

The system was calibrated, using a balloon-borne 6-inch sphere, before the first orbit, between orbits, and at the conclusion of the tests. Prior to the initial calibration the receiver systems were checked extensively by means of calibrated remote beacons.

DATA REDUCTION

Most of the data are reduced by a high-speed digital computer as indicated in Fig. 1. The overall process consists of distinct procedures linked by input-output operations. This allows some flexibility in processing and allows also for monitoring of the process at any one of the intermediate steps. Two preliminary procedures are the computation of ship's aspect and radar calibration and data screening. The ship's aspect is determined by correlating data recorded on board the ship (ship's gyrocompass as a function of WWV time) with tracking information recorded at the radar site (range, train, and elevation angles as a function of WWV time). The data recorded at the radar site are recorded not only as a function of WWV time but also as a function of data time, which permits full time synchronization. The aspect analysis consists of trigonometric computation of the angle between the ships fore-and-aft line and the radar line of sight and results in a single magnetic tape containing the raw aspect data and the final solution as a function of data time.

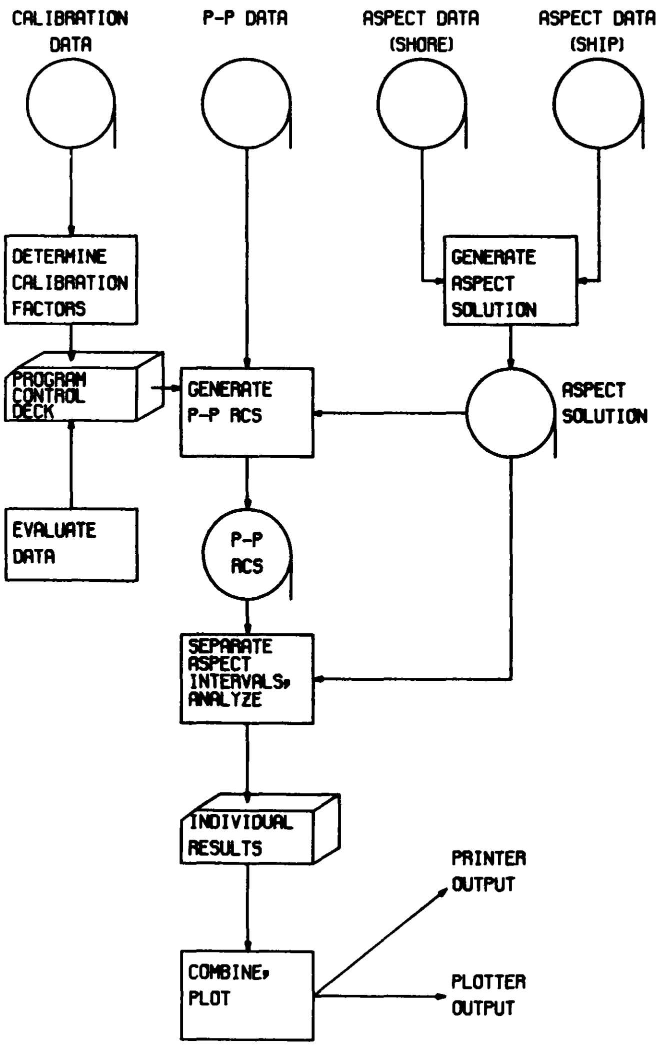


Fig. 1 — Outline of the computer routine used in processing the data. (P-P indicates pulse-by-pulse.)

Concurrent with the aspect analysis is the preparation of a program control deck which includes radar calibration data and data-quality information derived from scanning the supporting data recordings, primarily the chart recordings, audio tape recordings, and boresight films (16-mm recordings). This deck designates areas of questionable data and results in those areas being deleted or flagged in such a way that they are not considered in later processing stages.

The next procedure in the processing uses the aspect tape (for range data), the program control deck, and the pulse-by-pulse recording of the amplitude data and attenuator positions (P-P data). This procedure compensates the video data for inserted attenuation compared to the calibration, compensates for target range, and calibrates each received pulse to an absolute RCS value. The RCS data is then written onto another magnetic tape for subsequent processing.

The next procedure in the processing is the subdivision of the RCS data into appropriate aspect cells and the formation of the distribution function on each of those intervals. The pulse-by-pulse RCS and the aspect data, both as functions of time, serve as inputs to this stage in the processing. The aspect data are examined, and cell division points are determined and tabulated. This table then provides a sequence of times to control the subdivision of the RCS data. Once the distribution function is determined, the 20, 50, and 80 percentiles are read and punched on a card for input to display routines. The distribution analysis is continued for each channel in each aspect cell.

The final procedure in the analysis is the compilation of data from like conditions (polarization, frequency, and aspect) and the presentation of the resulting values. When more than one value exists for a given set of parameters, each of the values is weighted in significance proportional to the sample size and an arithmetic mean determined. This is then the RCS value presented for those conditions. The presentations are tabular outputs of RCS versus aspect for the different frequencies and polarizations considered and also a polar plot of the RCS values versus aspect.

RESULTS

The Arethusa is a general-purpose frigate, pennant number F-38, with a full-load displacement of 2860 tons, an overall length of 372 feet, and a beam of 41 feet [3]. The shipboard search-radar antennas were rotating during the measurements, but the transmitters were in standby. The 20, 50, and 80 percentile values of the RCS distribution function are plotted in Fig. 2 through 5 and are designated by a circle, a triangle, and a cross respectively. The k^{th} percentile denotes that value such that $(100 - k)\%$ of the received pulses are greater than or equal to it. All units are in decibels greater than 1 square meter.

The L-band results (Fig. 2) are characterized by a level of approximately 35 dB above 1 square meter (dBsm) with the exception of the beam aspects, where the median (50 percentile) RCS rises as high as 51 dBsm. There are evidences in the pattern of the effects of ship's structure. At 12 degrees off the bow either way, the level drops sharply for one 2-degree cell. At 46 to 48 degrees off the bow there is an increase in the RCS. At 74 degrees off the bow there is another symmetric peak. There is approximately a 5-dB difference in the maximum response at the beam aspect between the port side (90 degrees) and starboard side (270 degrees). This effect is not evident in the measurements at the two higher frequencies however.

The S-band results (Fig. 3) are similar to those at L band; however the overall level is higher than at L band, being near and above 40 dBsm for most aspects. The relative null

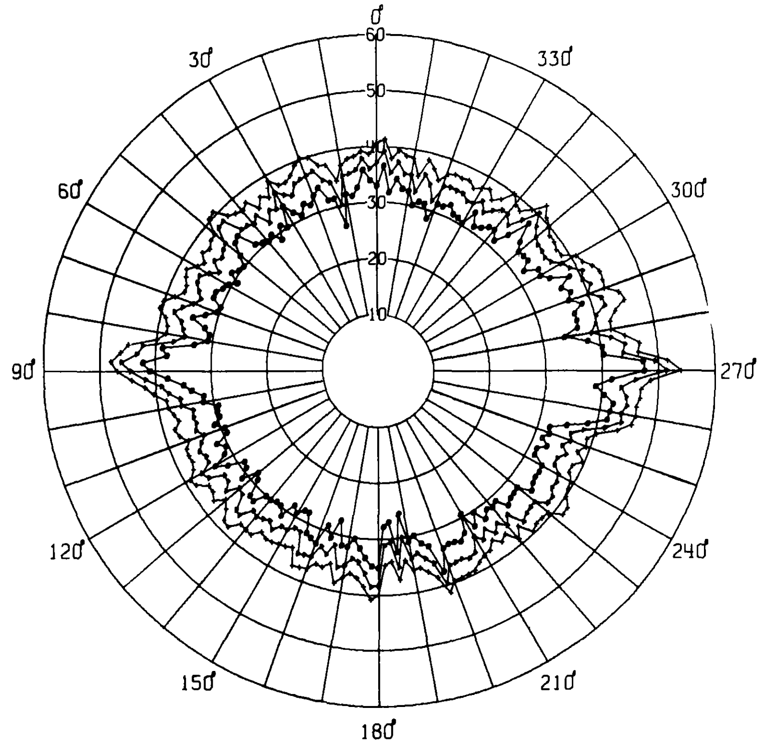
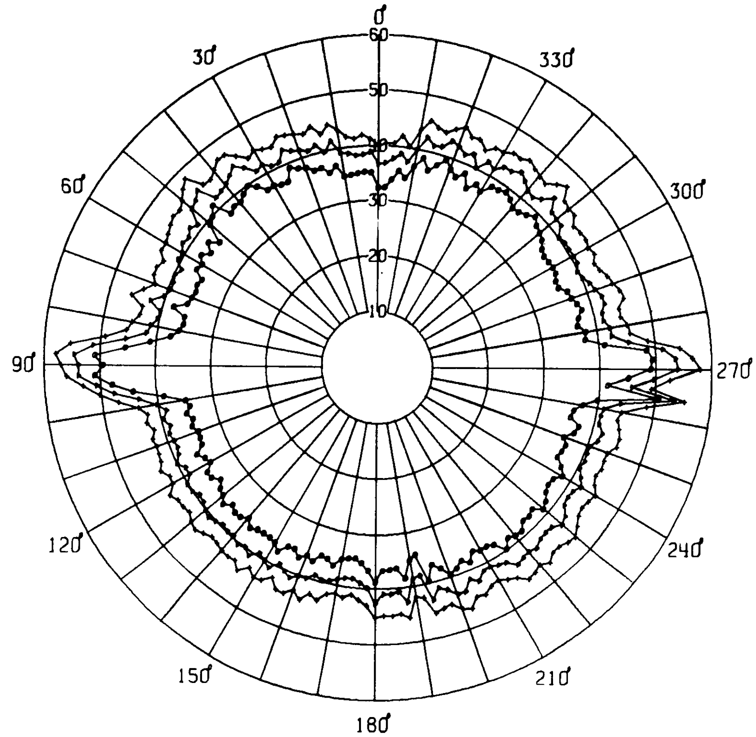


Fig. 2 — Radar Cross Section of the HMS Arethusa at grazing incidence for 1300 MHz. Horizontal polarization was used on transmission and reception. The bow aspect is designated as 0 degrees, and the beam aspect on the port side is designated as 90 degrees.

at 12 degrees is no longer evident, but the peaks at 46 and 74 degrees are still present. In addition there is a strong peak at 264 degrees. The median RCS at the beam aspect is 54 dBsm, and there is less fluctuation in the RCS values from one cell to the next as compared to the L-band results.

The X-band horizontal-polarization results (Fig. 4) show characteristics similar to those at both L and S bands: the high beam responses and the peaks at 46 to 48 degrees and 74 degrees. The median RCS values for the beam aspects are very nearly the same as at S band, but in general the median RCS tends to be higher at X band than at S band for other aspects, significantly the forward aspects. The vertical-polarization results at X band (Fig. 5) show only minor differences in level from the horizontal-polarization results, and the patterns for the two cases are nearly identical.

There are structures on the ship which could give rise to the peaks at 46 to 48 degrees and 74 degrees. The coamings forward of the gun mount would present normal incidence at approximately 50 degrees off the bow, and a bulkhead at the base of the mast on the same level as the bridge would present normal incidence at approximately 70



RADIAL SCALE: σ (DB ABOVE 1 M²)

Fig. 3 — Radar Cross Section of the HMS Arethusa at grazing incidence for 2800 MHz. Horizontal polarization was used on transmission and reception.

degrees off the bow. Accurate diagrams were not available to determine these angles precisely or to determine if these structures would have a sufficient RCS to be the mechanisms.

The RCS would appear to be a function of frequency, since the levels increased with the use of a higher frequency. The similarity of X-band results at horizontal and vertical polarization would indicate that the RCS is not a sensitive function of the transmitted polarization.

CONCLUSIONS

The RCS of the HMS Arethusa varies as a function of viewing aspect and transmitted frequency. At 1300 MHz (Fig. 2) the median RCS varies from a low of 30 dBsm (1000 m^2) to a high of 52 dBsm (158,500 m^2), with most median values falling in the 35 to 40 dBsm range (3000 to 10,000 m^2). The extremely large value occurs at beam aspects and persists for only a short angular interval. At 2800 MHz (Fig. 3) the median RCS is near 40 dBsm for most aspects, with the beam aspects exhibiting values of approximately 54 dBsm (250,000 m^2). Evidences of resonant structures giving rise to higher than average values are present at azimuth aspects of 46, 74, and 264 degrees. At 9225 MHz and horizontal polarization

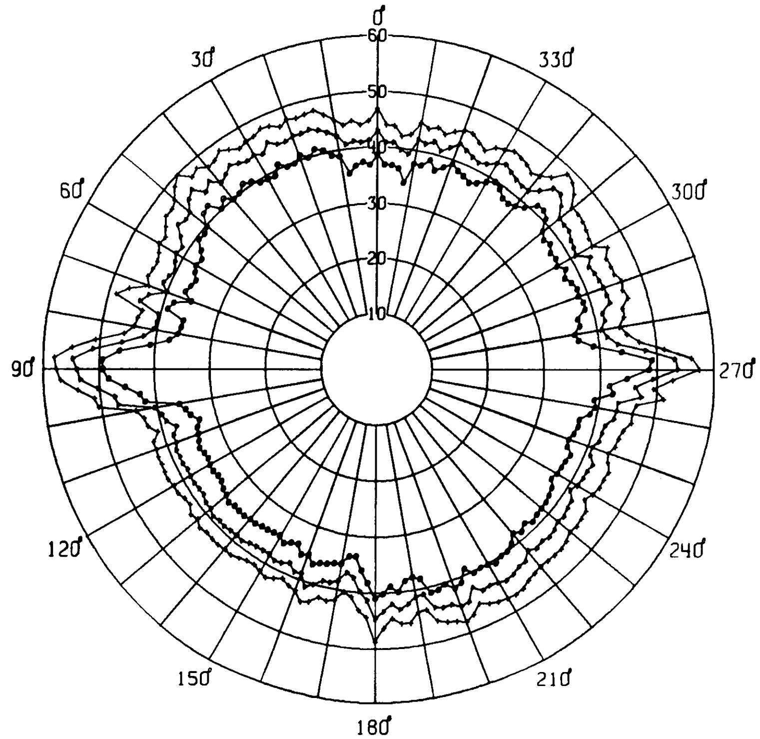


Fig. 4 — Radar Cross Section of the HMS Arethusa at grazing incidence for 9225 MHz. Horizontal polarization was used on transmission and reception.

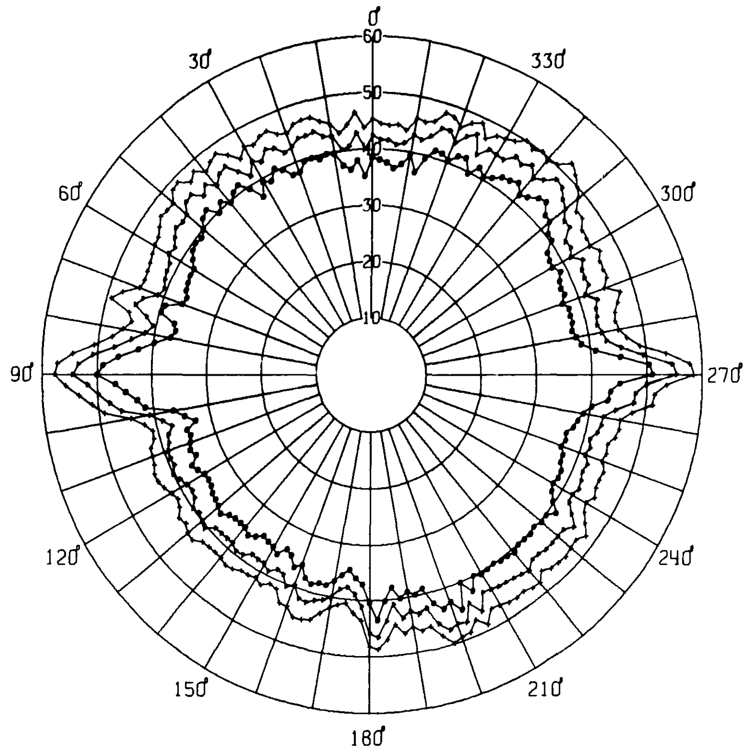


Fig. 5 — Radar Cross Section of the HMS Arethusa at grazing incidence for 9225 MHz. Vertical polarization was used on transmission and reception.

(Fig. 4) the median RCS is greater than 40 dBsm but generally below 45 dBsm (31,600 m^2) for most aspects, with the exception of the aspect interval from 100 to 180 degrees, where it is approximately 39 dBsm (8000 m^2). The same evidences of resonant structures as seen at 2800 MHz are visible also. There are only minor differences in the vertical-polarization and horizontal-polarization results at 9225 MHz.

ACKNOWLEDGMENTS

The assistance of A.E. March, D.C. Hut, C.E. Jedrey, Jr., P.A. Curran, and P. Ward in the system-preparation, checkout, and data-acquisition phases of the measurement is gratefully acknowledged as is the cooperation and assistance of the officers and crew of the HMS Arethusa in the installation and removal of recording equipment.

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3. R.V.B. Blackman, compiler and editor, "Jane's Fighting Ships," McGraw-Hill, New York, 1968-1969.

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

Naval Research Laboratory
Washington, D.C. 20390

2a. REPORT SECURITY CLASSIFICATION

2b. GROUP

XGDS-3

3. REPORT TITLE

Radar Cross Section of the HMS Arethusa at Grazing Incidence (U)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* This is a final report on this ship measurement. Measurements on additional ship classes will continue.

5. AUTHOR(S) *(First name, middle initial, last name)*

F.D. Queen and E.E. Maine, Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 13, 1972	14	3

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
NRL Problem R06-44	NRL Report 7510
b. PROJECT NO. S3315	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Department of the Navy Naval Ship Systems Command Washington, D.C. 20360

13. ABSTRACT (Unclassified)

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DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ships						
Radar cross sections						
Frigates						
HMS Arethusa						
L band						
S band						
X band						
Vertical polarization						
Horizontal polarization						