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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

DEVELOPMENT OF A HEAVY WEATHER OPERATOR GUIDANCE CATALOG FOR FF-1052 CLASS SHIPS

BY

SUSAN L. BALES

AND

EDWARD W. FOLEY

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

SHIP PERFORMANCE DEPARTMENT

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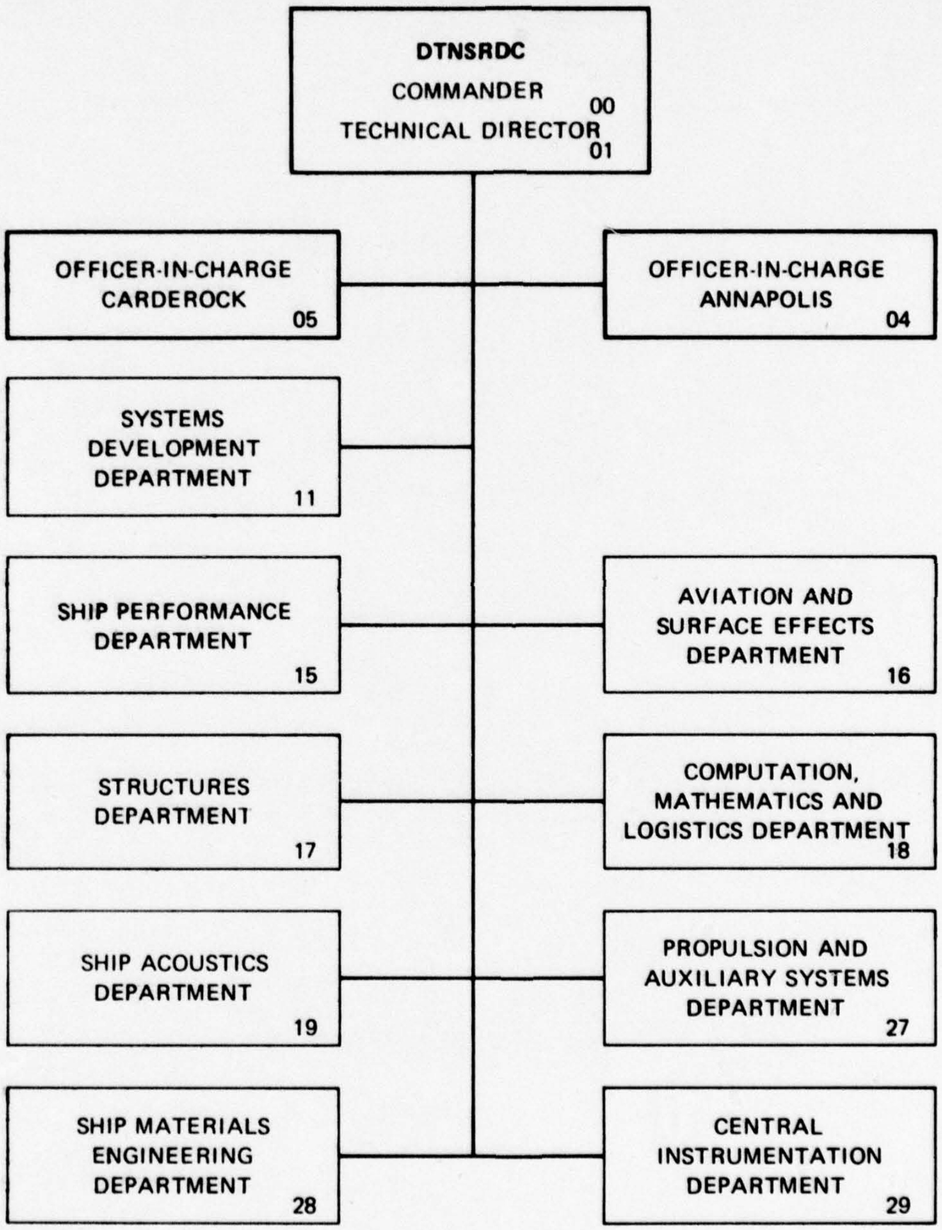

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This report is the second in a series describing ongoing efforts to include ship seakeeping performance data in ship operations planning and decision making.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report is the second in a series that considers the inclusion of seakeeping data in ship operations planning and decision making. It presents a condensed version of a Catalog of Heavy Weather Operator Guidance (HWOG) developed for FF-1052 Class ships. The Catalog provides the ship operator with hard copy, quantitative predictions as to how the ship responds in a seaway and some guidance for avoiding excessive ship motions or related events, such as slamming and wetness, that may cause damage to the ship during heavy weather conditions. The Catalog makes no attempt to tell the

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In brief, the HWOG Catalog consists of graphs which indicate the ship heading and speed combinations, for a variety of sea conditions, that may cause excessive ship motions or related events, and hence damage to the ship, or, some loss of mission effectiveness, combat readiness, or crew safety. In addition, the Catalog indicates heading and speed combinations which may minimize ship motions. The criteria used for identifying ship damage potential were developed upon examination of Casualty Reports (CASREPTS) for the FF-1052 Class ships. The criteria are considered somewhat tentative due to the lack of quantitativeness in these reports. A wide variety of operational environments have been considered due to the complexity and variability of sea conditions that occur throughout the worldwide naval operational area.

In addition to presenting a condensed version of the HWOG Catalog, this report also briefly describes the analytic procedures used and the assumptions made in the development of this Catalog, which, it should be noted, are the result of the cooperative efforts of the design, R&D, and operations communities.

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ABSTRACT

This report is the second in a series that considers the inclusion of seakeeping data in ship operations planning and decision making. It presents a condensed version of a Catalog of Heavy Weather Operator Guidance (HWOG) developed for FF-1052 Class ships. The Catalog provides the ship operator with hard copy, quantitative predictions as to how the ship responds in a seaway and some guidance for avoiding excessive ship motions or related events, such as slamming and wetness, that may cause damage to the ship during heavy weather conditions. The Catalog makes no attempt to tell the operator what to do, but rather describes, through seakeeping operator envelopes (SOE's), what he may expect under a set of arbitrary sea conditions. It is intended that the application of the provided data should be made with good judgment, the consideration of mission requirements, and the operator's firsthand interpretation of prevailing conditions.

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ADMINISTRATIVE INFORMATION

The work reported herein was carried out at the request of the Naval Sea Systems Command (NAVSEA 934) and authorized by the Naval Ship Engineering Center (NAVSEC) Work Requests WR-75932 and WR-81527 and the Conventional Ship Seakeeping Research and Development Program, which is funded under Project Number 62543N and Block Number SF 43 411 212. It is identified by the Work Unit Numbers 1-1568-884, 1-1568-889, and 1-1504-100-18, respectively, at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC).

INTRODUCTION

This report is the second in a series that will address the generic topic of the use of seakeeping in ship operations. Simply speaking, the topic implies the use of quantified descriptions of the ship's potential dynamic responses to the encountered natural environment in order to minimize

a. transit times

b. fuel consumption

c. degradation of mission effectiveness

d. shipboard damage

e. the possibility of catastrophe (e.g., broaching, capsizing, or major structural failure)

The first report in this series, see Reference 1,* provides an overview of available technology that can be applied to the development of tools to provide such seakeeping intelligence. This report concentrates on the area of damage avoidance due to heavy weather.

Specifically, this report documents the development of seakeeping intelligence applicable to heavy weather damage avoidance for FF-1052 Class ships. The FF-1052 has been singled out for this pilot study because of persistent heavy weather damage to the Class and requests from the fleet to Naval Sea Systems Command for improved ship seakeeping performance.

The work reported herein is an attempt to transfer state-of-the-art seakeeping prediction tools from the ship design and R&D communities to the fleet in order to provide some guidance for avoiding damage in heavy weather. Other efforts (e.g., ship alterations such as the installation of bulwarks and spray rails) aimed at improving seakeeping performance of the ship class are not addressed in this report. In brief, this report describes the development of the Heavy Weather Operator Guidance (HWOG) Catalog for FF-1052 Class ships, based on procedures that have been developed using state-of-the-art analytical techniques. Initially, a description is given of these procedures. Then, a condensed version of the Catalog, which is voluminous in its complete form, is given. In addition to the seakeeping

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*A complete listing of references is given on page 11.

operating envelopes (SOE's) and ship response data base graphs provided in the Catalog, a simple procedure for operator modification of the SOE's is outlined. Also, a simple survey aimed at soliciting fleet feedback is provided.

Other topics on the operational use of seakeeping intelligence in such areas as enhanced mission effectiveness, improved personnel comfort, and optimum task group routing will be addressed in future reports.

CALCULATION PROCEDURES

The calculation procedure developed to produce the FF-1052 HWOG Catalog is shown in Figure 1. State-of-the-art techniques for predicting ship motions and defining directional seaways were used so that only brief descriptions of the techniques are provided in this report. New computer program development was minimized, but that required was completed such that the entire procedure could be easily generalized to address a variety of other ship performance prediction applications. Additionally, the procedure was developed in a modular fashion such that modification of any one component for future applications, such as those described in Reference 2, could be efficiently achieved.

The ship response amplitude operator (RAO) functions were mostly developed using the well-known six-degree-of-freedom program documented in Reference 3, and identified as HANSEL.* As the HANSEL program uses a heading convention based on a head seas definition of 180 degrees, port beam seas definition of 90 degrees, etc., a post-processing program was developed to convert the RAO's to the required convention. The CONVERT program reorders the RAO's such that head seas are defined by 0 degrees, starboard beam seas are defined by 90 degrees, etc.

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* Antiroll fin stabilized roll motion RAO's were computed for a pair of fins with a 75 ft^2 planform area, using a simplified application of the FINCON computer program. Documentation for this computer program, which is based on the work of Reference 4 for antiroll fin design and performance evaluation procedures, will be published in late 1979.

This convention is acceptable to the ship operator, being consistent with the use of the compass onboard ship, and was considered appropriate for the presentation of the operationally applicable data given in the HWOG Catalog. The speed polar graphs, described later, also utilize this convention.

A new program, which predicts ship responses in a directional seaway, SHREDS, was developed as the main calculation tool of the procedure. The program permits the calculation of any ship response at any location along the ship. Absolute longitudinal, lateral, and vertical responses at arbitrary locations were calculated using the procedure given in Reference 5. Kinematic relative motions are calculated using the vector sum of the absolute motions and the wave elevation at a specified location. Slamming at a specified location is calculated using procedures given in Reference 6. The summation of the discrete products of the RAO's and the wave spectral variances was accomplished using an algorithm given in Reference 7. The seaways used in this particular work were defined using the two-parameter Bretschneider formulation, see Reference 8. Either long-crested or short-crested seas were specified. Short-crested seaways were defined in the conventional manner using a cosine squared, ±90-degree spreading function, though Reference 2 indicates the potential for using additional energy spreading widths. Additional features of SHREDS are given in the user's manual provided by Reference 9.

The actual hard copy guidance, provided in the HWOG Catalog, was developed using interactive graphics techniques. The SEAKEEPING graphics program* provides speed polar graphs of the ship responses and identifies regions where certain limiting values of the ship responses are attained. The program is generally run in an interactive mode so that the utilization of the previously developed ship response limits is done as the speed polar graphs are generated. Speed polar graphs were first formally introduced to the ship design and engineering communities in Reference 10, and are described in such detail in the HWOG Catalog that they are not further discussed here. The ship response limits were derived in part by an analysis of Casualty Reports (CASREPTS) for storm damage incurred on FF-1052 Class ships, see Reference 11. These limits are also described in detail in the Catalog and, because of the tentativeness associated with them, a procedure for operator modification of the SOE's is provided.

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* The program was developed by Code 1843 personnel at DTNSRDC, and as yet, is not formally documented.

One additional calculation, not indicated in Figure 1, was also performed for inclusion in the [illegible] Catalog. This was the determination of wave-induced [illegible] angles. The expression developed by [illegible] and [illegible] given in Reference [illegible] was used for this calculation.

SEAWAY SPECIFICATION

At the onset of this work, it was necessary to determine some definition as to what seaway severity corresponds to heavy weather conditions. In the context of the FF-1052 Class ship, it was decided that significant wave heights from 3.0 (10) to 12.2 (40) meters (feet) would be appropriate for this designation. This decision was based on the limited amount of quantitative environmental (sea state) information found in the [illegible], discussions with ship operators, and an examination of sea state definitions used by operators.

In order to make the Catalog as universally applicable as possible, it was also decided to use worldwide wave statistics. These were derived from Reference 3 using the [illegible] relationship for converting observed wave height, $\bar{H}_{obs}$ to significant wave height $(\bar{H}_w)_{1/3}$, as is customary in most naval ship design support studies, see Reference 14. For example,

$$(\bar{H}_w)_{1/3} = 1.68\,(\bar{H}_{obs})^{0.75} \text{ when } \bar{H}_{obs} \text{ and } (\bar{H}_w)_{1/3} \text{ are in meters} \quad (1)$$

or

$$(\bar{H}_w)_{1/3} = 5.51\,(\bar{H}_{obs}/3.28)^{0.75} \text{ when } \bar{H}_{obs} \text{ and } (\bar{H}_w)_{1/3} \text{ are in feet}$$

The actual significant wave heights used in the calculation were 3.0 (10), 4.6 (15), 6.1 (20), 9.1 (30), and 12.2 (40) meters (feet), see Table 1 of the Catalog text provided in the Appendix. As indicated previously, the range of 3.0 (10) to 12.2 (40) meters (feet) was selected to correspond to apparent heavy weather operations for the FF-1052 Class ship. The intermediate values were selected so as to maximize the range of calculated ship responses. In addition, the wave height values were developed to span the wide range of values that might be observed by the ship operator in the absence of reliable wave forecasts. The Catalog provides the suggested range of applicable operator observed (visual) heights as 2.1 (7) to 16.7 (55) meters (feet).

These were derived in part by examination of the Nordenström relationship given in Equation 1.*

As indicated in the Catalog, modal (peak) wave periods which occurred five percent or more of the time for each wave height were included, see Table 1 in the Catalog text in the Appendix. A 2-second interval on the included period was specified to correspond to the observed data of Reference 13 and is considered to provide appropriate definition of the ship response characteristics.

The specification of the occurring seaway is the key used to access each ship response chapter of the HWOG Catalog and is discussed in full detail in the Catalog text. Of special note is the guidance provided for proper estimation of the wave period in the absence of reliable forecasts of the parameter. The guidance figures provided as Figure 1 (head and following seas) and Figure 2 (bow and quartering seas) in the Catalog text were developed by solving

$$\frac{1}{T_E} = \left|\frac{1}{T} - \frac{0.33\ V \cos \mu}{T^2}\right| \qquad (2)$$

for values of T_E, the encountered wave period in seconds, given values of V, the ship speed in knots, μ, the ship-to-wave heading angle in degrees, and T, the true wave period in seconds. Generalization of the solutions for various ship headings and speeds was achieved by examining the data base of FF-1052 ship responses developed utilizing the SHREDS computer program.

As indicated previously, seakeeping guidance for both long-crested and short-crested seas was included in the Catalog. The short-crested seas were represented using the cosine squared, ±90-degree model though a brief study using alternative spreading widths was undertaken. The study was conducted because of early findings in the development of the Navy's 20-Year Hindcast Wind and Wave Climatology described in Reference 14. Those findings appear to indicate that the energy about a point is frequently spread about ±60 degrees rather than the traditionally used ±90 degrees. Speed polar graphs for a variety of ship responses

*It should be noted that only dimensions of feet were used throughout the Catalog. This was done at the request of NAVSEA and due to the fact that the operational Navy does not yet use metric units.

were developed and compared for various spreading widths, e.g., ± 45, ± 60, ± 90 degrees. As one would expect, the ± 45-degree cases generally showed similar ship response contour trends to the ± 60-degree cases. However, the ship response contours for the ± 60 and ± 90-degree cases generally varied enough that different operator decisions (selections of combinations of headings and speeds) would result depending on which spreading width was used. Ultimately, it was decided that the ± 90-degree spreading width would be used to generate the short-crested sea data for the HWOG Catalog. This was considered appropriate as the results from the 20-year climatology work are, as of yet, somewhat tentative.

Other initial results from the climatology work indicate a frequent occurrence of asymmetric energy spreading which appears to be dependent, at least in part, on geographic location. The cosine squared function used in this work permits only symmetric energy spreading. Thus, at some future time, as the final climatology results become available, it may be necessary to update the short-crested model used in this and other ship response simulations to permit variable shapes and widths in wave energy spreading. The modularity of the operator guidance implementation technique, discussed in Reference 2, should facilitate this type of update to the SHREDS (or other) ship response computer program. Further discussion about the currently used cosine squared model is given together with a generalized form in Reference 2.

CATALOG CONTENTS AND STRUCTURE

The HWOG Catalog is structured such that the operator, upon reading the introductory, self-teaching text, is ready to begin accessing and applying the ship seakeeping graphs which are provided as individual, removable chapters in the notebook containing the Catalog. Each chapter provides the ship's seakeeping characteristics for one seaway type defined by height, period, and directionality values. The chapters contain first the Seakeeping Operating Envelopes (SOE's) and then the Data Base Speed Polar Graphs. The Data Base Graphs permit the operator to modify the SOE's to reflect alternative motion or event damage limiting criteria.

The complete FF-1052 Class HWOG Catalog has been issued as a NAVSEA report, see Reference 15, and distributed to Fleet Commanders for initial evaluation.

The Appendix to the current report provides a selected extraction of material from Reference 15. The self-teaching introductory text is included in its entirety. Then a typical seaway chapter, for example for the long-crested seaway characterized by a height of 20 feet and a period of 9 seconds, is given.

A simple procedure for operator development of modified SOE's is described in the text, and transparent speed polar grid overlays are provided for this purpose. Also included is a simple survey aimed at soliciting user feedback. A standard form that is already familiar to the fleet was included for this purpose. The form has been used in the past for providing a simple user evaluation of combat system technical manuals and lends itself readily to the current purpose. A sample grid and survey sheet are provided herein after the seaway chapter.

It should be noted that feedback from the fleet regarding the utility of the HWOG Catalog is considered essential. Whether the operators' evaluation of this tool is negative or positive, it is expected that the design and R&D communities will benefit from the exchange. It is especially likely that some insight into improved performance criteria may result as well as further identification of the need for realistic, real-time wave forecasting and/or measurement techniques.

CONCLUDING REMARKS

This report documents the development of the simplest and most economic form of seakeeping intelligence for operational usage. Two other implementation forms are

1. joint shore/onboard guidance developed in real time
2. sensor/onboard guidance developed in real time

and, though more sophisticated and hence more costly, may provide more useful seakeeping (representative) data to the fleet operator because of the improved quality of the sea surface description. A more detailed discussion of these techniques is given in Reference 2.

As the current Catalog is evaluated and used by fleet operators, work is continuing in the design and R&D communities to improve performance criteria, wave models, wave (and wind) statistics, and ship response amplitude operator prediction. In addition, several additional hard copy catalogs intended to provide fleet support in additional areas (Test and Evaluation (T&E) and Helicopter Operations), are currently planned for some recent new ship classes or ship modernizations.

The development techniques and operational evaluation of these catalogs will be reported as they become available. The current HWOG Catalog has been examined by the environmentalists at Fleet Numerical Weather Central (FNWC) and is being considered for dissemination to the fleet as a product to aid in ship routing. Also, it is currently planned to initiate a program to transfer ship motion and limiting performance criteria from NAVSEA and DTNSRDC to FNWC for a variety of naval ship classes. These data would then be combined with environmental forecasts to provide additional guidance to the fleet. This type of guidance development, a variation on those mentioned above, will provide additional insight into the value of seakeeping intelligence in ship operations planning and decision making.

ACKNOWLEDGMENTS

The authors express their appreciation to Mr. Edward N. Comstock (NAVSEA) for his support and guidance in the development of this Catalog. Additionally, the cooperation and assistance of Mr. Mel Haas and Mr. Richard Van Eseltine (Code 1843, DTNSRDC) in the development of the software to produce speed polar graphs is greatly appreciated. Other members of the staff at DTNSRDC as well as ORI, Inc. and Advanced Marine Enterprises, Inc. are too numerous to list but acknowledged with great appreciation for their assistance in developing figures in the text and in the production of the final Catalog copy.

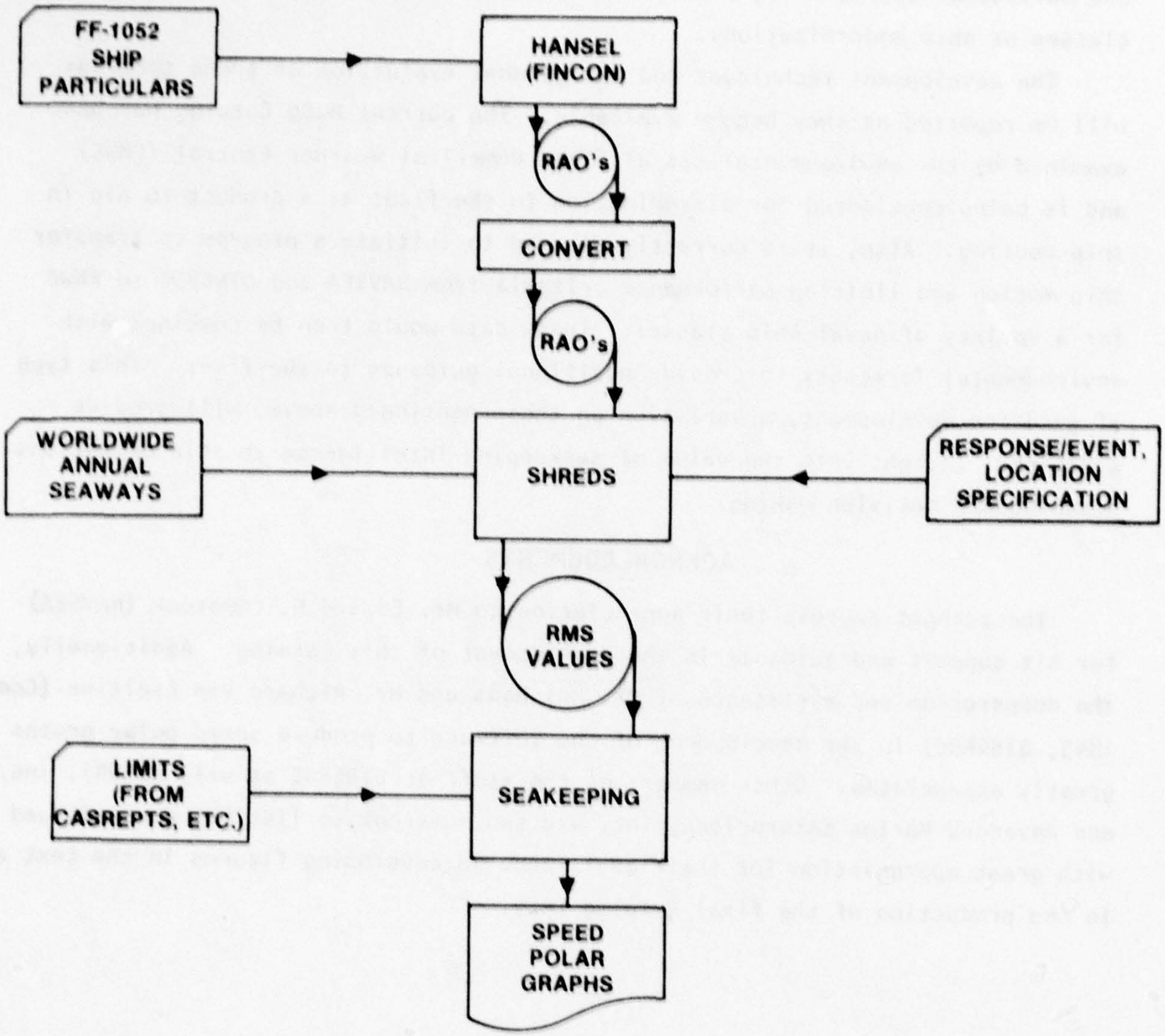

Figure 1 - Calculation Procedure for Development of FF-1052 HWOG Catalog

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APPENDIX

EXCEPRTS FROM FF-1052 CLASS HEAVY WEATHER
OPERATOR GUIDANCE CATALOG
FIRST DRAFT
NAVSEA REPORT SEC6136-79-03
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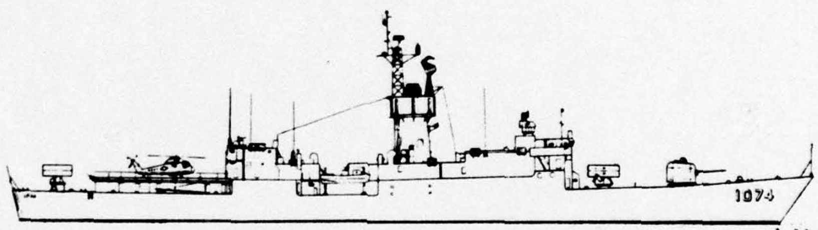
FF1052 CLASS

HEAVY WEATHER OPERATOR GUIDANCE CATALOG



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INTRODUCTION

In general, four types of seakeeping operator guidance may be useful to the fleet operator. These are Optimum Track Ship Routing (OTSR), Tactical Operations Ship Routing (TOSR), Heavy Weather Operator Guidance (HWOG), and [illegible] (SHMID). Table 1 provides definitions of the purpose, function, and applicability of these four seakeeping operator guidance areas. Of the four, only OTSR is currently available to fleet operators, and is provided upon request or when a movement report (MOVREP) to the Fleet Weather Centrals (FWC).

It is the purpose of this document to address the third, or HWOG area. This area has been singled out for immediate attention due to the numerous reports by FF-1052 Class ship operators of poor seakeeping characteristics, forgone mission objectives due to adverse weather, and shipboard damage due to excessive ship motions. Thus, the Heavy Weather Operator Guidance (HWOG) Catalog contained herein has been developed for distribution to FF-1052 Class ships. The Catalog permits the ship operator immediate access to certain engineering tools that have been developed by the ship design and R&D communities for quantifying seakeeping characteristics of modern naval combatants. The purpose of the Catalog is to provide the operator with quantitative information as to how the ship responds in a seaway and some guidance for avoiding excessive ship motions or related events such as slamming and wetness, during heavy weather conditions, that may cause damage to the ship. The Catalog makes no attempt to tell the operator what to do, but rather describes what he may expect under a set of arbitrary sea conditions. Application of the provided data should be made with good judgment, the consideration of mission requirements, and the operator's firsthand interpretation of prevailing conditions.

In brief, the HWOG Catalog consists of graphs which indicate the ship heading and speed combinations, for a variety of sea conditions, that may cause excessive ship motions or related events, and hence damage to the ship or some loss of mission effectiveness, combat readiness, or crew safety may be experienced. As well, the Catalog indicates heading and speed combinations which may minimize ship motions. The criteria used for identifying ship damage potential were developed primarily from an examination of Casulaty Reports (CASREPTS) for the ship class. A wide variety of seaways have been considered due to the complexity and variability of sea conditions that occur throughout the worldwide naval operational area.

The remainder of this Catalog provides the actual Heavy Weather Operator Guidance prefaced with instructions for its usage by FF-1052 Class ship operators. Additionally, a simple form for providing fleet feedback to the design and R&D communities is provided. Such feedback will facilitate assessment of the utility, content, format and completeness of this Catalog.

INSTRUCTION FOR USAGE

In brief, this Catalog of seakeeping guidance is structured such that having once determined the <u>seaway</u> in which the ship is operating, the operator may quickly turn to the section of graphs specifying ship motions or related events which could occur in that seaway. He can then proceed with a rapid evaluation of the ship's <u>Operating Envelopes</u> which summarize those heading and speed combinations likely to cause damage, and hence mission effectiveness degradation, to the ship. Additionally, a more thorough evaluation of the ship's motions and related events can be conducted using <u>Data Base</u> graphs provided for each seaway. As the seaway is the key by which the rest of the Catalog is accessed, its definition and specification are discussed in some detail. Subsequently, the two types of ship motion and event graphs will be introduced and discussed.

SEAWAY

The seaway, at any instant, is a unique combination of many waves which can change radically in a short time. Thus, the seaway environment in which a naval ship must operate is enormously varied both with respect to time and ocean location. However, in its simplest form, the sea can be regarded as varying combinations of three distinct physical parameters. These are wave height, wave period (or wavelength) and wave directionality. Scientists have found that by treating these three seaway parameters statistically, it is possible to provide a reasonably realistic description of the seaway in which the ship must operate. The Operating Envelopes and Data Base graphs which comprise this Catalog are defined using these three parameters, so values for these parameters must be determined in order to access the graphs.

Table 2 presents a summary of the wave height and period combinations associated with heavy weather and included in this Catalog. For example various wave heights from 10 to 40 feet and wave periods from 5 to 19 seconds have been included. The waves are considered to be either primarily confused or multidirectional and called short-crested or primarily unidirectional and called long-crested.

The ship operator must determine values of the height, period, and directionality parameters of the prevailing seaway to decide which section of the Catalog to turn to. At present the parameter values can be determined from any one of three means defined on Table 3. Both the FAX and WEAX reports described in the table can provide accurate estimates of the wave height parameter required to access the Catalog. However, wave period and overall directionality characteristics (long-crested or short-crested) are not routinely provided by either FAX or WEAX reports and local, fast moving phenomena may go unreported. The third alternative, shipboard (visual) observations, is limited by observer skill, though nominally, during periods of good visibility, all three of the required wave parameters can be estimated. As a general rule, it is recommended that the operator determine the three values by whatever means are both most expedient and provide the most accurate quantification of his operating environment. For example, if WEAX reports are available and appear reasonable to the local situation, they should be used to determine height and predominant direction values. If the visibility permits, the period (as well as the height and direction values in the case when forecasts are either unavailable or not realistic) should be determined from visual observations. If visibility does not permit visual observations, the operator should use the most likely period values, identified on Table 2 by the heavy blocking, as well as assume short-crested sea directionality to access the Catalog. Short-crested seas can be assumed in this case because they occur more often in nature than long-crested seas; however, it should be noted that more severe ship motions and related events can occur, at some predominant headings, in long-crested seas.

In order to assist the operator in making visual determination of the three seaway parameters, each of them is now briefly described, and visual aids for assigning values to them are suggested.

Wave Height

The visual observation of wave height is difficult and relies primarily upon the observer's ability to judge height. The value observed is the peak-to-trough or double amplitude height and is generally considered to be the so-called significant wave height (the average of the one-third highest of all waves in a given seaway). Experience indicates that observed values oscillate about the true, statistical significant wave height. Thus, Table 2 indicates a range of observed values about each significant wave height contained in the Catalog. For example, if the operator observes waves of 13 feet, then the Catalog graphs for 15 feet should be used.

If the operator has reliable FAX or WEAX reports available, the Catalog should be accessed using the forecasted height entry. For example, if significant wave height is forecasted as 13 feet, then the Catalog graphs for 10 feet should be used.

It is often convenient to use the term Sea State to indicate the severity of the seaway. Table 4 provides a Sea State Chart based on worldwide, all season naval operational environments. For example, the most likely Sea State that a ship will encounter is a State 5 wherein significant wave height ranges from 7.4 to 13 feet. In general, local open-ocean seas are caused by the severity and duration of the winds, so wind speeds have been indicated on the chart. In the open ocean, winds can be used as an indicator of significant wave height if both the direction and the speed have persisted for a number of hours. In cases where the seas are not a direct result of local wind action, the wave heights are referred to as swell waves and have traveled into the local area from a distant storm. In this case, the winds may be calm.

Wave Period

Determination of the wave period (or wavelength) is sometimes a difficult task for the observer. If the ship is underway in near head or following seas, it is customary to use the ship as a yardstick and estimate the distance between wave peaks. This distance is the wavelength and can be related to wave period by use of Figure 1. For example, if the ship is operating in head seas, and the distance between successive wave peaks is estimated at about the length of the ship, say 400 feet, then the wave period is about 9 seconds. This value is determined by reading along the bottom and the top scales indicated on the Figure 1 graph. The Catalog data for 9 second waves should be used in this case.

Wave period can also be determined with a stopwatch, though the period measured (time between successive peaks) is not the true wave period due to the effect of the ship's speed. In other words, the ship's speed alters the frequency with which the waves are encountered when compared to the case when the ship is not underway. However, this encountered wave period, T_E, can be converted to the true wave period by using Figure 1. For example, if the ship is steaming at 10 knots in head seas, and the wave period is measured to be about 8 seconds, then, by reading along the top scale of Figure 1, the true wave period is seen to be about 10.3 seconds. The Catalog data for 11 second waves should be used in this case.

Figure 2 presents similar graphs as Figure 1 for bow and quartering seas. The following heading definitions should be used with Figures 1 and 2 in order to determine the appropriate wave periods for accessing this Catalog:

1. Head seas - 330 to 30 degrees
2. Following seas - 150 to 210 degrees
3. Bow seas - 285 to 330 degrees, and 30 to 75 degrees
4. Quartering seas - 210 to 255 degrees, and 105 to 150 degrees

These headings are the predominat wave directions with respect to the ship and are discussed in the next section as well as in the Speed Polar Graph section of the Catalog. In beam seas (75 to 105 or 255 to 285), the true wave period is equivalent to the encountered wave period, and can be determined by measuring the period of the waves with a stopwatch. Thus, once the operator has determined the predominant wave directions, the true wave period can be determined using either Figures 1 or 2, or by measuring the wave period in beam seas.

Wave period can also be determined by measuring the duration of certain ship motion cycles. For example, in head and following seas, the period of heaving (vertical displacement in the vertical plane of the ship's center of gravity, for example, at Frame 83) motion approximates that of the waves.

Table 2 indicates that discrete values of wave period, at 2 second intervals, have been included in this Catalog. Therefore, some values of period determined by the operator will fall between the Catalog values. In such cases, the Catalog value nearest the operator determined value should be used. Otherwise, if the operator determined value is exactly between two adjacent Catalog values, both sections, e.g., for each respective Catalog value, of the Catalog should be consulted. Some ship motions, such as roll motion, are more sensitive to wave period than others, so that, if in doubt between two Catalog sections, the operator should select the one which maximizes roll motion. This is easily determined by comparing Data Base graphs, discussed in a subsequent section.

Wave Directionality

The final wave parameter which must be estimated in order to use the Catalog is wave directionality. Initially, the observer must determine whether the seas are multidirectional or unidirectional. In the former case, the seas are termed short-crested, while in the latter they are called long-crested. Short-crested seas are generally related to local seas generated by shifting winds and have a predominant direction about which the waves propagate. For example, in the northern northeastern Atlantic (Norwegian Sea), during the winter, the seas are generally confused seas, but propagating primarily from the west or the north-to-northeast. In other words, the higher waves are observed from the west or the north-to-northeast, though smaller waves are observed from the southwest. Long-crested seas, on the other hand, are characterized by waves all propagating in one direction, and generally relate to persistent, unshifting winds or to swells propagating from a distant storm. Long-crested seas are characterized by long, parallel wave trains. When the winds begin to shift to other directions, the direction of the waves will begin to shift, superimposing themselves upon the long-crested seaway so that the appearance of long, parallel wave trains is obscurred. The shorter waves formed by the superpositioning of wave trains are quite logically referred to as short-crested or confused seas.

As indicated in Table 2, and in the above discussion, the user must determine whether the ship is operating in short-crested or long-crested seas. If it is uncertain, short-crested seas should be assumed, though, as noted previously, more severe ship motions and related events can occur in long-crested seas at some headings.

The predominant wave direction (heading), with respect to the ship, must also be determined and may be available through FAX or WEAX reports. This parameter is required when examining the Operating Envelopes and Data Base graphs, of which the Catalog guidance is composed, as it provides a reference point for the ship's current operating conditions.

SHIP MOTION AND EVENT DAMAGE LIMITS

Though the dynamics of a ship in a seaway are complex, engineering tools are now available which permit a priori calculation of these ship motions and related events (such as slamming and wetness) given a reasonably realistic specification of the seaway. As stated previously, the primary purpose of this Catalog is to provide the fleet operator with an onboard capability for quantifying the ship's seakeeping characteristics in order to avoid those conditions (heading and speed) which may cause damage to the ship. Therefore, the Operating Envelopes, presented in the Catalog and discussed subsequently, are dependent upon the calculation of ship motions and events which are known to be correlated to some shipboard damage when their occurrences become excessive due to heavy weather.

A study to identify ship motion parameters which may cause damage revealed that Casualty Reports (CASREPTS), filed by the fleet describing incurred damage which may degrade mission readiness, were the best source of such information available. Over 123 reports of "storm/weather damage" for ships operating in either the Atlantic or the Pacific between 1 January 1972 and 17 August 1977 were examined. Figure 3 shows the distribution of reported casualties reported throughout the year. The low number of reports for January is likely due to reduced time at sea, while the high number reported for operations during April in the Atlantic may be due to increased time at sea (compared to winter), and to ships being "caught" by the last of the winter storms. The high number of reports in July in the Pacific are attributed to the periodic monsoons in the Indian Ocean and southeastern Asian areas.

Figure 4 shows the casualty distribution by year as well as by type of damage. The data have been normalized by the number of ships in service each year. A brief review of these figures reveals that ship alterations (SHIPALTS) made to the 5"/54 caliber gunmount since 1974 have been effective in reducing damage to the gunmount, while the other identified damage categories have generally remained unimproved. Though IVDS doors were installed at the stern starting in 1974, due to difficulties in fabrication, they have served to increase the potential for structural failure. However, a SHIPALT now being implemented should alleviate the problem and reduce the number of CASREPTS in that category. The increasing number of stub mast failures shown on the figure indicate that the stub mast is apparently susceptible to failures due to slam induced vibration and fatigue. SHIPALTS to generally improve the material condition of the FF-1052 Class ships are constantly being developed and implemented though they will not be discussed further herein.

Though the CASREPTS rarely provided quality ship motion or environment descriptors, it was possible to identify five ship motion or event types that were correlated to some reoccurring type of shipboard damage. These are rolling motion, pitching motion, ship slamming, foredeck immersion (or bow wetness), and stern wetness. Further, upon inspection of the CASREPTS and other FF-1052 Class ship-reported data, a list of tentative motion limits has been established to be used in this Catalog. Two levels of limits were identified. The first is the lowest level at which there is a reasonable possibility of damage occurring. The second is a level at which there is a reasonable probability that damage will occur. The possible and probable limits may tentatively be taken to represent a 5 percent and a 95 percent probability of damage, respectively.

Figure 5 presents the limits used in this Catalog to develop the Operating Envelopes, discussed in a subsequent section. For each of the five ship motions or events previously identified, occurrences are provided which reflect both probable and possible damage to the ship. The impact or type of damage primarily caused by each motion or event type is also noted. For example, RMS* roll motions of 10 degrees will

*RMS and other statistical terms are described in the Statistics section.

very probably cause a decrease in personnel safety as well as damage to sensors on the mast. RMS roll motions of 5 degrees, on the other hand, may only possibly cause some loss of crew safety or sensor damage.

STATISTICS

The roll and pitch motions provided in this Catalog are given in terms of root mean square or RMS values. The RMS value, statistically, is the square root of the variance or the standard deviation of a time history of ship motion measured in a seaway. It is related to the mean value of ship motion by the relation

$$\text{Mean Motion} = 1.25 \cdot (\text{RMS Motion})$$

The motion here is taken to indicate a single amplitude of response. For example, in the roll mode, the ship first rolls over, say to starboard, and then rolls back to upright before proceeding to roll to port. The total cycle of rolling is from upright-to-starboard-to-upright-to-port-to-upright. The sum of the excursion of rolling from upright to the starboard and then port sides is called the double amplitude of motion. Half of that maximum excursion (for example upright-to-starboard-to-upright) is called the single amplitude of motion.

The RMS values provided in this Catalog can be related to other statistical motion values (single amplitudes) by

$$\text{Significant Angle (Average of 1/3 Highest Angles)} = 2.00 \cdot (\text{RMS Angle})$$

$$\text{Maximum Angle (Highest in 100 Cycles of Wave Encounter)} = 3.03 \cdot (\text{RMS Angle})$$

In general, significant single amplitude values (2 · RMS) correspond to those observed by the operator. In calm to moderate seas, only the larger motions, due to occasional higher waves, are noted, and in seas associated with heavy weather, more cycles of motion will be of notice, and the larger ones may be of concern for ship damage consideration. In these conditions, if the operator can specify the height, period, and directionality characteristics of the seaway, then the Catalog should provide a reliable prediction of the ship motions and events. Some variations in magnitude may be noted and are due, in general, to simplifications made in the calculation process. However, the observed trends of increasing or decreasing ship motions and related events with heading and speed variations in the seaway should be reasonably consistent with the Data Base graphs.

It should be noted that the significant wave height values provided in Table 2 are double amplitude heights.

SPEED POLAR GRAPHS

Having discussed the seaway and the ship motion damage limits, the format of the HWOG Catalog is now described. As indicated previously, each seaway section consists of two sets of graphs, namely the Operating Envelopes, and the Data Base graphs, described in the next two sections. Each of these are presented in a graphical format called a speed polar graph, which has as its grid the regions of possible ship headings and speeds. Figure 6 illustrates this grid system which indicates constant ship speeds upon the concentric circles and constant ship headings (to the waves) along the radial lines. All possible ship headings and ship speeds up to a nominal value of 27.5 knots are contained upon this convenient grid.

Figure 7 provides a typical speed polar graph of ship roll motion with the fins inoperable. The contours drawn on the speed polar grid indicate lines of constant root mean square (RMS) roll angle. The seaway specified for this example is defined by a significant wave height of 20 feet, a period of 9 seconds, and is considered to be unidirectional or long-crested. The possible predominant directions of the seaway are indicated along the radial lines. The ship operator must observe the true predominant direction (or determine it from FAX or WEAX reports) as discussed earlier in order to establish a reference point for identifying the current operating conditions on the speed polar graph. Values of RMS roll angle are easily determined from the graph. For example, if the ship is operating in starboard, beam seas at about 15 knots, the RMS roll angle is about 5 degrees. If the ship is slowed down, the RMS roll angle may exceed 8 degrees at 5 knots or less. By altering the course to a bow sea heading, say 45 degrees to the waves, the RMS roll motion will be decreased to less than 2 degrees and, based on the tentative limit of Figure 5 (for example, 5 degrees), the 15-knot speed can be maintained with no possibility of damage due to rolling motion. Thus, the speed polar format provides a convenient means for selecting combinations of ship heading and speed to minimize ship motions within a specified seaway. The graphs can save time by avoiding trial and error selection of optimum heading and speed combinations. As well, the graphs can be used as a training aid for younger or newly assigned ship's officers.

DATA BASE

The five motion and event types listed on Figure 5 were calculated, at the locations indicated on the figure, for each seaway identified in Table 2. The calculations were performed for the ship in the fully loaded* condition with a mean draft of about 15.5 feet. The SHIPALT for bulwark and spray rails, being backfit to some members of the Class starting in 1977, was not considered, though the net effect of the SHIPALT is to decrease the severity of bow wetness. Roll motions were calculated for the ship both without (inoperable) antirolling fins and with them fully operable in an optimum stabilizing mode. These calculations are presented as speed polar graphs and comprise the Data Base portion of the Catalog.

The calculations of stern wetness indicated that, at the location selected (the base of the IVDS doors), excessive wetness would be present regardless of ship heading-to-the-waves or ship speed. This is due to the location's proximity to the waterline, and the severity of the wave height values selected to represent heavy weather conditions. Therefore, no further stern wetness data are provided in this Catalog. Rather, stern wetness should be considered a persistent problem for FF-1052 Class ships

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*Typical minimum ballast, or light load conditions, were found to be fairly similar to the full load case, in terms of ship geometry, and have therefore been ignored. For example, the "Damage Control Book, DE1052/1097," 1973, indicates only a variation of 0.6 feet in mean draft, 0.1 feet in metacentric height, and 140 tons in displacement between the light and full load conditions. Differences in ship motion due to such small variations in ship geometry are considered slight within the context of this Heavy Weather Operator Guidance Catalog.

operating in heavy weather conditions until the SHIPALT to improve the IVDS doors is accomplished on the subject ships.

OPERATING ENVELOPES

The remaining speed polar graphs found in this Catalog are Operating Envelopes which identify the ship heading and speed combinations, in the specified seaway, that may cause damage. In brief, the Operating Envelopes are developed by identifying operating regions, for example, heading and speed combinations, within which at least one ship motion or event limit, as defined on Figure 5, is exceeded. By examining Figure 7, it is straightforward to identify operation regions, where the roll limits are exceeded, and hence, damage may occur. For example, in the specified long-crested seaway, it is probable (10 degree limit) that damage will occur in quartering seas of about 120 degrees at ship speeds of 15 knots or less. In direct beam seas, the possibility of damage exists at speeds of about 15 knots or less.

Thus by locating the regions where the limits of Figure 5 occur on each motion or event Data Base graph, such as in Figure 7, it is a simple task to identify undesirable ship heading and speed combinations. This procedure is used to develop Operating Envelopes for each seaway and is further described in Figure 8.

In brief, Figure 8 provides an illustration of the development of the Probable and Possible Operating Envelopes using the same long-crested seaway specified for Figure 7. Figures 8a through 8d illustrate the probable limit contours for roll, pitch (no limit), bottom slams, and bow wetness. These limiting contours are extracted from the Data Base graphs such as the one shown for roll in Figure 7. Figure 8e shows the composite of the probable limits shown on Figures 8a to 8d. By shading out all regions contained within any one of the motion or event contours, and thus delineating those operating areas of probable damage, Figure 8f is developed. The shaded area indicates heading and speed combinations that will probably cause damage due to at least one of the four motion or event types. The white or open area is the safe-from-probable damage operating region. The contours shown on Figure 8f compose the Probable Operating Envelope, and indicate that operations in beam-to-head seas, regardless of speed, and in quartering seas (120°) up to about 13 knots, will probably cause damage to the ship. Adopting stricter motion and event limits (for example the possible values given in Figure 5) restricts the "safe" operating area even more and produces the Possible Operating Envelope shown in Figure 8g. Overlaying the two envelopes shown on Figures 8f and 8g produces the Combined Operating Envelope. It is this Combined Operating Envelope, simply called from here on the Operating Envelope, which is contained with the Data Base graphs in each seaway section of the HWOG Catalog.

The Operating Envelopes provided in this HWOG Catalog permit rapid evaluation of those headings and speed combinations likely to cause damage to the ship due to excessive ship motions or other related events. However, it should be noted that the potential for capsizing and broaching, while operating at high ship speeds in heavy following or quartering seas, has not been considered in the development of these Operating Envelopes. The operating conditions of concern here are those in which the ship speed tends to coincide with the wave speed, the ship length tends to coincide with the wavelength, and the ship may thus appear to ride the waves. The encountered wave frequency tends to zero while the encountered wave period tends to infinity for such conditions. Upon examining Figures 1 and 2, it is clear that the condition may occur in following seas (Catalog ship headings from 150 to 210 degrees) at ship speeds of 25 knots or greater. Therefore, the Operating Envelopes provided in the Catalog should be used with caution when following sea (150 to 210 degrees), high speed operating conditions are indicated as an alternative for avoiding ship damage. Proper ballasting of the ship to preserve rudder submergence essential for maintaining directional stability is of utmost importance at such operating conditions and may, at times, be difficult to achieve. Improper ballast at these conditions may cause the ship to broach or capsize, so that operations in following seas at high speeds should be accomplished with caution.

MODIFIED OPERATING ENVELOPES

Reference has been made throughout to the fact that guidance is provided in two forms in this Catalog. These are the Operating Envelopes and the Data Base graphs for each motion or event type. In general, the operator should refer to the Operating Envelopes as a first step. A more detailed evaluation of the ship motions or events might then follow if greater detail regarding a specific motion or event is required, or if the operator wishes to modify the provided envelopes. The limits (see Figure 5) used to construct the envelopes in this Catalog are considered tentative, and thus, operator experience may indicate that they should be modified in certain seaways. This is easily accomplished using one of the removable plastic speed polar grid overlays provided near the back of the Catalog. The transparent sheet can be overlayed on the Data Base graphs to trace, with a grease pencil, new limiting contours. New or Modified Operating Envelopes can thus be developed as in the procedure illustrated on Figure 8. This feature provides the opportunity to customize the Operating Envelopes to specific operator/ship experience in heavy weather. The Modified Operating Envelopes can be retained for future use in the same seaway.

CATALOG STRUCTURE

The HWOG Catalog is structured so that guidance for each seaway is provided in a separate section. Each section is delineated by a tab indicating the significant wave height, the modal wave period, and the wave directionality. The combinations of height and period are identified on Table 2. A tab title of 20 ft., 9 sec., LC indicates a long-crested seaway characterized by a significant wave height of 20 feet and a modal wave period of 9 seconds.

The seaway sections are ordered from lower to higher wave heights, and then lower to higher wave periods. Long-crested (LC) and short-crested (SC) sections alternate. For example,

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15 Ft., 13 Sec., SC
20 Ft., 7 Sec., LC

20 Ft., 7 Sec., SC

20 Ft., 9 Sec., LC

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illustrates the sequence of sections.

Each section is stapled together such that it can be removed from the spiral-bound Catalog for easy transport to and access on the bridge, in CIC, etc. The sections follow the order

Operating Envelope Without Fin Stabilizers
Operating Envelope With Fin Stabilizers
Roll; No Fins
Roll; With Fin Stabilizers
Pitch
Slams
Bow Wetnesses

The units of the motions and events and the location (events) for which they were calculated are given on Figure 5.

ROLLING DUE TO WIND

It should be noted that the roll motion Data Base graphs included in this HWOG Catalog are representative of the dynamic rolling of the ship in a seaway. In other words, the Catalog contains roll motion induced by the action of the waves upon the hull (primarily that portion of the hull below the waterline). However, ships at sea also experience a static roll motion, called heel, which is due primarily to the force of the wind on the above waterline hull and the superstructure.

Simple estimates of wind-induced heel angles have been made and are provided in Figure 9 by again using a polar format. The contours represent levels of constant heel angle as a function of relative wind direction (constant along radial lines) with respect to the ship and the relative wind speeds (constant on concentric circles), as measured with the ship's anemometer from 0 to 45 knots. The calculation of the combination of static (heel) roll due to the wind with dynamic roll due to the waves has not been attempted due to the variability of ambient winds for a given seaway. However, a simple estimate of the ship's heel in a seaway can be made by summing the static heel angles provided in Figure 9 with the dynamic roll angles provided for each seaway in the Data Base graphs.

SUMMARY

At this point, the FF-1052 Class ship operator has all of the essential instruction for accessing and using this HWOG Catalog. In brief, these steps should be followed:

1. Determine values of significant wave height, wave period, and wave directionality from FAX or WEAX reports or from shipboard observation. Then use Table 2 to identify specific values for accessing the Catalog. If wave period is unknown, use the most likely period. If wave directionality is unknown, assume short-crested seas. The wave height must be determined in order to access the Catalog.
2. Turn to seaway section labeled for three parameters defined in 1 above. Remove section from spiral binder for convenient transport and access.
3. Examine Operating Envelopes to determine damage likelihood. Determine optimum ship headings and speeds for meeting mission objectives and minimizing damage potential.
4. If Operating Envelopes are either too severe or too lax, based on own experience, turn to Data Base graphs to examine individual ship motions or events in more detail.
5. Locate preferred motion or event limits on Data Base graphs and trace new contours onto removable plastic speed polar grids provided at back of Catalog. Follow procedure of Figure 8 to develop Modified Operating Envelopes. Retain these envelopes for future use in same seaway.
6. Determine relative wind induced heel angle from Figure 9 by assuming it occurs simultaneously with the ship's dynamic roll about the heeled axis.

FLEET FEEDBACK

This HWOG Catalog is the product of a pilot project to provide FF-1052 Class operators with otherwise unavailable seakeeping intelligence data. The intent of the Catalog is to provide comprehensive, reliable, and readily accessible information to the operator for use as a training or decision making aid in avoiding heavy weather damage. Comments from the operators regarding the utility, content, format, and completeness of this Catalog will be valuable in determining whether to improve or continue with such efforts for FF-1052 Class ships. Additionally, copies of Modified Operating Envelopes could shed insight into the value of the tentative damage avoidance limits provided in Figure 5. Correspondence should be directed to

Commander, Naval Sea Systems Command
NAVSEA Code 934
Department of the Navy
Washington, D.C. 20362

and can be prepared using the NAVSEA (USER) TECHNICAL MANUAL DEFICIENCY/EVALUATION REPORT (TMDER) forms provided at the end of the Catalog.

TABLE 1 - TYPES OF SEAKEEPING OPERATOR GUIDANCE

Type	Purpose	Duration	Applicable Sea Conditions
Optimum Track Ship Routing (OTSR)	Minimize transit time or fuel consumption	Long-term (10 days or less), e.g. transit route	Avoid heights in excess of given limit, e.g., significant wave height of 12 feet
Tactical Operations Ship Routing (TOSR)	Minimize ship motions in order to conduct an operation	Short-term, e.g. local area	Significant wave heights of 20 feet or less
Heavy Weather Operator Guidance (HWOG)	Minimize ship motions in order to avoid damage	Short-term, e.g. local area	Significant wave heights between 10 and 40 feet
Ship Survivability in Extreme Weather (SSEW)	Avoid broaching, capsizing, or major structural failure	Short-term, e.g. local area	Significant wave heights in excess of 40 feet

TABLE 2 - CHARACTERISTICS OF SEAWAYS CONTAINED IN HEAVY WEATHER OPERATOR GUIDANCE CATALOG

Significant Wave Height, Feet			Wave Period (Modal or Peak), Seconds							
Observed	Forecasted	Catalog	5	7	9	11	13	15	17	19
7 to 10	10 to 13	10	x	x	x	x				
11 to 15	14 to 17	15	x	x	x	x	x			
16 to 25	18 to 25	20		x	x	x	x	x		
26 to 38	26 to 35	30		x	x	x	x	x	x	x
39 to 55	36 to 45	40			x	x	x	x	x	x

Notes: Significant wave height and modal or peak wave period combinations for which seakeeping guidance is provided in this Catalog are denoted by an "x". Each period occurs at least 5 percent of the time for each height, and together the periods represent 90 percent or more of occurrences at each height. Most likely periods are noted by the boxed in areas. Both long-crested and short-crested seas are included for each height and period combination.

TABLE 3 - CURRENT TYPES OF ROUTINELY AVAILABLE WEATHER DATA TO THE FLEET OPERATOR

Type	Contents	Availability	Data Weaknesses
Navy Facsimile (FAX)	Weather maps containing isobars, significant wave height contours, predominant wave direction, wind speeds and direction, temperature, etc., for large-scale ocean areas	Continuously from FWC	Dependent upon adequate weather observations and forecasts; wave periods and directionality (long-crested or short-crested) not routinely included.
WEAX Reports	Significant wave heights and predominant directions, wind speeds and directions, and other weather information for local operating area	Twice daily from FWC to ships that have filed a movement report	Same as for #1. Also, fast moving phenomena, such as fronts, are not always noted.
Shipboard Observations	Significant wave heights, modal wave periods, wave directions and directionality, and other weather information	During daylight hours or whenever observations can be made	Observer inexperience or inability to detect complex wave systems.

TABLE 4 - SEA STATE CHART FOR WORLDWIDE, ALL SEASON NAVAL OPERATIONS

Sea State	Significant Wave Height, feet	Sustained Wind Speed at 32.8 feet, knots	Percent Frequency of Occurrence
1	0 to 1.9	0 to 10	7.5
2	1.9 to 4.1	10 to 14	25.0
3	4.1 to 5.7	14 to 17	12.5
4	5.7 to 7.4	17 to 20	8.0
5	7.4 to 13.0	20 to 25	39.5
6	13.0 to 20.8	25 to 32	6.6
7	20.8 to 40.3	32 to 44	< 0.9
8	40.3 to 61.6	44 to 55	~ 0.0

Note: The percent frequency of occurrence statistics contained hereon were based on the best set of historical data currently published. Even so, major portions of the North Pacific are not covered in the data set.

The most likely occurrence is Sea State 5, with Sea State 2 being the second most likely. The apparent discontinuity in these two occurrences is due, at least in part, to the uneven spacing of the wave height ranges.

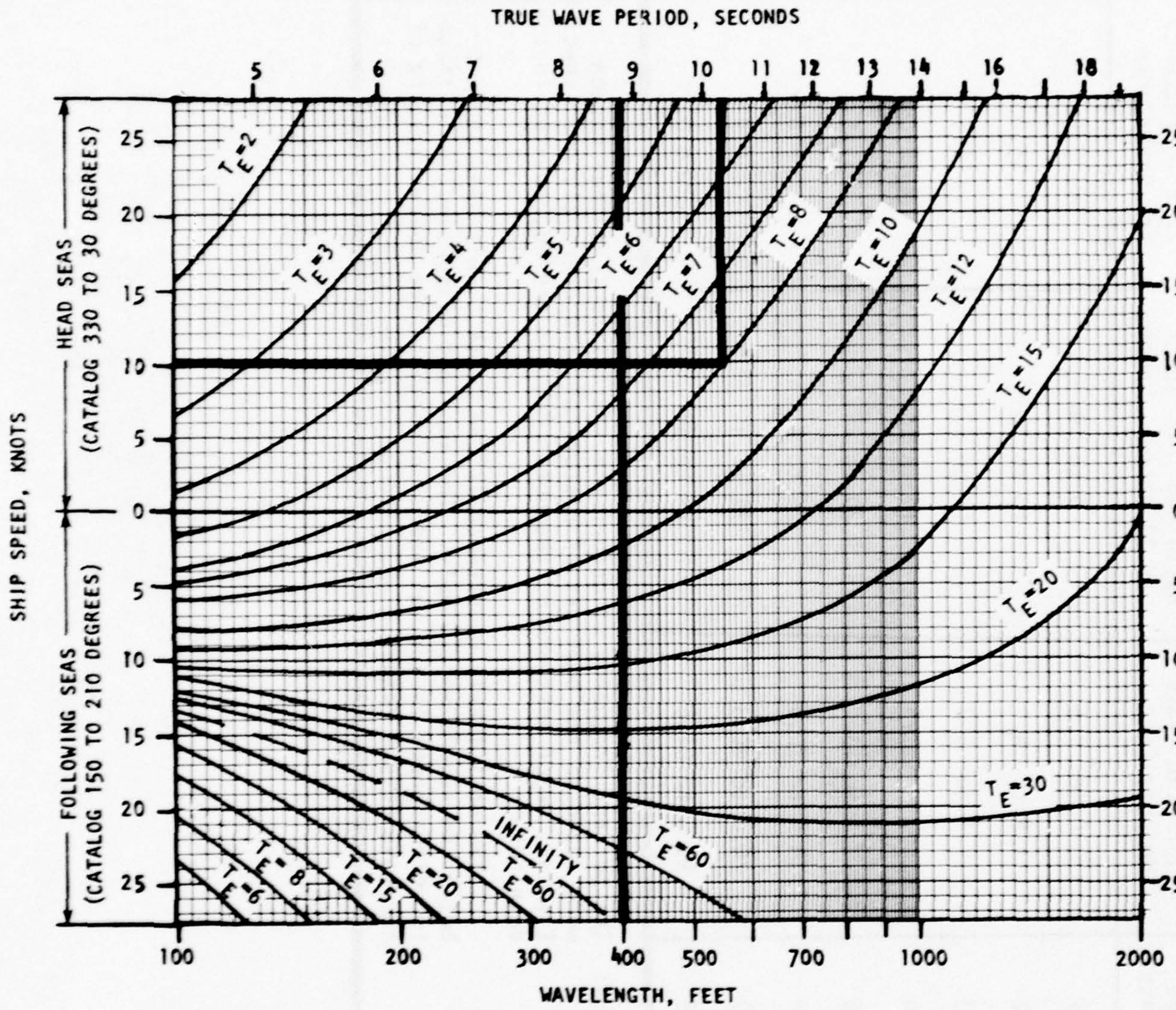


Figure 1 - True Wave Periods for Head and Following Sea Operations

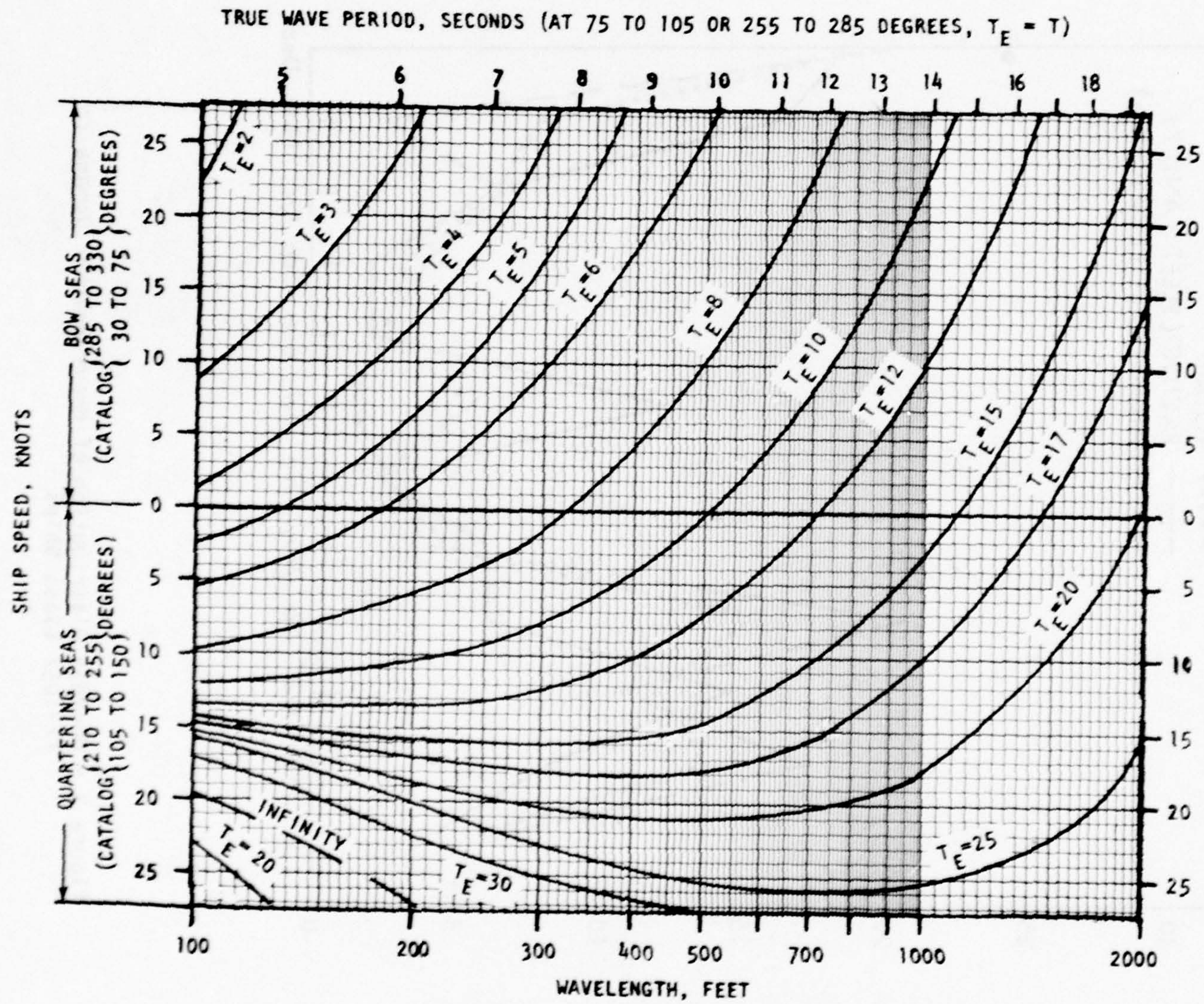


Figure 2 - True Wave Periods for Bow and Quartering Sea Operations

(DERIVED FROM ALL BASE CAUSE 5 CASREPTS 1/1/72 TO 8/17/77)

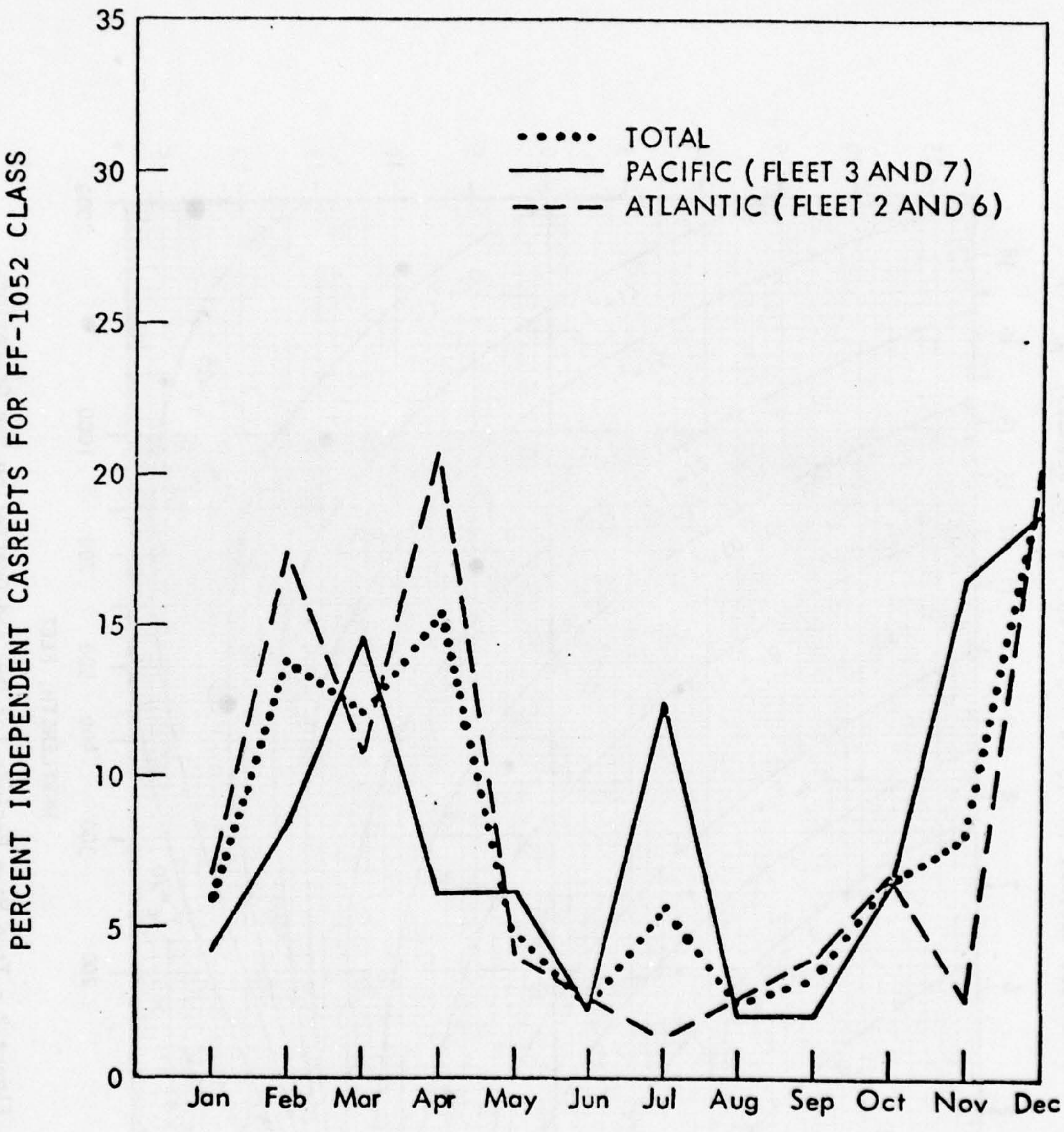


Figure 3 - Monthly Distribution of Heavy Weather Damage to FF-1052 Class Ships

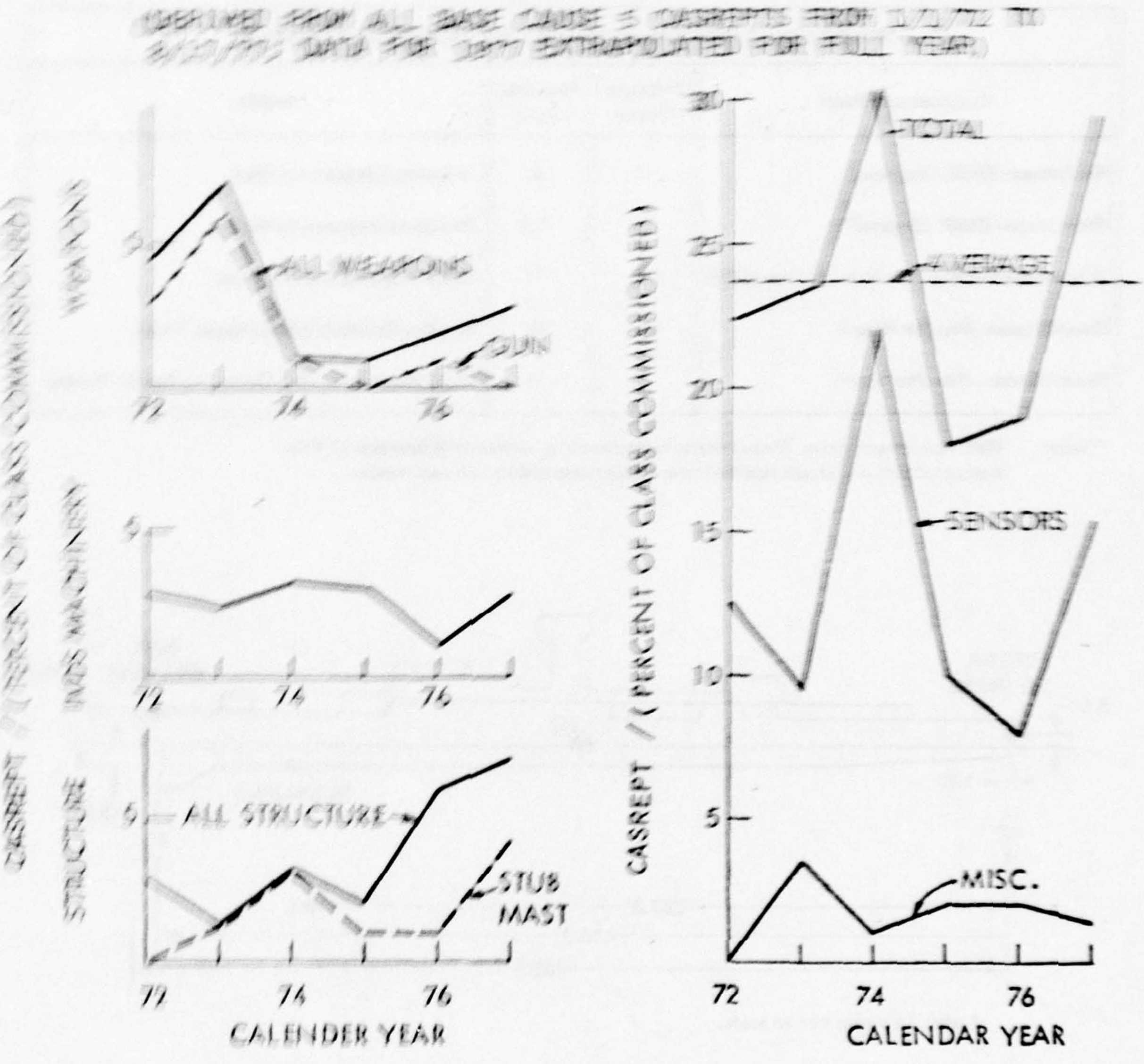
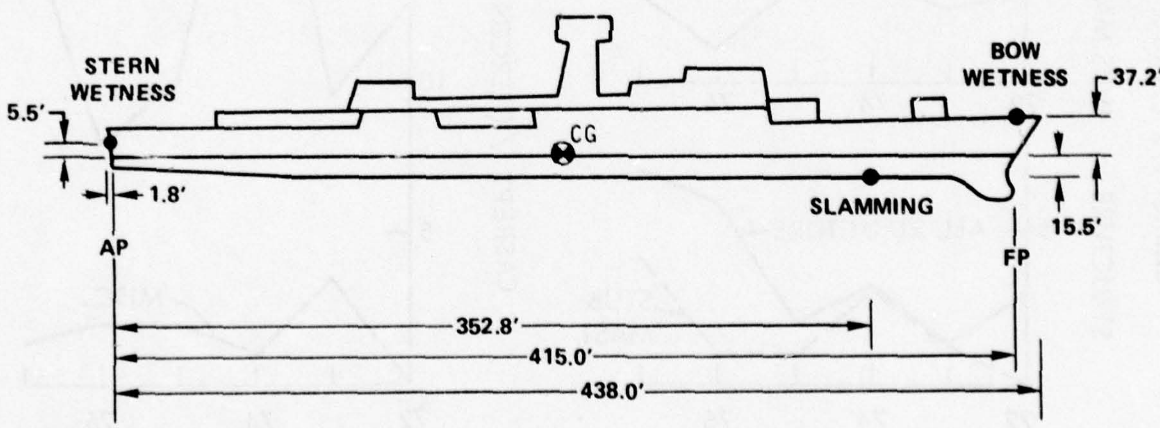


Figure 4 - Yearly Distribution of Heavy Weather Damage to FF-1052 Class Ships

FF-1052 CLASS MOTION OR EVENT LIMITS TO AVOID DAMAGE			
Response or Event	Probable *Limit*	Possible *Limit*	Impact
Roll Angle (RMS, Degrees)*	10	5	Personnel/Sensors on Mast
Pitch Angle (RMS, Degrees)*	3	1.5	Personnel/Sensors on Mast
Bottom Slams (No. Per Hour at Frame 25)	10	1	Mack/Mast/Sensors on Mast
Bow Wetness (No. Per Hour)	60	30	5" Gun Shield/ASROC/House Front
Stern Wetness (No. Per Hour)	3	1	IVDS Machinery (No Doors, or Poorly Fitted)

*Note: RMS Angles are given. These values correspond to standard deviations of ship motion which are about one-half the values observed in a heavy seaway.



Note: Drawing not to scale.

Figure 5 - Motion or Event Limits for Avoiding Damage

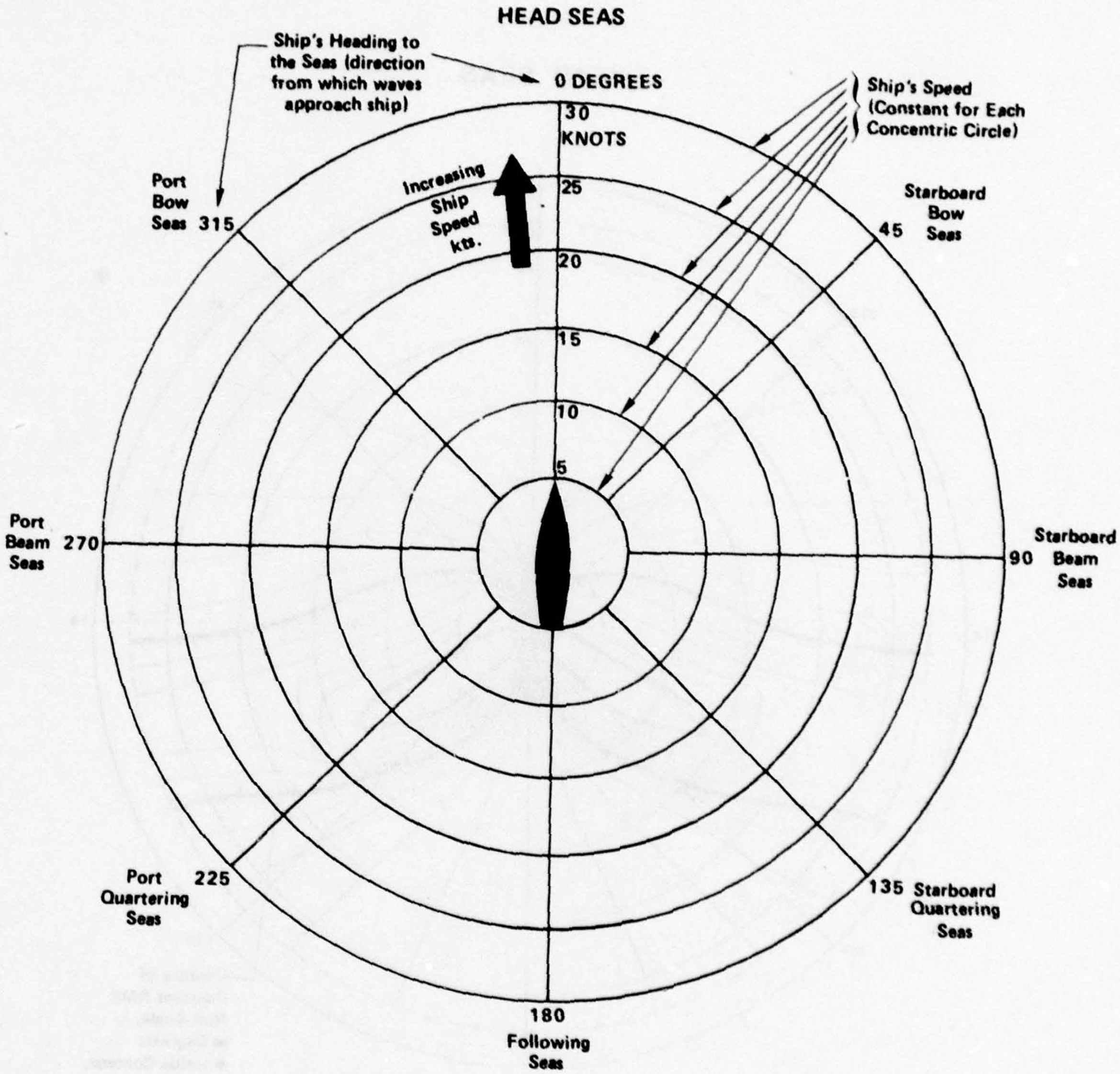


Figure 6 - Definition of Speed Polar Grid System

FF-1052: FULL LOAD
NO FINS

SEAWAY : WAVE HEIGHT 20 FT
PERIOD 09 SEC
LONG-CRESTED

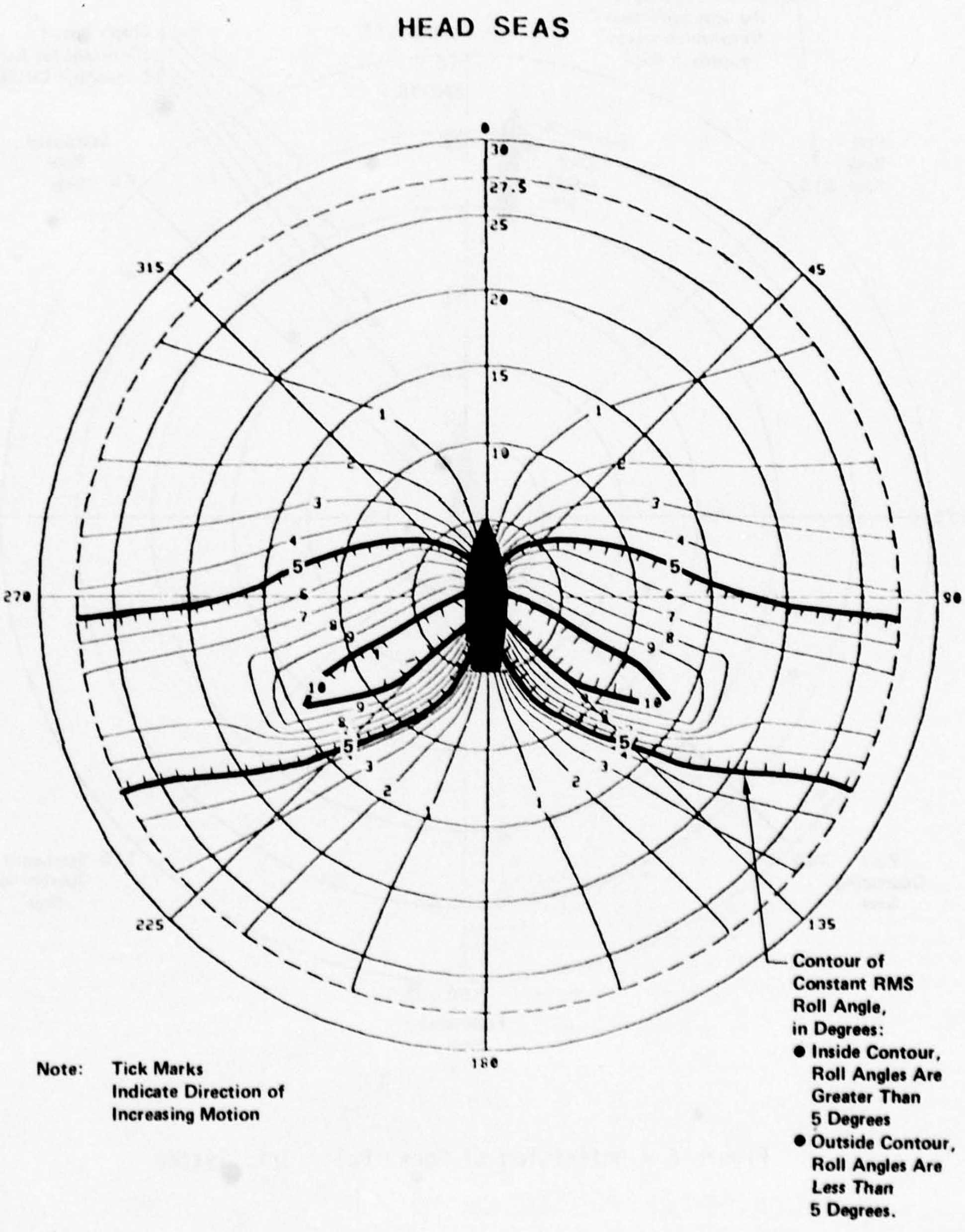
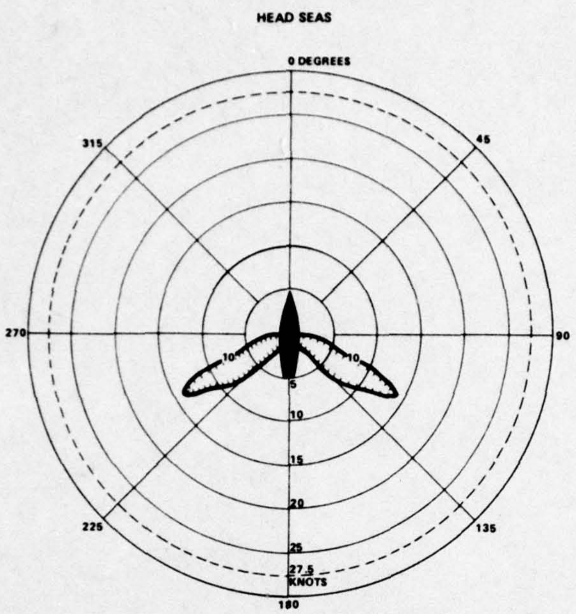
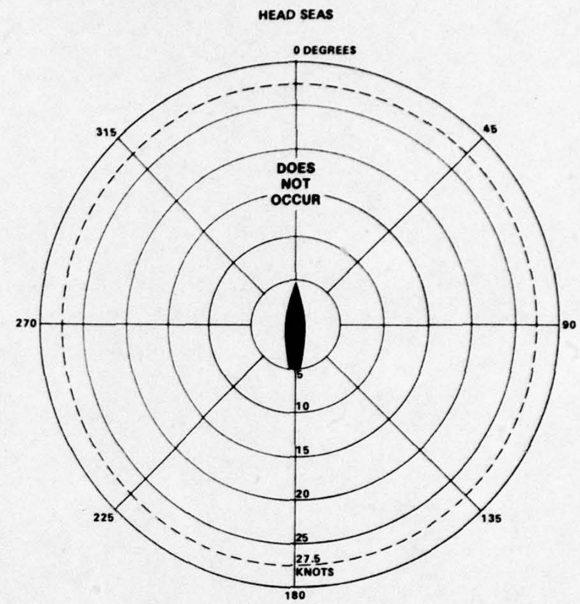


Figure 7 - Typical Speed Polar Graph Containing Ship Motion Contours

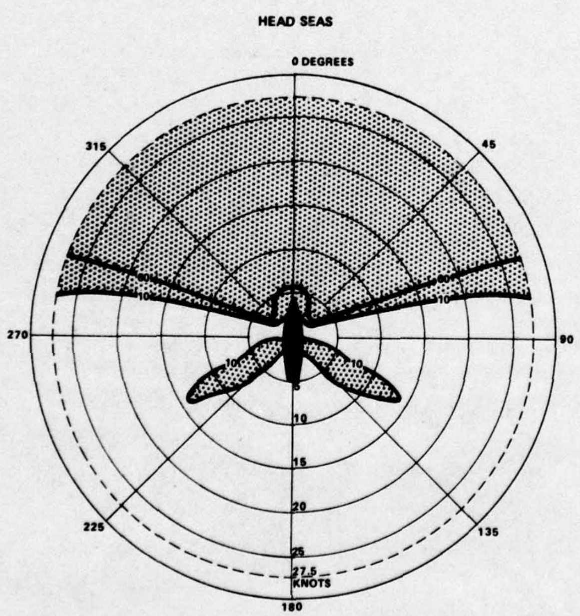
FF – 1052: FULL LOAD
NO FINS



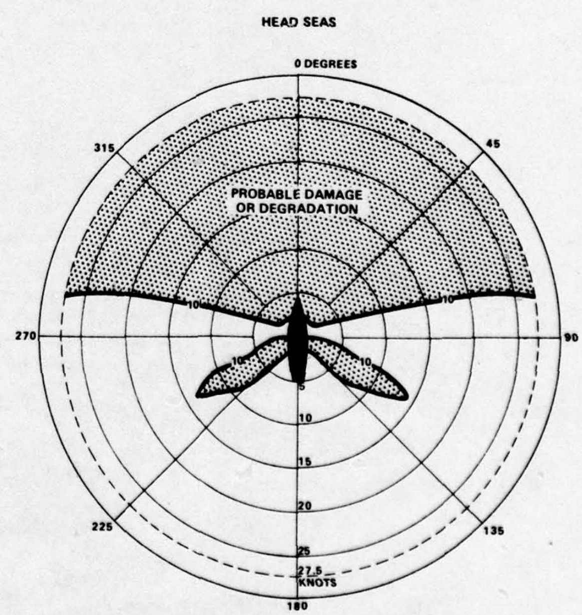
a) 10^o ROLL



b) 3^o PITCH



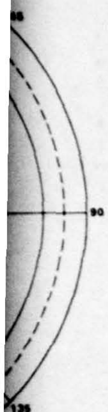
e) OVERLAY a THRU d

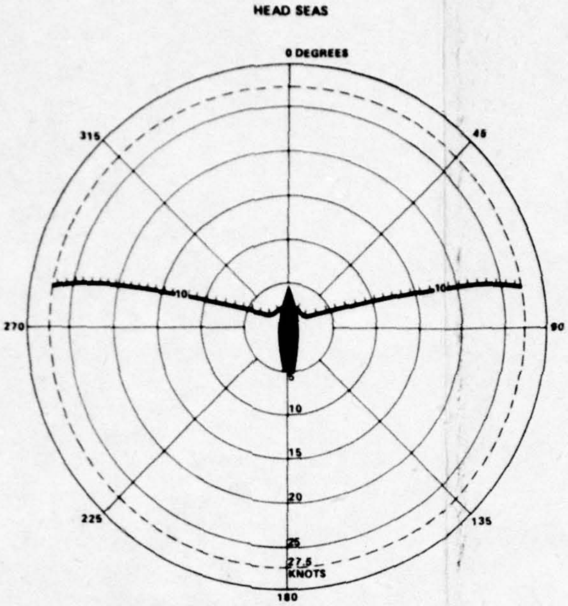


f) PROBABLE OPERATING ENVELOPE

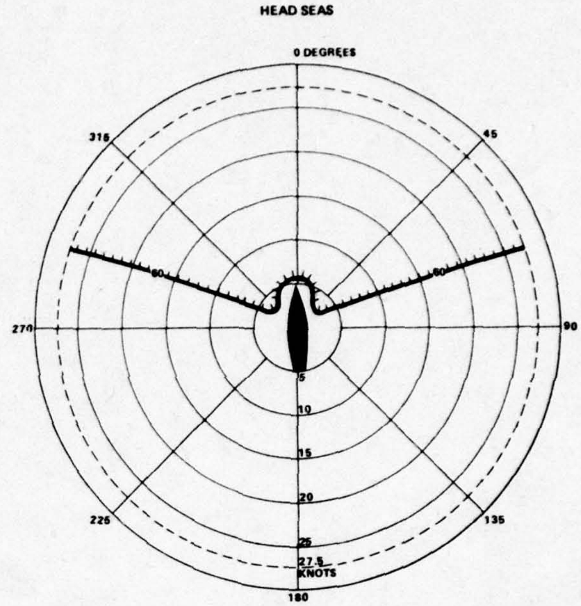
Note: Tick marks indicate direction of increasing motion.

SEAWAY: WAVE HEIGHT 20 FT.
PERIOD 09 SEC.
LONG–CRESTED

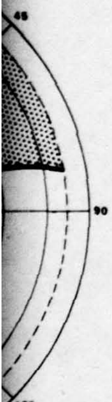




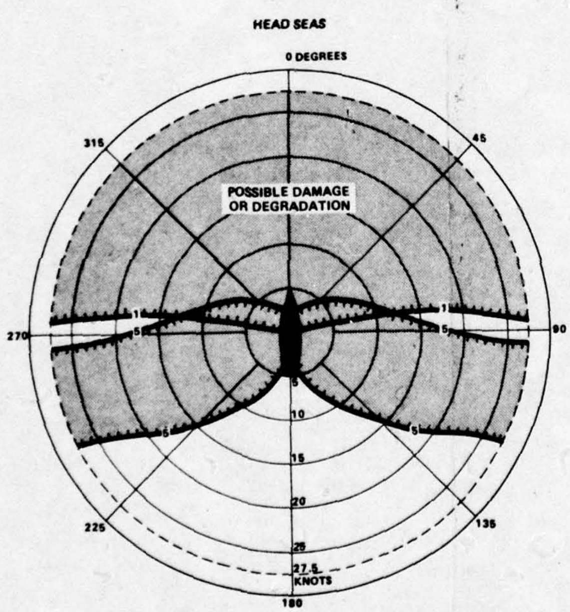
c) 10 BOTTOM SLAMS PER HOUR



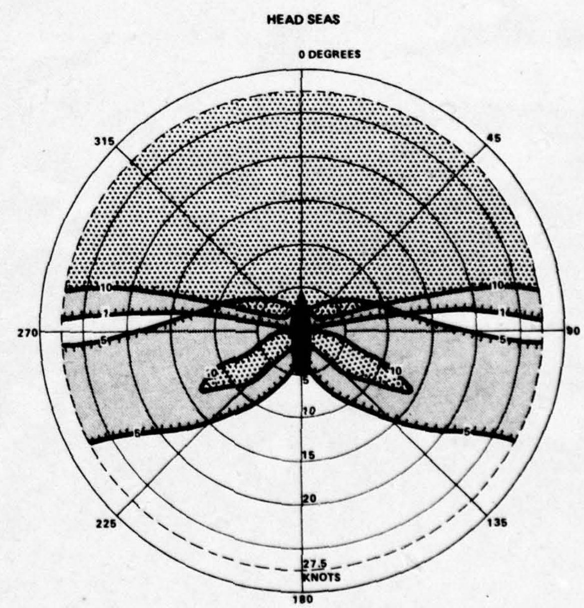
d) 60 BOW WETNESSES PER HOUR



LOPE



g) POSSIBLE OPERATING ENVELOPE



h) COMBINED OPERATING ENVELOPES

Figure 8 - Development of Ship Operating Envelopes for a Given Seaway

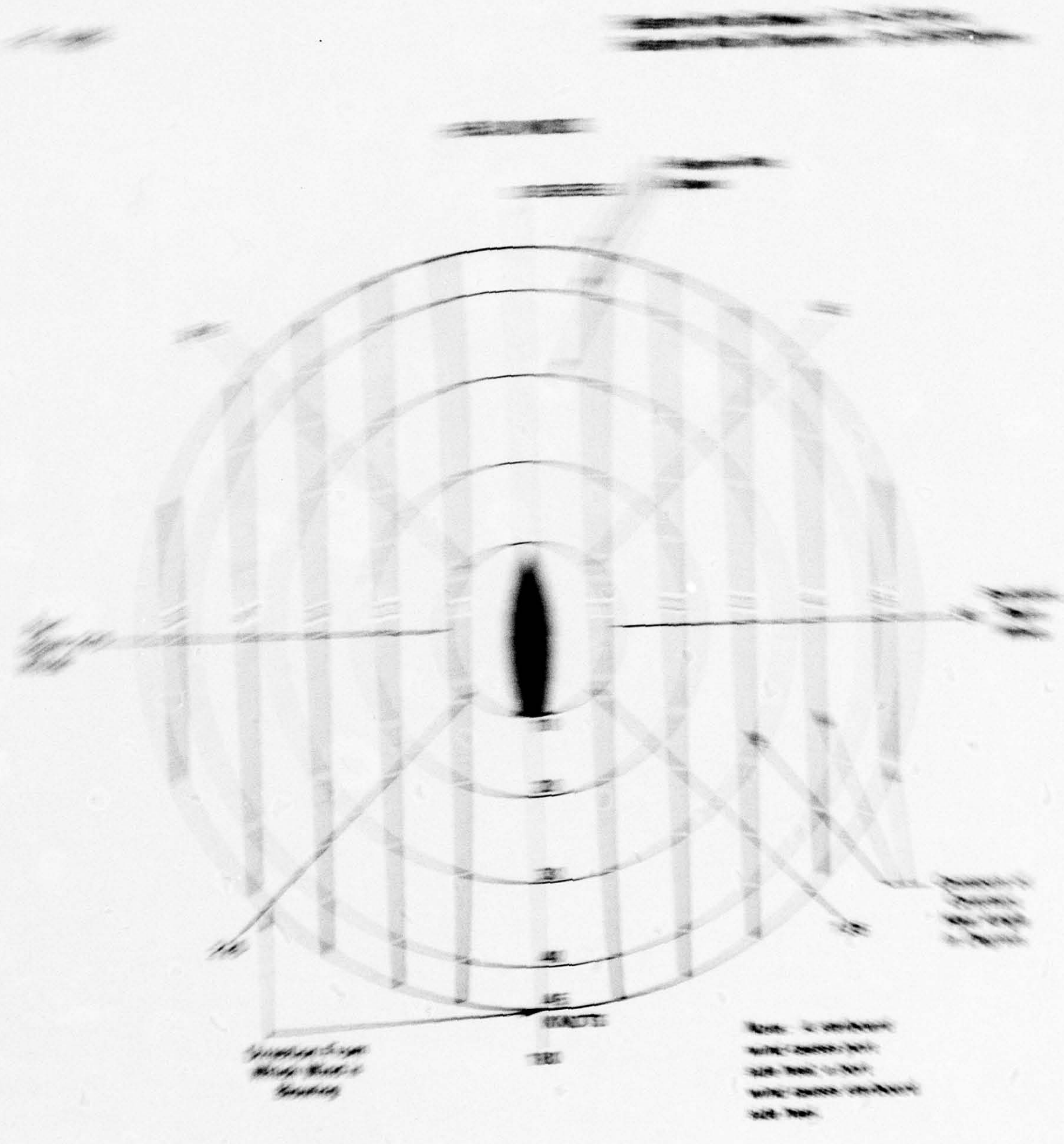


Figure 9 - Wind-Induced Heel Angles

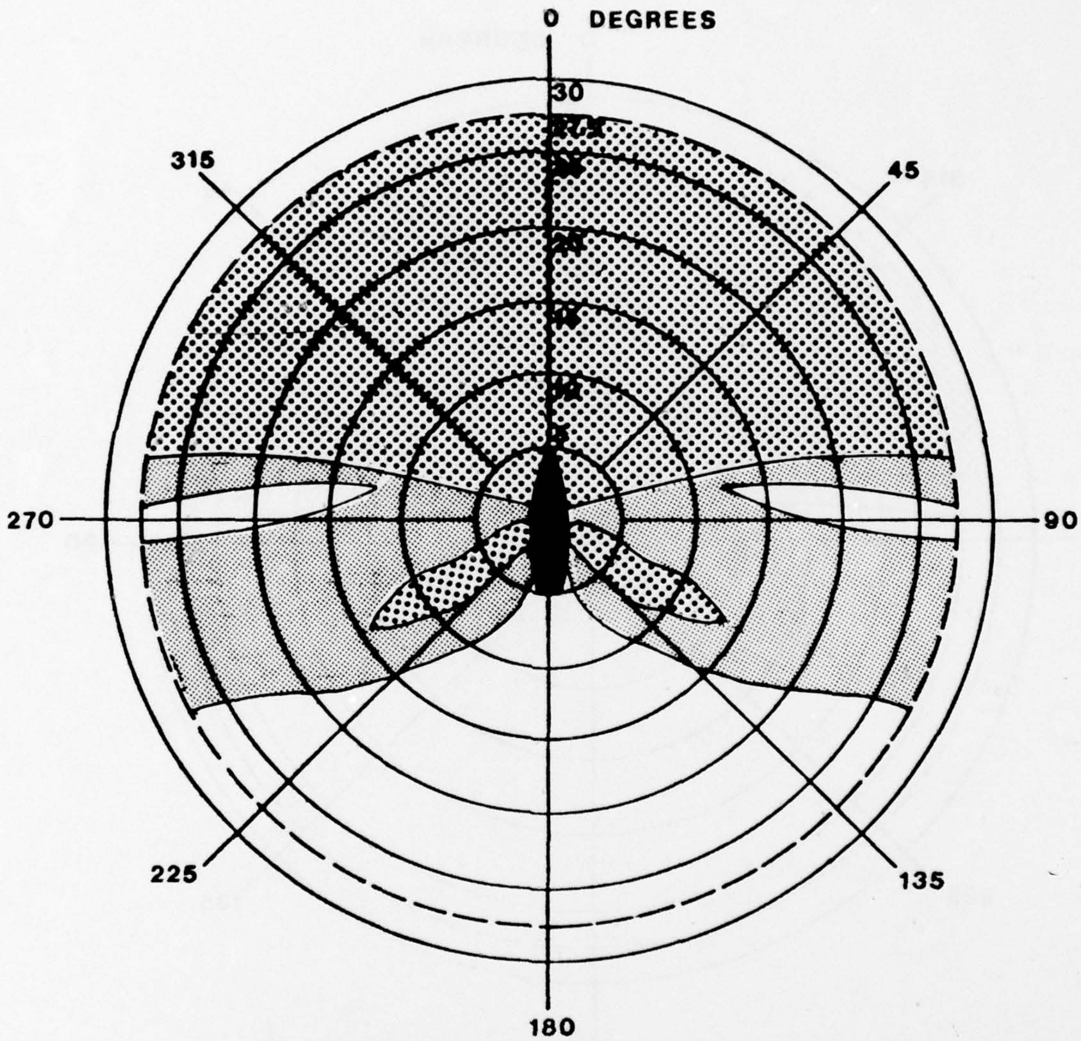
20 Ft., 9 Sec., LC

FF 1052 FULL LOAD

SEAWAY: WAVE HEIGHT 20 FT
PERIOD 09 SEC
LONG-CRESTED

POSSIBLE DAMAGE

PROBABLE DAMAGE



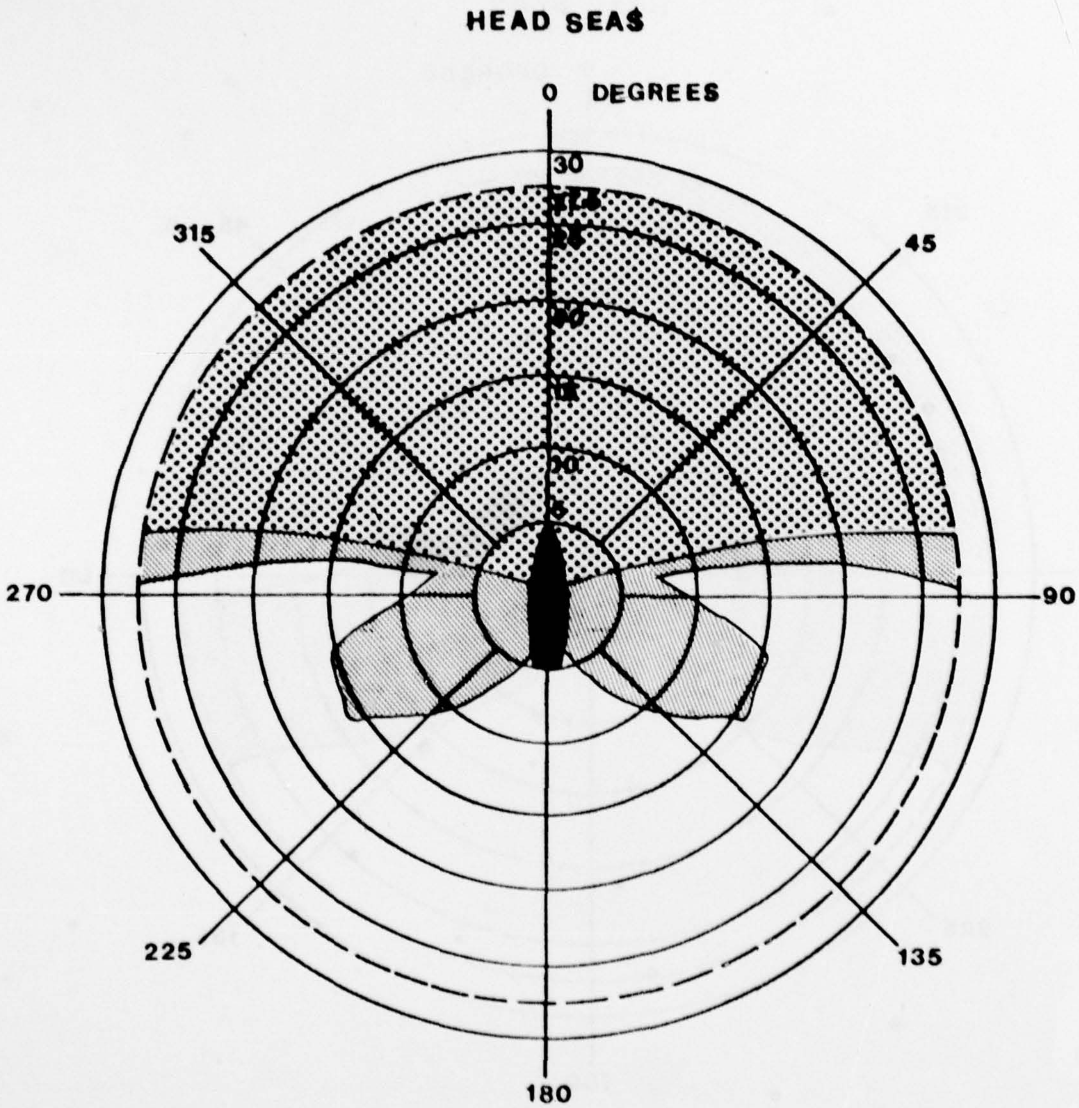
OPERATING ENVELOPE WITHOUT FIN STABILIZERS

FF 1052 FULL LOAD

SEAWAY: WAVE HEIGHT 20 FT
PERIOD 09 SEC
LONG-CRESTED

POSSIBLE DAMAGE

PROBABLE DAMAGE

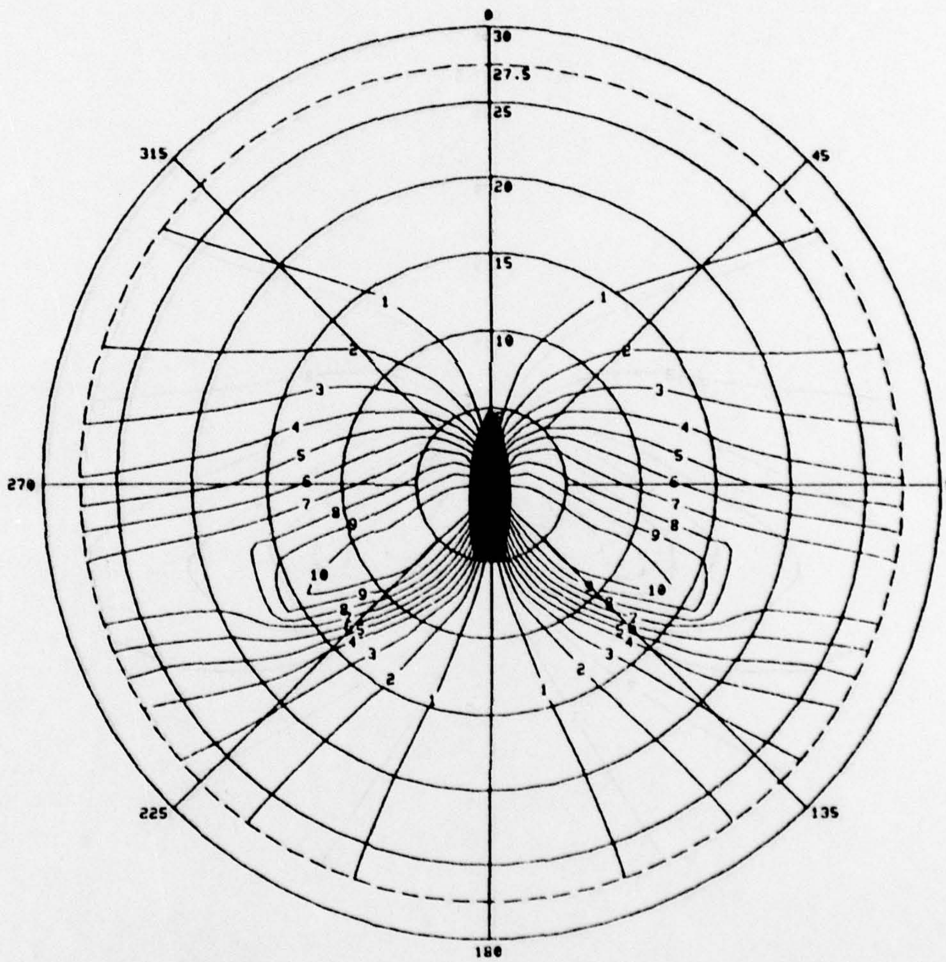


OPERATING ENVELOPE WITH FIN STABILIZERS

FF-1052: FULL LOAD

SEAWAY : WAVE HEIGHT 20 FT
PERIOD 09 SEC
LONG-CRESTED

HEAD SEAS

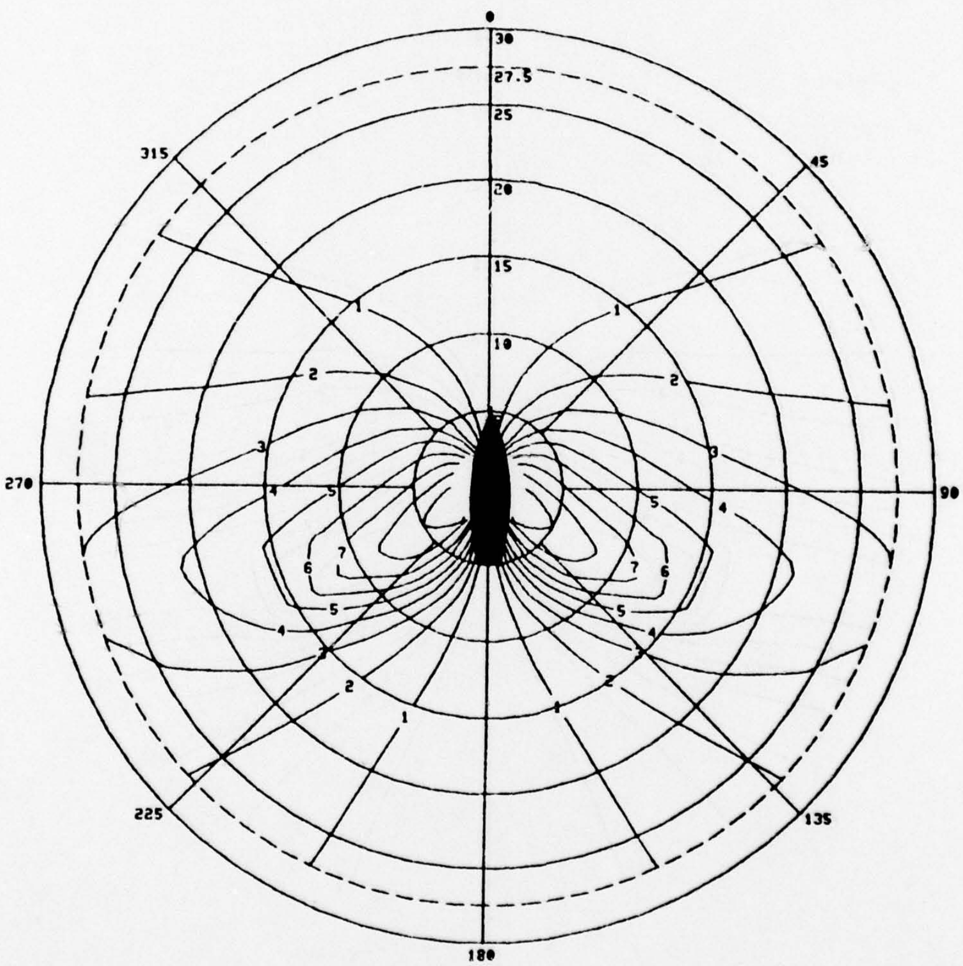


ROLL; NO FINS

FF-1052: FULL LOAD

SEAWAY : WAVE HEIGHT 20 FT
PERIOD 09 SEC
LONG-CRESTED

HEAD SEAS

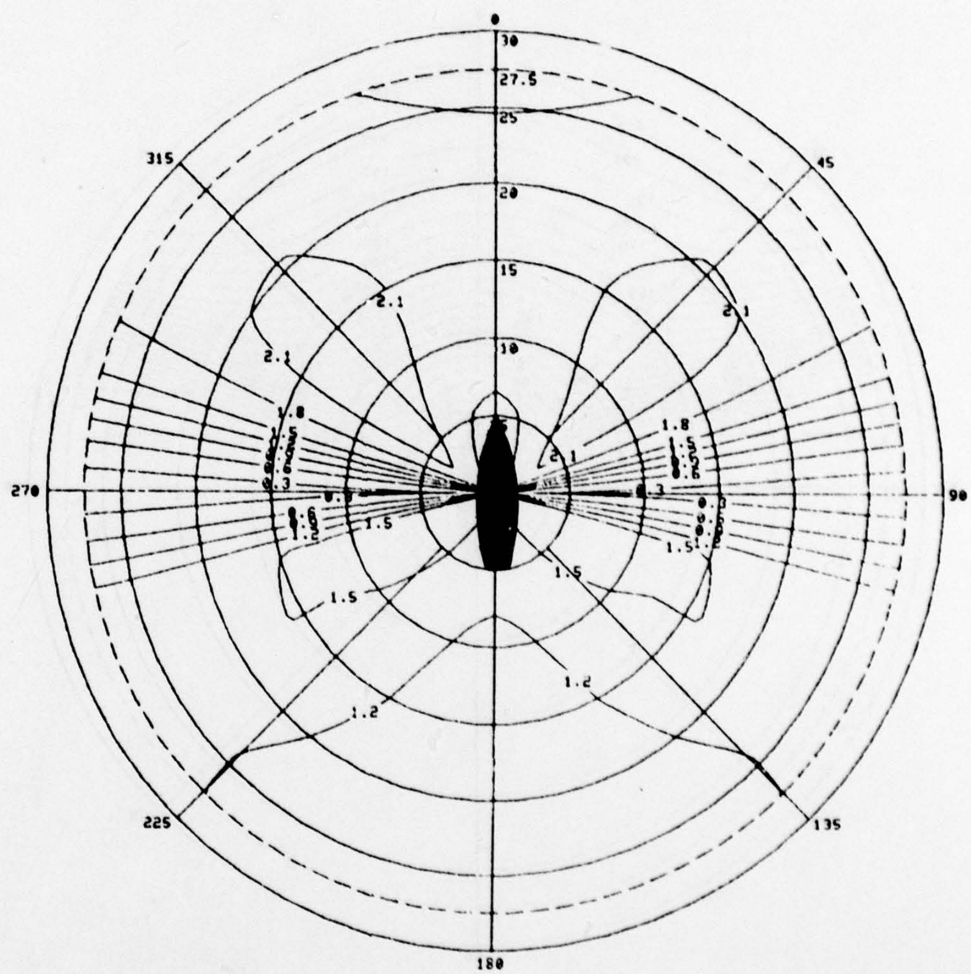


ROLL; WITH FIN STABILIZERS

FF-1052: FULL LOAD

SEAWAY : WAVE HEIGHT 20 FT
PERIOD 09 SEC
LONG-CRESTED

HEAD SEAS

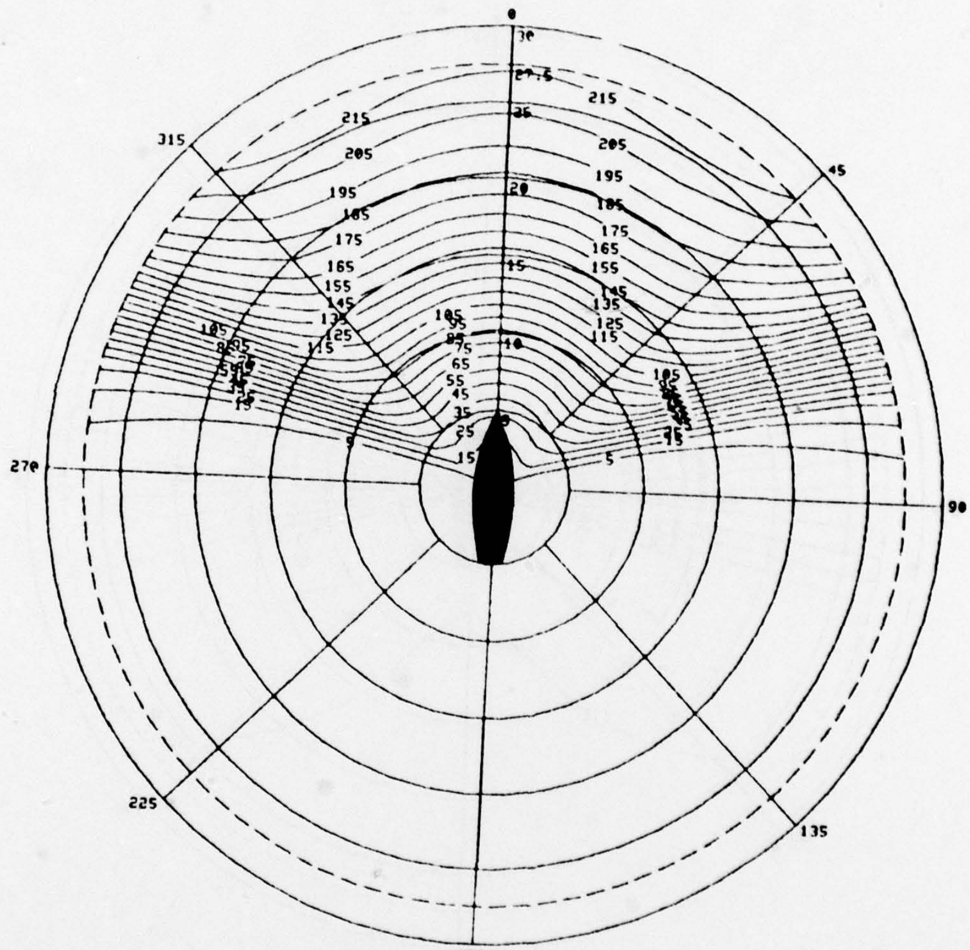


PITCH

FF 1052: FULL LOAD

SEAWAY : WAVE HEIGHT 20 FT
PERIOD 09 SEC
LONG-CRESTED

HEAD SEAS

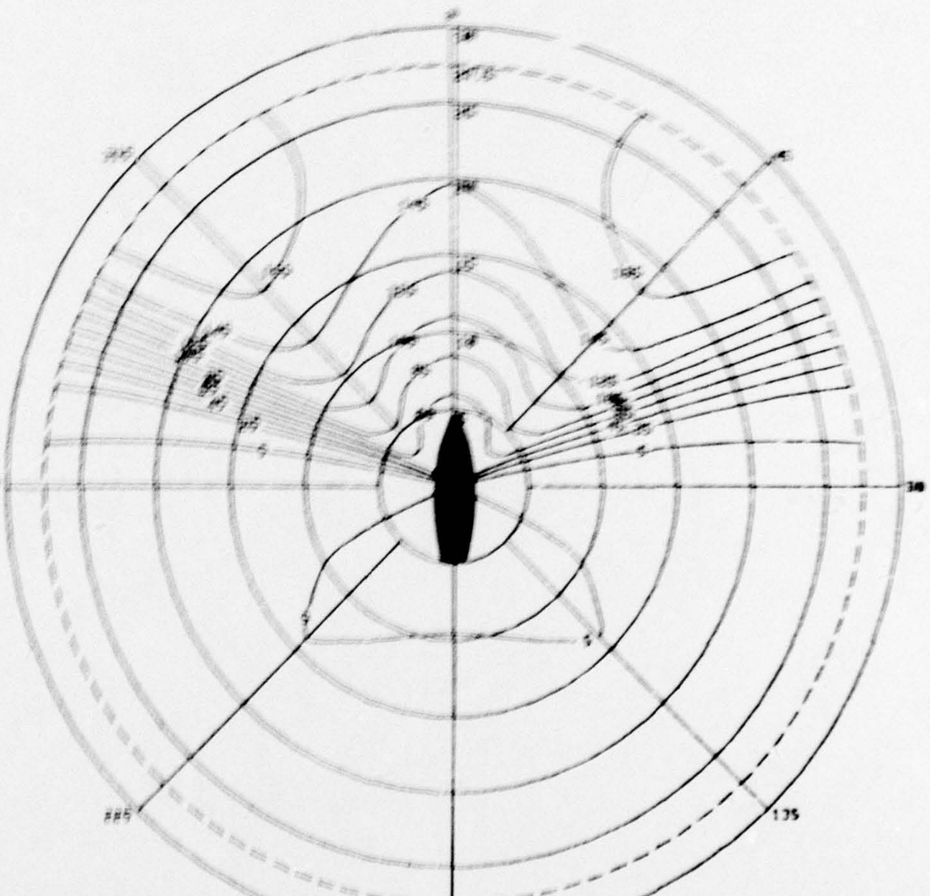


SLAMS

FF-1052 FULL LOAD

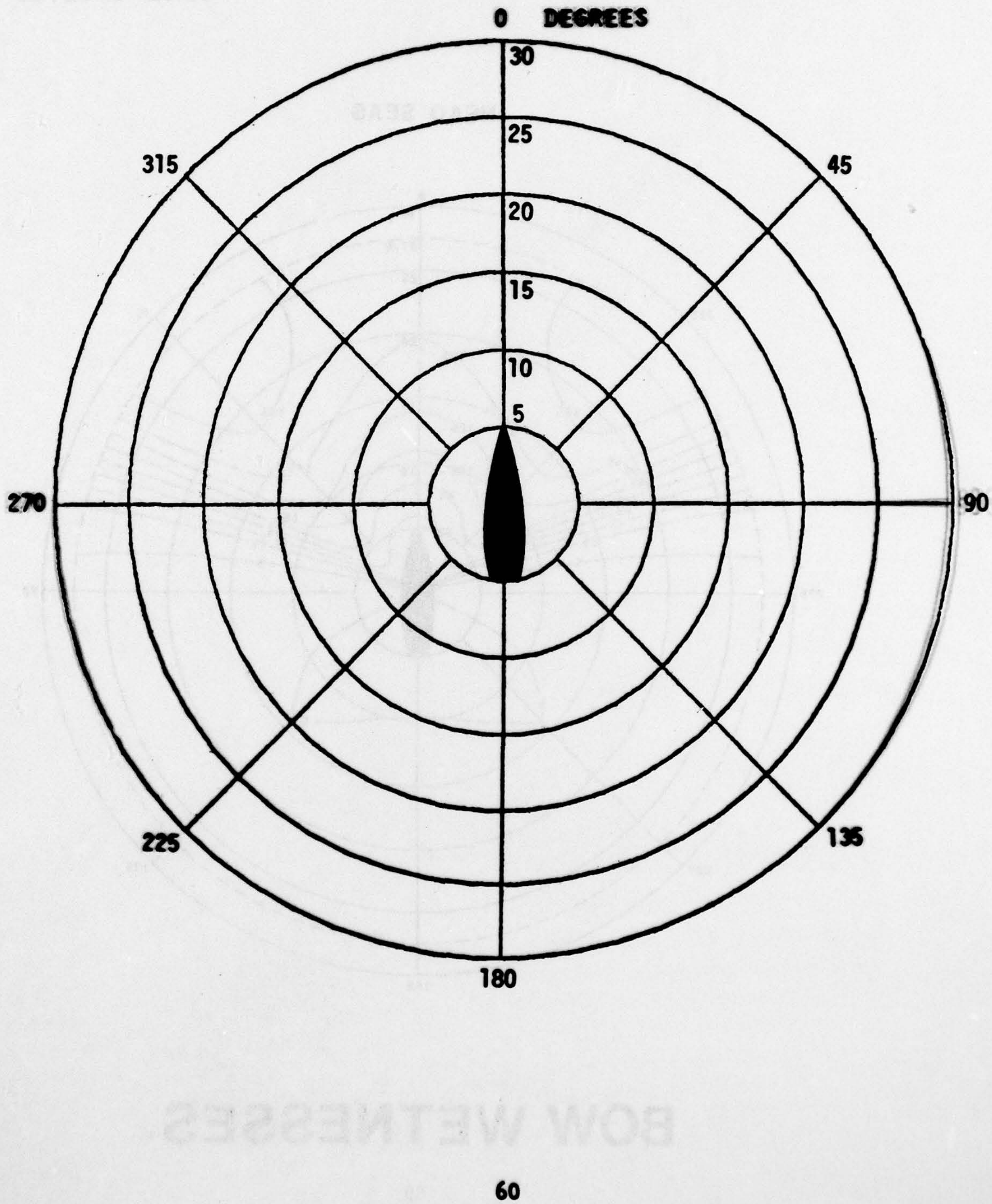
SEAWAY: WAVE HEIGHT 20 FT
PERIOD 19 SEC
LONG-CRESTED

HEAD SEAS



BOW WETNESSES

HEAD SEAS



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