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A METHODOLOGY FOR QUANTIFYING THE OPERATIONAL EFFECTS OF SHIP SEAKEEPING CHARACTERISTICS

CENTER FOR NAVAL ANALYSES
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Arlington, Virginia 22209
SYSTEMS EVALUATION GROUP

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February 1977

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This paper presents a methodology for quantifying the operational effects of the seakeeping characteristics of ships and documents the computer program developed for this purpose. Potential modifications that can be applied to the program are also discussed.

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I. ANALYTIC APPROACH

Naval architects and hydrodynamists take considerable pride in designing hull forms that are "seakindly." There are, however, few tools available to quantify their success and to relate their efforts to the operational environment of the seafarer. The problem is particularly difficult when considering the impact of motion on the effectiveness of the crew, sensors, and weapon systems of the warship. This paper presents a methodology for quantitatively assessing the operational effects of ship seakeeping characteristics, which is believed to represent a step toward an eventual systematic treatment of this problem.

The approach suggested is a relatively simple one. It requires estimates of the motions of a ship in various seaways. As would be expected, these motions are dependent on a ship's design and speed, and the heading of the sea relative to the ship, as well as the characteristics of the seaway itself. If we also identify allowable motion limits based on the ship's mission, a reasonable seakeeping assessment can then be calculated. This paper describes the analytic approach and the computer model used to carry out these calculations.

TERMINOLOGY

Before proceeding with a general discussion of the approach, some terms need to be defined:

- *Significant wave height.* The average height of the highest one-third waves present in a seaway. This is a commonly used oceanographer's term and is thought by many to be the height normally "seen" by mariners making wave height observations. Technically, wave height is defined as the vertical distance from the crest of a wave to the bottom of the succeeding trough.
- *Significant.* The significant roll is the average of the greatest one-third rolls. The term significant is thus applied to ship motions in the same manner as it is for waves.
- *Single amplitude.* The one-way displacement from the normal rest position. For roll, this is the same as the phrase "vertical-to-out."
- *Double amplitude.* The peak-to-peak displacement. It is equivalent to twice the single amplitude.
- *Heading angle.* A 000° heading angle is a following sea, while a 180° heading angle is a head sea. This is the convention used by the Naval Ship Research and Development Center where the heading angle is equivalent to the angle of incidence between the heading of the ship and the direction in which the predominant sea is moving.
- *Head sea.* A head sea is herein defined as the 45° sector centered at the bow, i.e., heading angles from 157.5° to 202.5°.

- *Head sea criteria.* Criteria that are only considered valid in head seas. To some extent this is because ship motion data required to evaluate the criterion at other headings is not available.
- *Modal wave period.* The period of the waves associated with the maximum spectral energy of a seaway.
- *Limiting wave height.* The maximum significant wave height in which a ship can operate without violating a specified criterion. This is a function of ship design, ship speed, heading angle, and modal wave period.
- *Simple criterion.* A simple criterion is herein defined as a seakeeping criterion whose evaluation is a function of a single motion parameter. For example, ten degrees average roll is a simple criterion.
- *Complex criterion.* A complex criterion is herein defined as a seakeeping criterion whose evaluation is dependent on two or more motion parameters. For example, a criterion might be stated as a combination of conditions, such as 7 feet per second velocity at the flight deck, *and* 3° single amplitude pitch, where both of these conditions must be exceeded before the criterion itself is violated.

DISCUSSION AND OUTPUT DESCRIPTION

The seakeeping evaluation described in this paper requires a set of selected seakeeping criteria, i.e., explicit statements of motion thresholds, such as 12 degree average roll, which reflect considerations of personnel or system effectiveness. There may be many such criteria that reflect a variety of seakeeping considerations.

The SEAMON computer program is designed to evaluate these criteria at discreet combinations of ship speed, heading, and modal wave period. The program identifies the criterion that is violated before all others in each case, and estimates the significant wave height at which that criterion is exceeded. This concept might best be understood by considering the "seakeeping matrix" shown in figure 1. The matrix shows the ship represented at the center with concentric speed bands of 5, 10, 15, 20, and 25 knots. Also shown are arcs, in 15 degree increments, which represent the heading of the sea. Thus, there are 120 cells representing unique combinations of ship speed and heading of the sea. SEAMON uses estimates of the ship motion to evaluate every criterion in each cell of the matrix and thus provides a comprehensive seakeeping assessment for a ship. An individual matrix may also be displayed as a three dimensional seakeeping contour.

The program is also supplied with oceanographic data reflecting frequencies of observed sea conditions in a specified environment. Using this data, and straightforward assumptions regarding ship speeds and headings, the program calculates the percent of time that a ship can expect to operate in the environment without violating any criterion.

The foregoing description is best understood by observing the computer program output.

Table 1 shows the first form of output that consists of two matrices and explanatory information. The top matrix contains codes as a function of ship speed and heading (i.e., incidence angle) of the seas. These codes identify the limiting seakeeping criterion as defined in the list

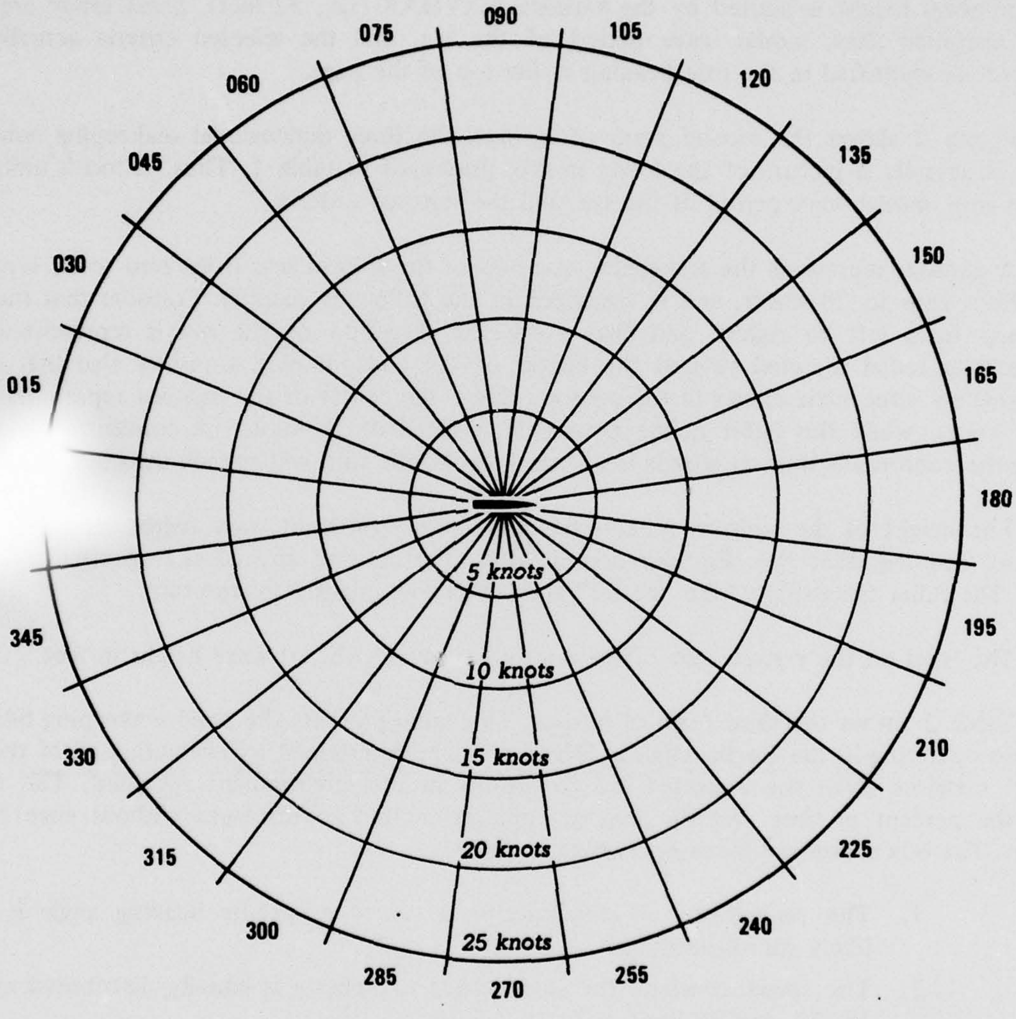


FIG. 1: THE SEAKEEPING MATRIX

immediately below the matrix. The bottom matrix identifies the significant wave height (in feet) at which the specified criterion (from the top matrix) is being exceeded. Thus, the two matrices are complementary. The top matrix explains what criterion is being exceeded first, and the bottom matrix identifies the level of ocean wave activity at which that criterion is exceeded. (The maximum wave height is limited by the variable WAVMAX (i.e., 32 feet). These tables are unique for the specified ship, modal wave period of the sea, and the selected criteria actually being considered, as identified in the title heading at the top of the page.

Figure 2 shows the second form of output, the three dimensional seakeeping contour. A contour is actually a picture of the lower matrix presented in table 1. Thus, it too is unique to a specified ship, modal wave period of the sea, and the selected criteria.

A contour represents the seakeeping qualities of the ship in seas from zero to 32 feet and at speeds from zero to 28 knots, and is visualized in the following manner. Consider that the ship is proceeding from left to right,* and that a specific direction of the sea is represented by its corresponding radial directed toward the center of the contour plot. Consider also that speed is represented by concentric circles in the contour. Thus, the center of the contour represents a speed of zero knots, while the outer radius represents a speed of 28 knots. (A convention adapted in drawing the contours is that, at speeds less than 3 knots, the ship will broach into beam seas.)

The height of the contour reflects the maximum significant wave height, at the particular speed and heading, that the ship can accept without exceeding any of the specified seakeeping criteria. The fuller the contour, the "better" the seakeeping qualities of the ship.

The label on the vertical axis of the contour is the significant wave height in feet.

Table 2 shows the third form of output. This table presents the basic seakeeping box scores for a ship operating in the North Atlantic. The scores are determined by evaluating all of the "table 1 type" matrices given the expected sea conditions in the environment specified. The numbers reflect the percent of time that the ship can operate in that environment without exceeding any criterion. The box scores are based on two assumptions:

1. The probability of encountering a sea at a specific heading angle is equally likely for all headings.
2. The speed at which the ship desires to operate is equally distributed at 5, 10, 15, 20, and 25 knots.

This second assumption can easily be relaxed by exploring the effect of speed on the box score; this is displayed for the "All Criteria" case shown in table 2. Note that the current program prints this speed information for the "All Criteria" case *only*. Program modifications to print the speed effect for other groupings of criteria are discussed in section III.

*The contour is symmetric about this left-to-right axis.

TABLE 1

PROGRAM OUTPUT EXAMPLE

LIMITING FACTORS FFG 7 ALL SEAKEEPING CRITERIA
(1 - 10)
13.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA 0	15	30	45	60	75	BEAM SEA 90	105	120	135	150	165	HEAD SEA 180
5	8	8	7	7	7	7	7	7	7	7	7	7	8
10	8	8	8	7	7	7	7	7	7	7	7	8	8
15	8	8	8	7	7	7	7	7	7	7	8	10	10
20	8	8	8	8	7	7	7	7	3	3	3	10	10
25	8	8	8	8	7	7	7	3	3	3	3	3	10

LIMITING SEAKEEPING FACTORS

0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY TWO MINUTES

7 12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

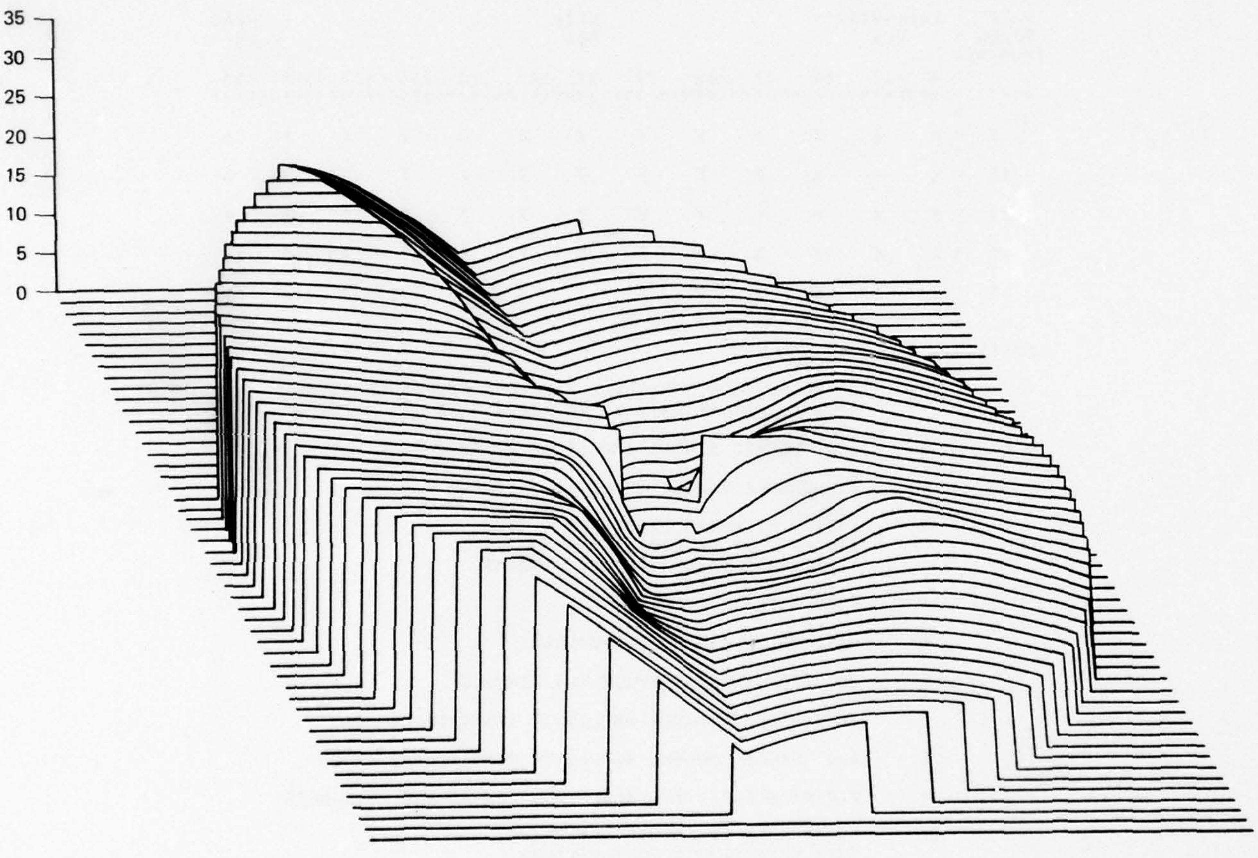
9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	19	19	12	7	6	6	7	7	7	7	9	15	16
10	20	20	20	12	7	7	8	8	8	9	12	15	15
15	21	21	21	20	10	8	10	10	11	13	15	13	13
20	22	22	23	23	14	7	10	11	12	13	13	12	12
25	23	23	24	25	16	7	11	11	10	10	10	10	11



FFG 7 ALL SEAKEEPING CRITERIA *(1-10) (13 SECWAVE PERIOD)*

FIG. 2: SEAKEEPING CONTOUR EXAMPLE

TABLE 2

EXAMPLE OF SEAKEEPING BOX SCORES

FFG 7 BOX SCORES

		North Atlantic	
		SUMMER	WINTER
GENERAL CRITERIA ONLY	(1 - 6)	0.95	0.82
GENERAL AND HELICOPTER CRITERIA	(1 - 9)	0.83	0.61
GENERAL AND DOME EMERGENCE CRITERIA	(1 - 6, 10)	0.95	0.81
ALL SEAKEEPING CRITERIA	(1 - 10)	0.83	0.61
5 KNOTS		0.77	0.49
10 KNOTS		0.82	0.59
15 KNOTS		0.87	0.67
20 KNOTS		0.87	0.66
25 KNOTS		0.84	0.62

DATA REQUIREMENTS

The program requires estimates of RMS (root mean square) motion responses in modal wave periods of 7, 9, 11, and 13 seconds for heading angles from 000° to 180° in 15°-increments, and at speeds from 5 to 25 knots in 5-knot increments. It assumes that the RMS values are for seas having a significant wave height of 1 foot, and that responses for other wave heights can be obtained by multiplying the unit RMS response by the wave height. Because of the requirements for motion responses in different modal wave periods, the data base requirements would typically be generated from a two-parameter sea spectra, such as the Bretschneider spectra.

The reader may wonder whether or not this extensive data requirement can be satisfied. Fortunately, for a large variety of Naval warships and motion parameters, the answer is yes. Data already exist for the DD 963, FFG 7, FF 1052, FF 1040, and CG 26 classes of naval warships. (See work by Baitis, reference 1.) A somewhat limited data base for a conceptual 3,400 ton Small Waterplane Area Twin Hull (SWATH) frigate has also been developed (reference 2). Table 3 identifies the parameters for which motion data exist for the monohulls, while table 4 identifies the availability of SWATH motion responses. The specific motion parameters evaluated by the program are determined by the seakeeping criteria selected by the user.

SEAKEEPING CRITERIA

The reader is reminded that this paper presents a *methodology* to assess the seakeeping qualities of ships. This methodology is quite general and is in no way unique to the specific criteria identified in this paper. Thus, a detailed discussion and justification of these particular criteria is not presented here. Such a discussion will be provided in a forthcoming CNA memorandum (reference 3), which specifically addresses a seakeeping evaluation of four selected monohulls and a representative Small Waterplane Area Twin Hull (SWATH) design.

Evaluating a criterion is solely dependent on the availability of the appropriate ship motion data. If the data is available, imposing the criterion is straightforward. The only manipulation required is to convert the selected criterion to an equivalent RMS value using table 5. (See references 1, 7, 8, and 9, for discussions of ship motion statistics.)

For example, suppose we believe that personnel effectiveness is significantly degraded when the average roll of a ship exceeds 10° single amplitude. From table 3, the correct RMS threshold is 8.0 (i.e, = 10/1.25).

TABLE 3

MOTION DATA PREPARED BY BAITIS ET AL.
FOR THE DD963, CG 26, FF 1052, FFG 7,
AND FF 1040 SHIP CLASSES

	Displacement	Velocity	Acceleration
Roll	X		
Pitch	X		
Vertical motion	X	X	X
Lateral motion	X	X	X
Longitudinal motion	X	X	X

Source: Reference 1

Note: The above data are provided for both longcrested and shortcrested seas, as described by the Bretschneider spectra, and for modal wave periods of 7 through 21 seconds in 2-second intervals. The data is provided for three points on each ship: (1) the center of gravity, (2) the helicopter landing spot, and (3) the location of the aft perpendicular at the main deck.

TABLE 4

MOTION DATA AVAILABLE FOR
A 3500 TON SWATH

- RMS roll in degrees
- RMS pitch in degrees
- RMS vertical acceleration at the Combat Information Center (CIC) in units* of 100·G. The CIC is located 51.7 feet forward of the center of gravity (CG).
- RMS vertical velocity at the helicopter landing spot in feet per second. The landing spot is located 66.5 feet aft of the CG.
- RMS relative** vertical displacement at the bow (i.e., 4 feet forward of the strut, 102.5 feet forward of the CG) in feet.
- RMS relative vertical displacement at the propeller (i.e., 148.5 feet aft of the CG) in feet.

Source: Reference 2
*G = Acceleration due to gravity at the earth's surface.
**Relative means the distance from a point on the ship to the top of a wave.

TABLE 5

CONSTANTS FOR SINGLE-AMPLITUDE STATICS

Single Amplitude Statistics	
Root mean square amplitude, rms	1.00σ
Average amplitude	1.25σ
Average of highest 1/3 amplitudes, significant	2.00σ
Highest expected amplitude in 10 successive amplitudes	2.15σ
Average of highest 1/10 amplitudes	2.55σ
Highest expected amplitude in 30 successive amplitudes	2.61σ
Highest expected amplitude in 50 successive amplitudes	2.80σ
Highest expected amplitude in 100 successive amplitudes	3.03σ
Highest expected amplitude in 200 successive amplitudes	3.25σ
Highest expected amplitude in 1000 successive amplitudes	3.72σ

Definitions

σ^2	=	Statistical variance of time history
N	=	Number of successive amplitudes
CONSTANT	=	$\sqrt{2}\,(\ell n\ N)^{1/2}$, where CONSTANT relates σ to the highest expected amplitude in N successive amplitudes.

Source: Reference 1 (page 27)

Notes:

1. The highest expected amplitude in N amplitudes is the most probable extreme value in N amplitudes. This value may be exceeded 63 percent of the time.
2. To obtain wave height or double amplitude statistics from RMS values, multiply single amplitude constants by 2.0.

Criteria for Head Seas Only

In the course of the author's seakeeping investigations, a unique category of seakeeping criteria became apparent. Recall from the earlier discussion on data requirements that, while a wide variety of motion data may be found in reference 1, the available data are limited to the absolute motions of the ship. There are, however, many criteria in which the motion of a point on the ship relative to the ocean surface is of particular interest. These criteria are generally concerned with seakeeping phenomena in head seas, such as slamming and deck wetness. Indeed, obtaining estimates of ship motion relative to the wave surface in other than head seas is fraught with theoretical and computational difficulties. While criteria limited to head seas are not completely compatible with the analytic approach described earlier, it was considered essential to incorporate their impact in a comprehensive seakeeping evaluation.

The program listing and output contained in this paper reflect a consideration of four head sea criteria in the evaluation of the FFG 7.

- Bottom plate damage
- 3 slams in 100 motion cycles
- 1 deck wetness every 2 minutes
- Sonar dome emergence during no more than 3 out of 5 consecutive 30-second time intervals.

The data used to evaluate these criteria were obtained from NAVSEC's YF-17 ship motion computer model using the single parameter Pierson-Moskowitz sea spectra. The motion data therefore displayed no dependence on the modal period of the waves. The above criteria were evaluated with this data, and relationships for maximum speed versus significant wave height were determined for each, as shown in figure 3.

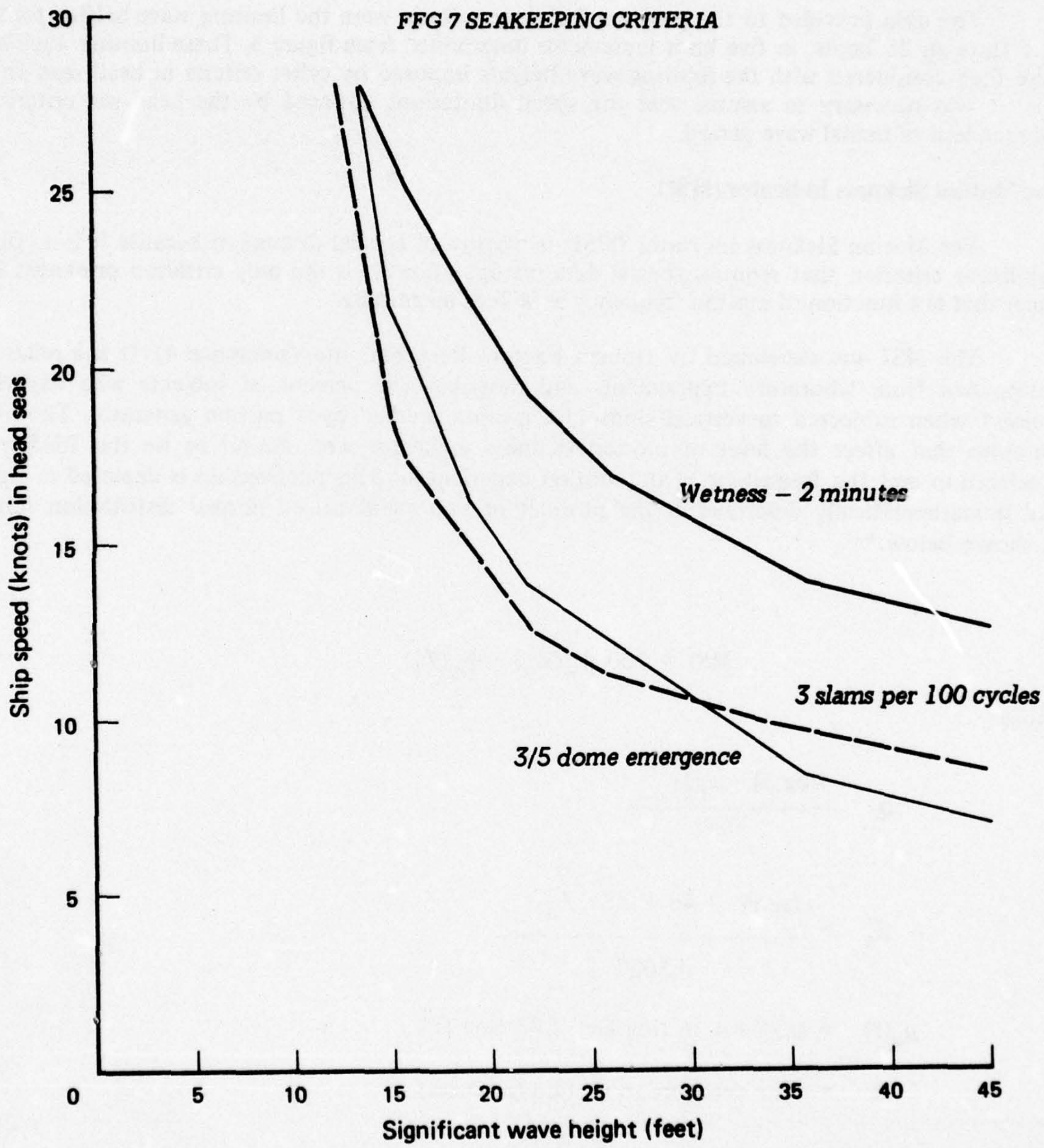


FIG. 3: HEAD SEA CRITERIA

No curve is shown for the bottom plate damage criterion because the very fine lines at the bow of the FFG 7 indicated that plate damage was not a realistic consideration for that ship.

The data provided to the program for these criteria were the limiting wave heights for speeds of 5 through 25 knots, in five knot increments determined from figure 3. These limiting wave heights were then considered with the limiting wave heights imposed by other criteria in head seas. In doing this, it was necessary to assume that the speed limitations imposed by the head sea criteria were independent of modal wave period.

The Motion Sickness Indicator (MSI)

The Motion Sickness Indicator (MSI) is worthy of special discussion because it is a complex, non-linear criterion that requires special data manipulation. It is the only criterion presented in this paper that is a function of motion frequency as well as magnitude.

The MSI was developed by Human Factors Research, Inc. (reference 4). It is a relationship determined from laboratory experiments and describes the percent of subjects who experienced emesis* when subjected to vertical sinusoidol motion created by a motion generator. The primary variables that affect the level of motion sickness incidence were found to be the RMS vertical acceleration and the frequency of the motion experienced. This relationship is depicted in figure 4, and is mathematically described as the product of two standardized normal distribution functions as shown below:**

$$MSI = 100\ \Phi_z(Z_a) \cdot \Phi_z(Z_t') \qquad (1)$$

where:

$$Z_a \; \frac{(\log a) - \mu_a(f)}{0.47}$$

$$Z_t' = \frac{(\log t) - 1.46 + 0.57\ Z_a}{0.5027}$$

$$\mu_a(f) = 0.87 + 4.36\ (\log f) + 2.73\ (\log f)^2$$

t = time exposure to motion (minutes)

*Emesis is the medical term for vomiting.

**All logarithims are to base 10.

f = frequency of vertical motion (hz)

a = RMS vertical acceleration (g's)

$\Phi(z)$ = the standardized cumulative normal distribution function, as given in equation 2

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} \exp\left[\frac{-x^2}{2}\right] dx \qquad (2)$$

The developers of the MSI found that for periods of exposure greater than 2 hours, the MSI is asymptotic, i.e., individuals who did not experience emesis in the first 2 hours rarely experienced it during subsequent prolonged exposure. Therefore, it seems reasonable to assume a 2-hour exposure period (i.e., t = 120 minutes) as representative of the minimum exposure period encountered in the ship motion environment.

It was also found that the MSI was independent of roll and pitch motions when these were superimposed on the vertical accelerations. Thus, if we know the frequency, f, and the RMS vertical acceleration, a, we can calculate the corresponding MSI value.

The MSI is obviously nonlinear, and the relationship between f and a is itself a nonlinear function of ship speed and heading angle. We therefore chose to use an iterative mathematical approach to calculate the MSI value for each cell in the seakeeping matrix. This technique is fully described in reference 5, and is basically a combination of the bisection and secant methods to estimate the roots of a nonlinear function. ZEROIN is a specific subroutine that is included in SEAMON for this purpose.

In solving equation 1, we also need a way to estimate the normal function of equation 2. Many approximating methods are available, and we chose the one suggested by the authors of the MSI in reference 3:

$$W = \frac{1.0}{1.0 + .2316419|Z|}$$

$$D = .3989423 \exp\left[\frac{-Z^2}{2}\right]$$

$$X = .3193815\,W - .3565638\,W^2 + 1.781478\,W^3 - 1.821256\,W^4 + 1.330274\,W^5$$

$$\Phi(Z_0) = 1 - (D \cdot X)$$

$$\Phi(Z) \approx \Phi(Z_0)\ ,\ Z \geq 0$$

$$\approx 1 - \Phi(Z_0)\ ,\ Z < 0\ .$$

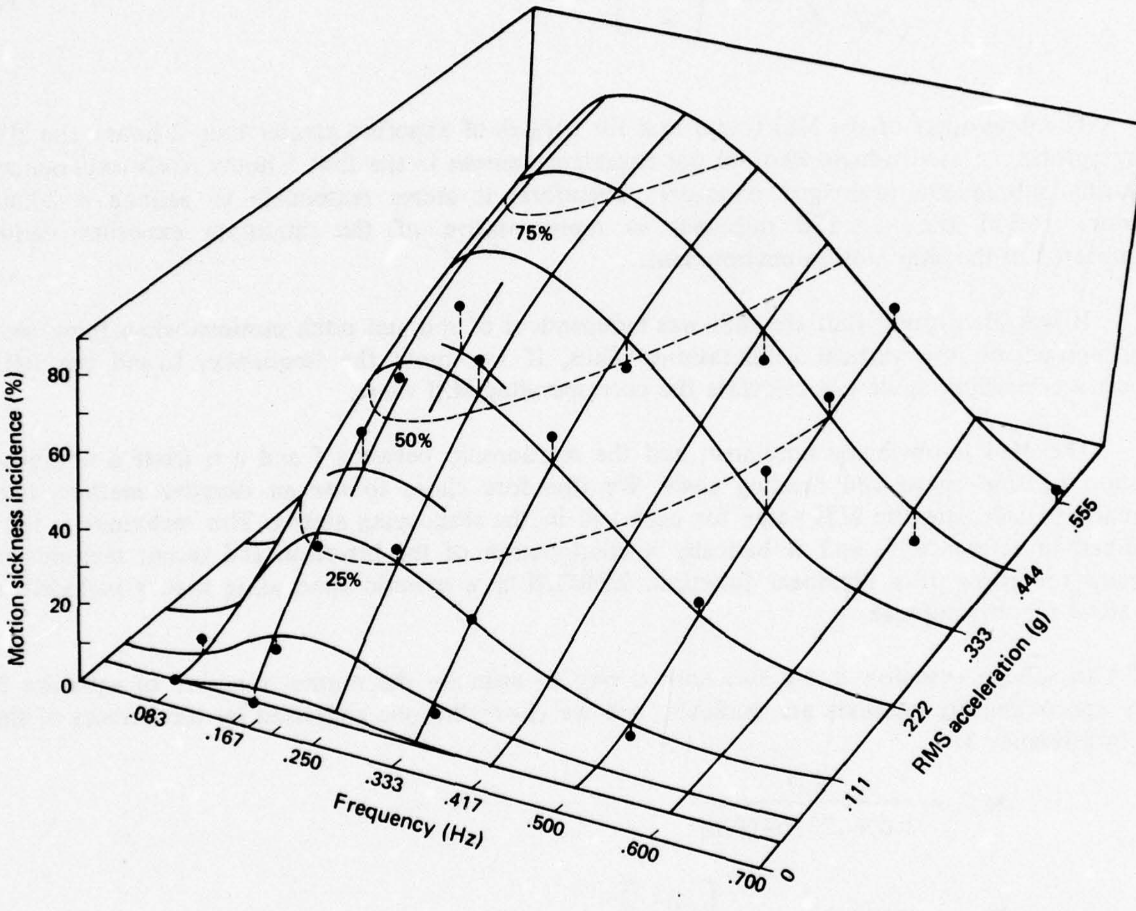


FIG. 4: THREE-DIMENSIONAL REPRESENTATION OF MOTION SICKNESS INCIDENCE AS A FUNCTION OF WAVE FREQUENCY AND ACCELERATION FOR 2-HOUR EXPOSURES TO VERTICAL SINUSOIDAL MOTION

SOURCE: REFERENCE 4

The subroutine CALMSI is used to evaluate this function.

It is appropriate to point out that the MSI criterion is the only one that uses the "encountered modal period," which is available for all the motions in Baitis' data base (reference 1). Thus, while these data are read by SEAMON (and stored in the vector ENCVEC) for all motion data, it is only used when the vertical acceleration data are being processed to evaluate the MSI criterion.

Finally, the data used to evaluate the MSI are the vertical accelerations at the ship's center of gravity. It is worthwhile to note that accelerations at the bow and stern will generally be greater by a factor of two, or more.

Criteria Summary and Categories

The criteria selected for purposes of illustration in this paper are shown in table 6. Criteria 4, 5, 6, and 10 are for head seas only. Because criteria are dependent on the mission of the ship, it is useful to observe the impact of seakeeping considerations as a function of various mission categories. The program described in this paper therefore considers four mission-related categories:

1. *General.* The general category identifies those criteria that are derived from considerations of safety, prudent seamanship, and an adequate level of personnel effectiveness. Criteria 1 through 6 are in this category.
2. *General and Helicopter.* The addition of criteria 7, 8, and 9 is appropriate when considering the ability to safely conduct helicopter operations. Note that criteria 7 and 8 will always be exceeded before criteria 1 and 2, respectively.
3. *General and Dome Emergence.* The addition of criterion 10 to the general criteria is appropriate when considering the effectiveness of the hull-mounted sonar.
4. *All Criteria.* The "All Criteria" case is appropriate when considering the total combat system effectiveness of the ship using all available criteria.

We would like to point out that the criteria listed in table 6 are not considered to be all inclusive. The FFG 7, for example, has an AAW missile system, but no seakeeping criteria have been identified for this system. Furthermore, the criteria identified in table 6 are, at best, rough estimates of what the true motion criteria might be. Indeed, the weakest area in our ability to evaluate the seakeeping qualities of ships is the ability to quantify the effect of motion on people and on sensor and weapon systems.

BOX SCORE CALCULATIONS

The calculations for the seakeeping box scores require data on the observed occurrence of wave heights and modal wave periods. Data for the North Atlantic example depicted in this paper were obtained from reference 6.

TABLE 6

SELECTED SEAKEEPING CRITERIA

General Criteria

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY 2 MINUTES

HELICOPTER OPERATING CRITERIA

7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9 7.0 FEET/SECOND VERTICAL VELOCITY AT THE FLIGHT DECK

HULL-MOUNTED SONAR CRITERION

10 SONAR DOME EMERGENCE CRITERION (3 OUT OF 5 DETECTION OPPORTUNITIES)

Data for the eight points shown in figure 5 were averaged over the months of December and January for the winter season, and June and July for the summer season. The resultant matrices showing frequencies of occurrence are presented in table 7. For the purpose of simplicity, further discussions are limited to the summer data.

A box score is obtained by considering each entry in the limiting height matrices for the four modal wave periods. (Note that a specific column in table 7 corresponds to the modal period of a matrix.) Using linear interpolation down the appropriate columns of table 7, we can substitute the probability of wave heights less than or equal to the limiting wave height for each element of the original limiting wave height matrices. Because the matrix is symmetrical, we then multiply the entries for all the headings by 2, except for the heading angles of 000 and 180°. Having assumed that the encountered heading angle is random (i.e., uniformly distributed), and that we have no preference for a particular speed, we can then sum all the entries for the four matrices and divide by 120 (5 speeds X 24 heading angles) to get the box score.

A mathematical statement of this procedure is provided in the next section on methodology.

METHODOLOGY

This section provides a discussion of the general methodology, in mathematical terms, assuming a set of simple criteria.

The evaluation of criteria is straightforward because each criterion is stated in units of RMS. The motion data are also stated in RMS and can be linearly scaled for wave height. Thus:

$$WL_i\ (C_i,\theta,s,T_o) = \frac{C_i}{X\ (\theta,s,T_o)} \qquad (3)$$

where:

- WL_i = limiting wave height, in feet, determined for the i^{th} criterion
- C_i = RMS threshold value for the i^{th} criterion
- X = the appropriate RMS motion response for seas with a 1 foot significant wave height
- θ = heading angle (degrees)
- s = ship speed (knots)
- T_o = the modal wave period of the sea (seconds)

Matrices similar to the example shown in table 1 can be constructed by considering a selected category containing N criteria, where the limiting criterion k, and the overall limiting wave height WL′, is determined by:

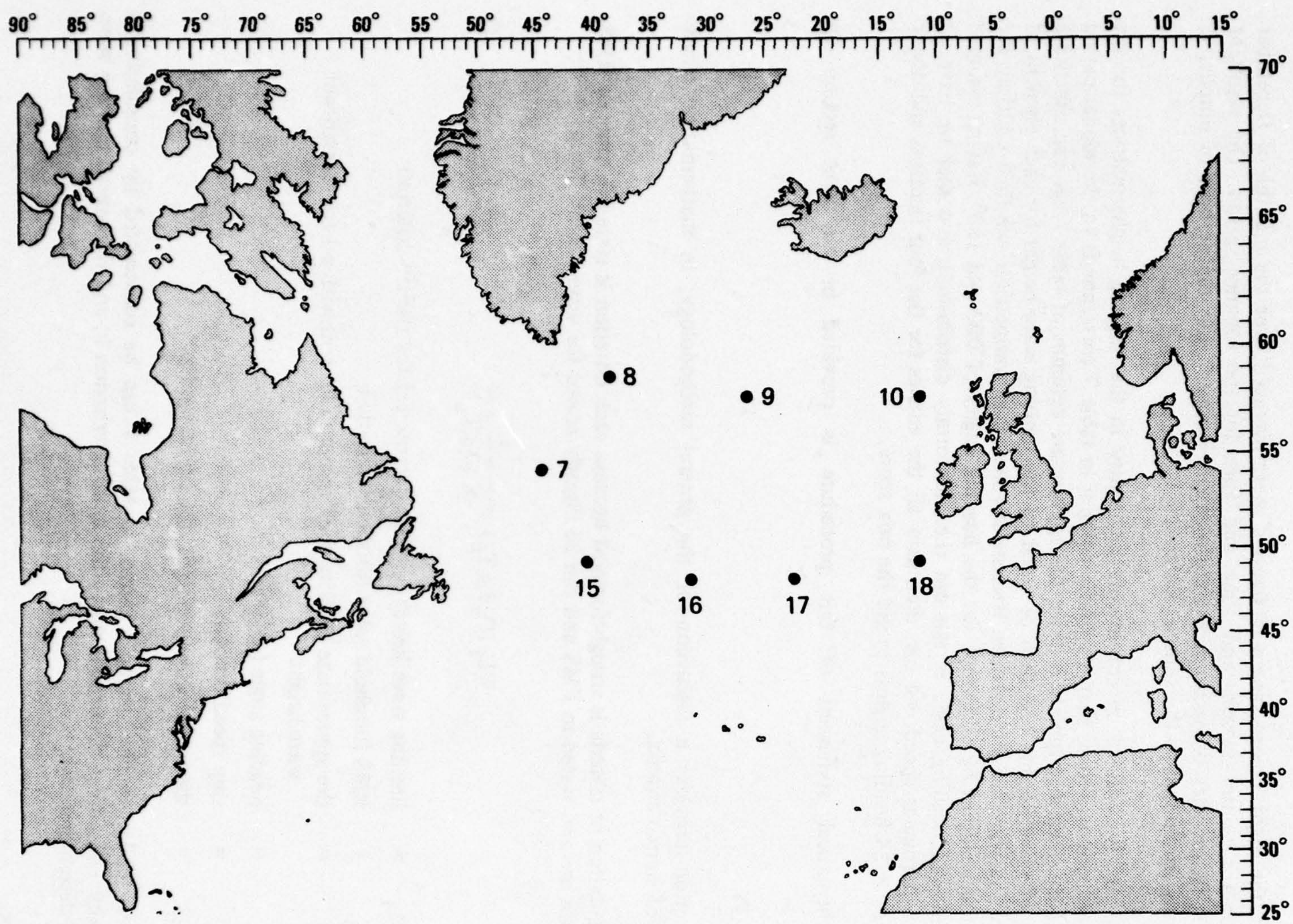


FIG. 5: WEATHER OBSERVATION AREAS IN THE NORTH ATLANTIC
(NUMBERS CORRESPOND TO THOSE USED TO IDENTIFY AREAS IN REFERENCE 6)

TABLE 7

WAVE HEIGHT DISTRIBTUIONS

NORTH ATLANTIC SUMMER
(June, July)

Significant wave height ($\bar{H}$, feet)	Wave period (T, seconds)			
	T ≤ 7	8 ≤ T ≤ 9	10 ≤ T ≤ 11	12 ≤ T
$\bar{H}$ ≤ 2.5	.12	.00	.00	0
2.5 < $\bar{H}$ ≤ 5.7	.37	.06	.01	.01
5.7 < $\bar{H}$ ≤ 9.0	.15	.09	.03	.01
9.0 < $\bar{H}$ ≤ 12.3	.04	.03	.02	.01
12.3 < $\bar{H}$ ≤ 18.9	.01	.02	.01	.01
18.9 < $\bar{H}$ ≤ 25.4	0	.00	.00	.00
25.4 < $\bar{H}$ ≤ 32.0	0	0	.00	.00

NORTH ATLANTIC WINTER
(December, January)

Significant wave height ($\bar{H}$, feet)	Wave period (T, seconds)			
	T ≤ 7	8 ≤ T ≤ 9	10 ≤ T ≤ 11	12 ≤ T
$\bar{H}$ ≤ 2.5	.03	.00	.00	0
2.5 < $\bar{H}$ ≤ 5.7	.15	.03	.00	.01
5.7 < $\bar{H}$ ≤ 9.0	.13	.10	.04	.02
9.0 < $\bar{H}$ ≤ 12.3	.06	.07	.05	.03
12.3 < $\bar{H}$ ≤ 18.9	.02	.05	.06	.04
18.9 < $\bar{H}$ ≤ 25.4	.01	.02	.02	.02
25.4 < $\bar{H}$ ≤ 32.0	.00	.01	.01	.02

$$WL'(\theta,s,T_o) = WL_k(C_k,\theta,s,T_o) \quad (4)$$

where: $WL_k(C_k,\theta,s,T_o) < WL_i(C_i,\theta,s,T_o)$
for all $i = 1, \ldots, N, i \neq k$

The top matrix in table 1 identifies the limiting criterion k for different heading angles (ϕ) and speeds (s), while the bottom matrix is the corresponding limiting wave height WL′. A separate set of matrices is generated for each value of T_o.

The seakeeping box score $B(\nu,\ell)$ for a particular season ν, and world location ℓ, is then calculated as follows:

$$B(\nu,\ell) = \frac{1}{120}\sum_{\theta}\sum_{s}\sum_{T_o} P(WL'(\theta,s,T_o)\mid \nu,\ell) \quad (5)$$

where:
$P(WL'(\theta,s,T_o)\mid\nu,\ell)$ = the probability of occurrence of waves having a modal period of approximately T_o seconds and heights less than or equal to WL′, for the specified season and location.

and θ = 0, 15, 30, ... 330, 345
s = 5, 10, 15, 20, 25
T_o = 7, 9, 11, 13 .

$B(\nu,\ell)$ is thus the percent of time that a ship can expect to operate in a given season and location without any of the N selected criteria being exceeded. It reflects the assumption that the ship's desired operating speed is equally distributed among the five speeds and that the heading angle is a random phenomenon and is uniformally distributed about all headings.

The assumption of ambivalence regarding ship speed is easily relaxed by considering each speed independently, as in equation 6.

$$B(\nu,\ell,s) = \frac{1}{24}\sum_{\theta}\sum_{T_o} P(WL'(\theta,s,T_o)\mid\nu,\ell) \ . \quad (6)$$

A complex criterion can be simply considered as an independent category. For example, suppose we have two thresholds, C_{M1} and C_{M2}, and our criterion is such that both C_{M1} and C_{M2} must be exceeded before the criterion M is itself violated. All that is necessary is to calculate WL_{M1} and WL_{M2} and combine these results as follows:

$$WL_M = \text{Maximum}(WL_{M1}, WL_{M2}) \ .$$

WL_M is then treated as any other seakeeping criterion and incorporated into the appropriate category.

Complex criteria of this sort are not evaluated within the current version of SEAMON, but can be incorporated by a user who is familiar with the program.

CONCLUSIONS

The methodology presented in this paper is believed to have far-reaching implications about the ability of ship designers and hydrodynamists to evaluate the seakeeping qualities of warship designs. The approach considers both the mission of the ship and the areas in which it is expected to operate. It can be used to identify the most significant motion parameters that affect the seakeeping qualities of a ship design. Given an adequate understanding of the effect of motion on sensor and weapon systems, the method can also be used to identify deficiencies in subsystem design and potential interface problems. It may also be useful in determining reasonable specifications for motion compatability for these shipboard systems. Finally, it can be used to select, among alternative designs, the hull form that offers the greatest operational flexibility.

Perhaps the reader can best appreciate the potential of this approach by observing the example output for the FFG 7 in appendix C. It should be obvious that a wealth of visual and quantitative information is available, that can stimulate new insights into questions about the significance of seakeeping.

There are, however, two major areas of concern in implementing this approach.

First, ship motion data must be available. An excellent data base for ships already in the fleet is available, but in most cases it is too late to significantly affect the seakeeping qualities of these ships. The Naval Ship Research and Development Center is presently working on an inexpensive method to predict the motion of a ship based on design data. This effort is essential if the Navy is to consider seakeeping early in the ship design process.

The second area of concern is the poor state of the Navy's knowledge of the impact of ship motion on the effectiveness of people, sensors, and weapons. This makes the establishment of meaningful seakeeping criteria difficult, and in many cases impossible. If we cannot assess the effects of motion on combat readiness and effectiveness, a serious seakeeping evaluation is impossible. This author has observed very little progress in this regard due to what is a basic lack of interest in understanding the ship motion environment.

If an adequate motion data base is available, and if the impact of motion on the ship's crew and subsystem can be reasonably estimated, the approach in this paper can put the information together into a meaningful seakeeping assessment.

II. PROGRAM DESCRIPTION

SEAMON is a FORTRAN Program written to be compatible with the CDC 3800 computer at CNA. The program may actually be considered to be in two parts. The first part consists of 7 routines and functions (SEAMON, WRITE, CONTUR, BOXSCR, WAVLIM, CALMSI, ZEROIN) specifically written or modified by the author to evaluate seakeeping criteria. The second part consists of 10 routines that make up the "canned" PLOT3D package used at CNA to produce a 3-dimensional contour plot on a CalComp 565 Digital Incremental Plotter. The PLOT3D package was used without any modifications by this author, and the basic documentation and program listing is presented in appendix D. We must point out that no attempt is made in this paper to explain how the PLOT3D package is coded or to address potential compatibility problems with the package at other facilities. However, if a facility already has a 3-dimensional plotting package, simple modifications to the subroutine CONTUR and function WAVLIM should permit an easy transition to another plotting routine.

PROGRAM FLOW

A basic flow diagram for the program is shown in table 8. The number at the upper right hand corner of each flow symbol corresponds to the line of the program listing in appendix A. It identifies the general location for the operations described.

The following is a brief description of each of the 7 routines and functions.

- SEAMON is the main program. It reads in all input data and evaluates the seakeeping criteria. It also prints the box scores as shown in the example in table 2.
- WRITE is a subroutine, called by SEAMON, to print tables in the format shown in table 1. Each time it is called, four tables are printed for modal wave periods of 7, 9, 11, and 13 seconds. The specific criteria shown in the table are uniquely determined by the calling arguments. It is essential that the label specified as a calling argument is consistent with the matrices, which are also identified in the call to WRITE. (See the program flow diagram.)
- CONTUR is a subroutine, called by SEAMON, that actually calls the PLOT3D program to generate a contour plot.* CONTUR may be called in a variety of locations within SEAMON depending on the type of criteria and wave periods of interest. The period specified must be either 7, 9, 11, or 13 seconds, or 0. If 0 is specified, 4 plots, one for each of the 4 periods, will be printed. As in the case of WRITE, the matrix SEAMAT and the TITLE used in calling CONTUR must be internally consistent. When CONTUR calls the PLOT3D package, it passes the function WAVLIM to PLOT3D.
- BOXSCR is a subroutine, called by SEAMON, to calculate the box scores.

---

*The numbers printed at the edge of the planar axes of the contour plots are idiocyncracies of the computer plotting program. They would indicate the ship speed if the plotter boundaries passed through the center of the contour.

- WAVLIM is a function that is passed to PLOT3D by CONTUR. PLOT3D requires a function which, when provided with an X and Y in cartesian coordinates, will return the corresponding Z value (e.g., the third dimension of elevation). WAVLIM is thus a function that receives the X and Y values, converts them to polar coordinates (R and THETA) and, using multiple linear interpolation, estimates the value of Z. Note that, for our purposes, R is the ship speed, THETA is the heading angle, and Z is the limiting wave height.
- CALMSI is a function that is called by both SEAMON and ZEROIN. It is essentially a zero value function when the specified Motion Sickness Indicator (MSI) is precisely equal to some preset threshold value. It is a function of the RMS vertical acceleration linearly scaled for wave height, and the frequency of motion response. The method used to approximate the MSI value is that suggested by the authors of the MSI in reference 4.
- ZEROIN is a subroutine called by SEAMON. Because the MSI is a nonlinear function, it is not readily evaluated in closed form. Therefore, a numerical search algorithm is used to estimate the root of the function CALMSI. The method is a combination of the bisection and secant methods reproduced from reference 5.

TABLE 8

PROGRAM FLOW

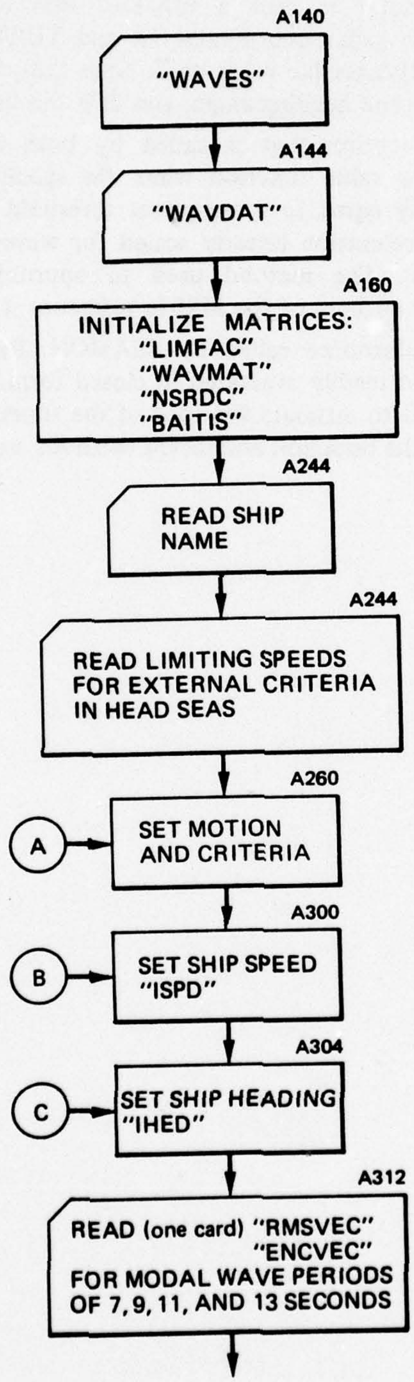


TABLE 8 (Continued)

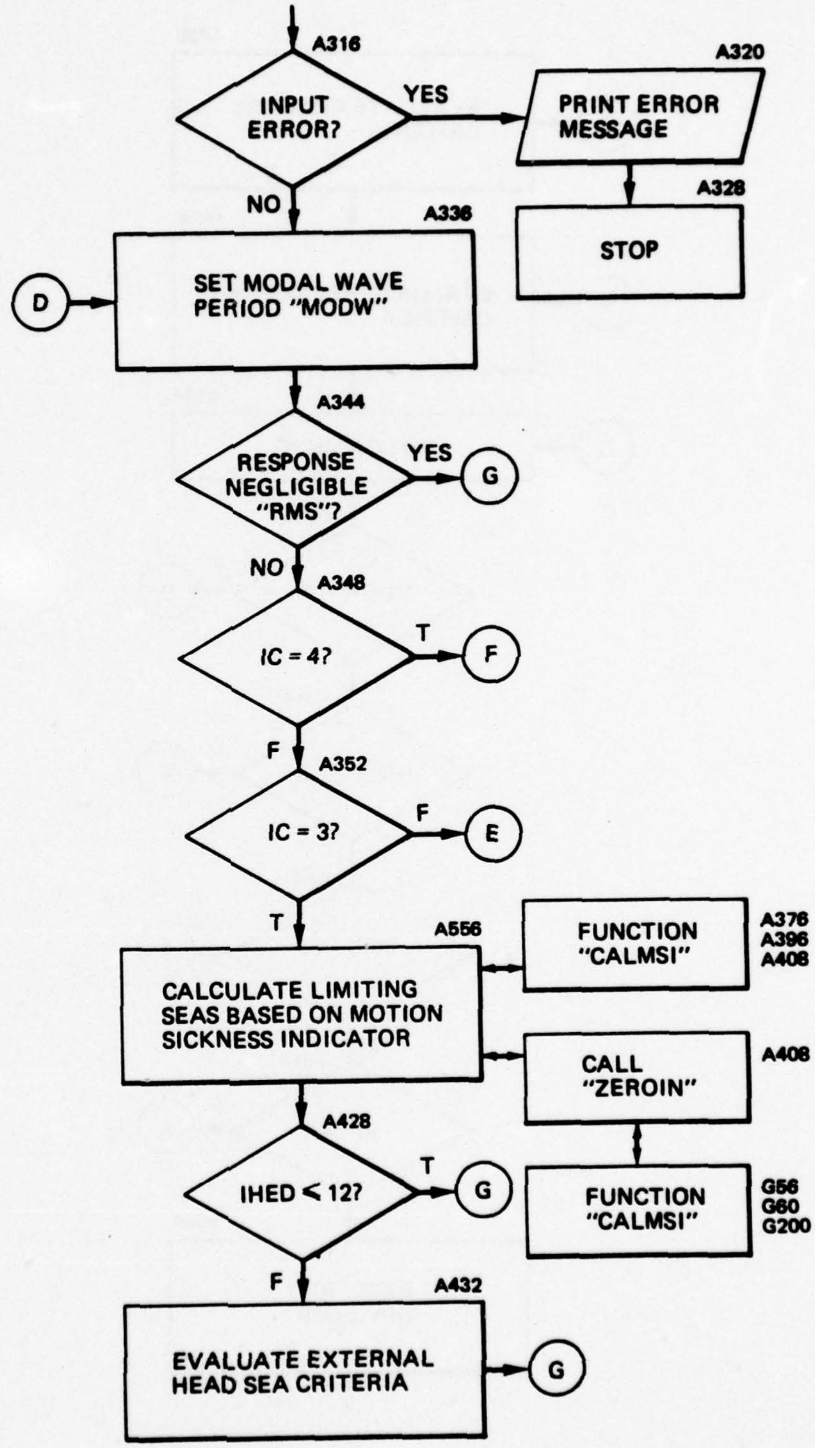


TABLE 8 (Continued)

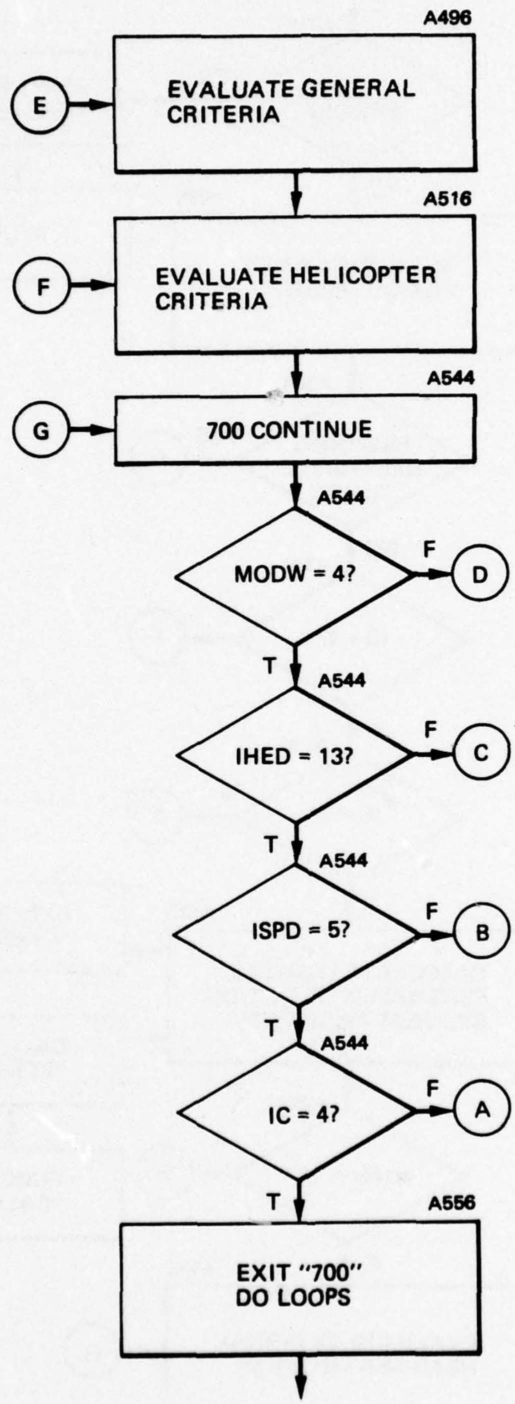


TABLE 8 (Continued)

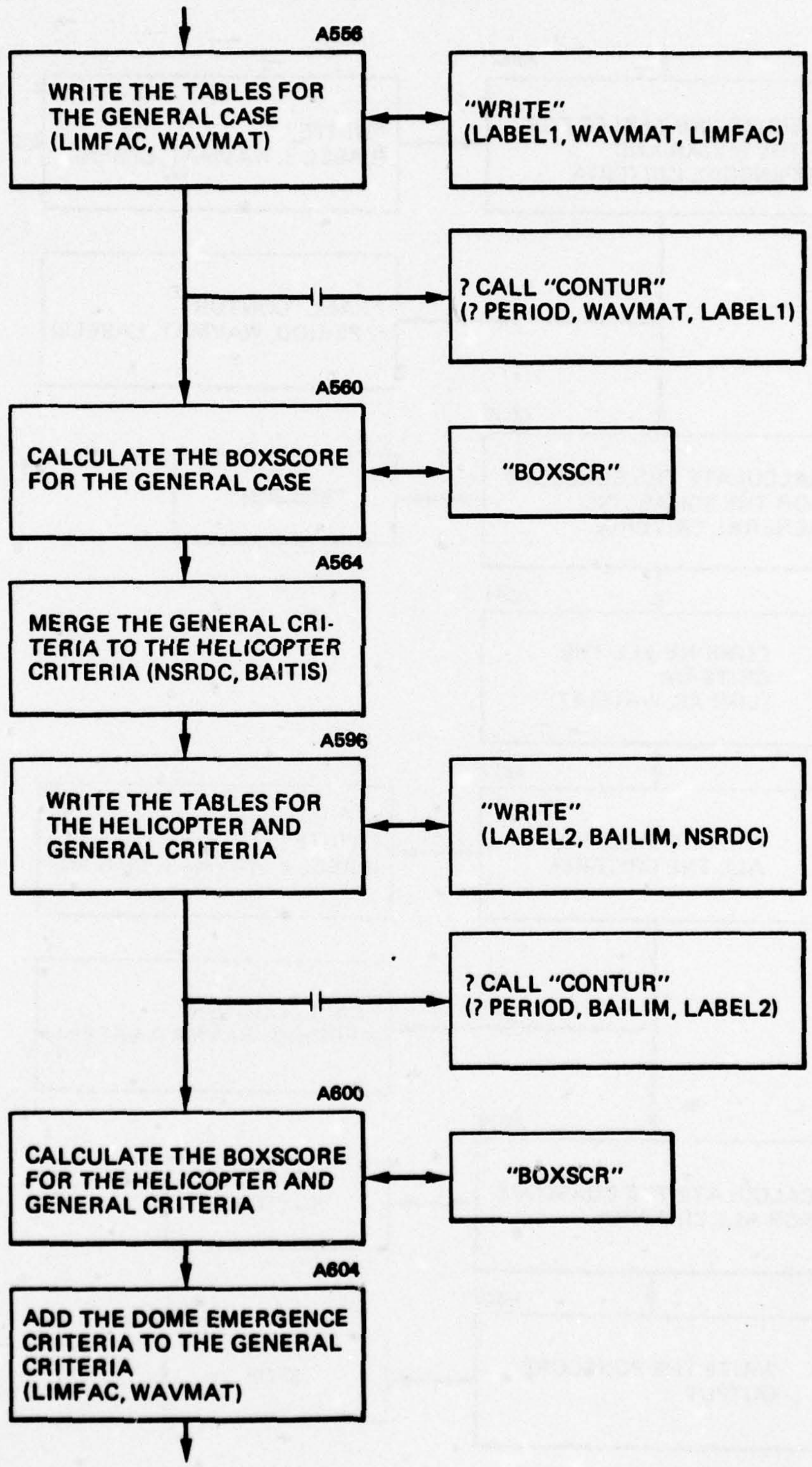
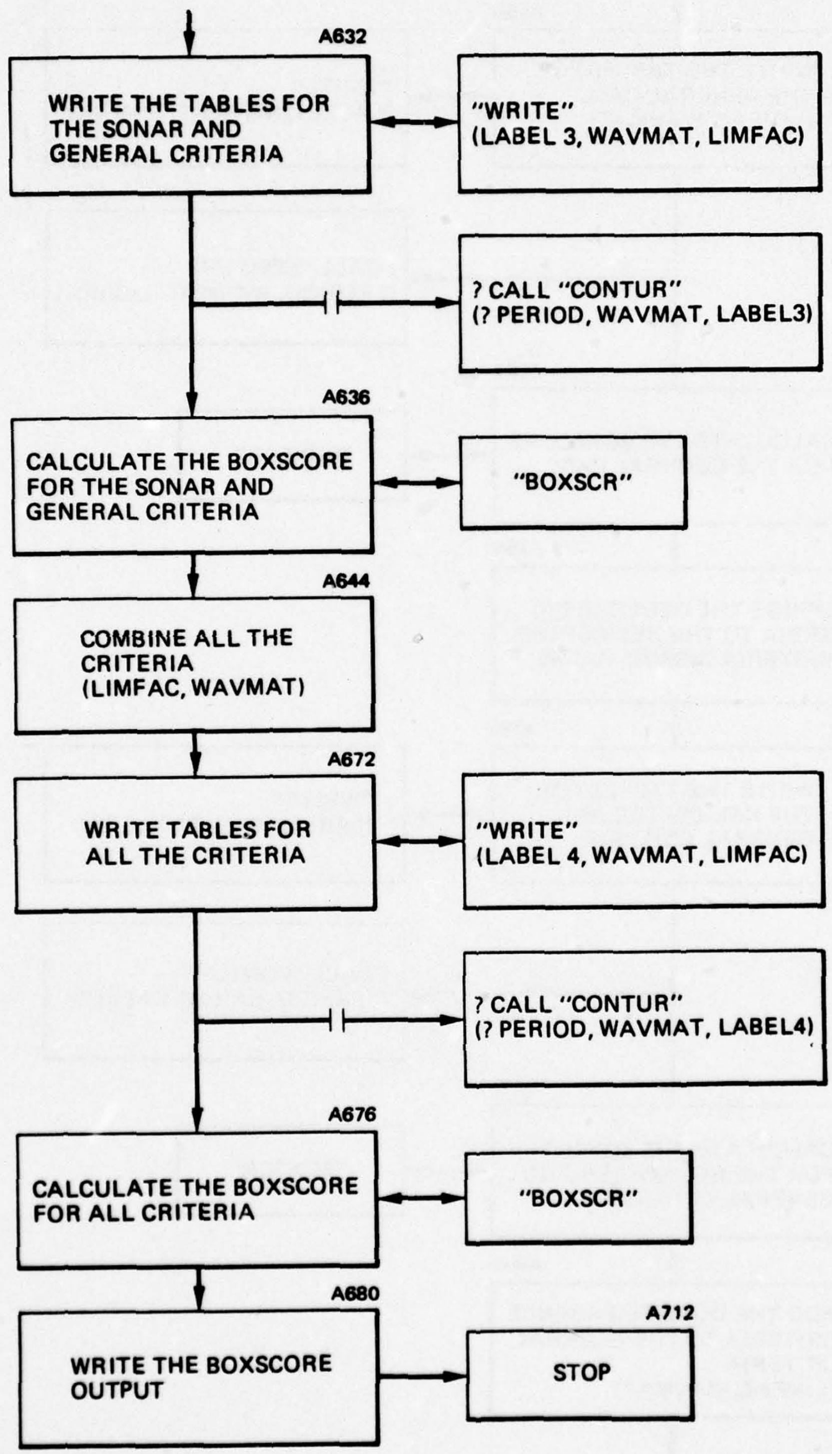


TABLE 8 (Continued)



DATA INPUT

Four basic classes of data are read into the program. (The complete set of input data required to reproduce the output in appendix C is contained in appendix B.)

The first set of data consists of 9 cards in the format (7F5.0). The first card identifies the height segregation of the succeeding 8 cards. It identifies the upper limits of significant wave heights in feet used to segregate the distribution of wave heights into seven "bins." The next four cards then identify the percentage of occurrence of these wave heights for the summer for modal periods of 7, 9, 11, and 13 seconds, respectively. The last four cards contain the same data for the winter. The units of the data in cards 2 through 9, used in the current program, are in percent observed (e.g., 25.0 *not* .25) times 16.* The data actually used in the analysis were based on data contained in reference 5 at the eight points shown in figure 5. The months of June and July were used for the summer, and the months of December and January for the winter. If a future user desires to use different units, this may be accommodated by considering changes to lines A96, A140, A144, D124, and D132.

The second set of data consists of a single card (card #10) that identifies the ship being evaluated. The program actaully only uses the alphanumeric title information in columns 1 through 8.

The third set of data consists of four cards, in *(20X, 5F10.0)* format, that describe the limiting significant wave heights in head seas, at speeds of 5, 10, 15, 20, and 25 knots for four criteria: bottom plate damage (Card 11); three slams in 100 motion cycles (Card 12); one deck wetness every 2 minutes (Card 13); and, 3/5 dome emergence criterion (Card 14). These data are actually only available for the following ships: DD 963, FFG 7, FF 1052, and CGN 38.** These are the only criteria not actually evaluated within SEAMON. Due to time limitations, the program to estimate these limiting wave heights is not being documented. We should note that the limiting conditions are based on YF-17 ship motion estimates for operations in head seas using the Pierson-Moskowitz spectra.

The final set of data is the RMS motion response estimates as a function of ship speed, heading angle, and modal wave period. A total of 65 cards are read, in the following sequence; for each response being evaluated:

---

*We summed the observations for two different months at 8 points in the North Atlantic, thus 16.

**See reference 3.

Speed	Heading Angle
5	180
	165
	.
	.
	.
	015
	000
10	180
	165
	.
	.
	.
	000
etc.	

Each card, uniquely identified by the speed and heading angle, contains 8 additional data elements, 2 for each modal wave period of 7, 9, 11, and 13 seconds. The format of an individual card is as follows:

Card Columns	Format	Description
1-17	–	Noun description of data – not read
18-19	I2	Ship speed in knots
20-24	I5	Heading Angle in Degrees*
25	–	Blank
26-29	F4.3	RMS response for a 7-second modal wave period
30	–	"/"
31-33	F3.1	Encounter period for a 7-second modal wave period
34	–	Blank
35	–	Blank
36-39	F4.3	RMS response for a 9-second modal wave period
40	–	"/"
41-43	F3.1	Encounter period for a 9-second modal wave period
44	–	Blank
45	–	Blank

*Throughout this work we have adopted the NSRDC convention of heading angle being the angle of incidence. Thus, 180 is a head sea, and 000 is a following sea.

Card Columns	Format	Description
46-49	F4.3	RMS response for an 11-second modal wave period
50	–	"/"
51-53	F3.1	Encounter period for an 11-second modal wave period
54	–	Blank
55	–	Blank
56-59	F4.3	RMS response for a 13-second modal wave period
60	–	"/"
61-63	F3.1	Encounter period for a 13-second modal wave period.

The data used in the example were obtained from reference 1 for ship responses in longcrested seas as described by the Bretschneider spectra. The example required estimates of four different ship response parameters. These were read in the following sequence: (The value of the controlling index parameter "IC" (line A260) in SEAMON is also noted.)

- RMS roll in degrees (IC = 1)
- RMS pitch in degrees (IC = 2)
- RMS vertical acceleration at the CG in G's × 100 (IC = 3)
- RMS vertical velocity at the helicopter deck in feet/second (IC = 4).

III. MODIFYING THE PROGRAM

CHANGING A CRITERION

The threshold level for a criterion may be changed simply by changing the program line that sets the threshold, (e.g., lines A268 through A296) and the corresponding label in format statement 180 in subroutine WRITE. Table 2 provides the relationships that can be used to state a threshold in units of RMS response.

CHANGING THE MSI LEVEL

The MSI level is changed by altering the values in lines F100 and F112, and making the appropriate change in FORMAT statement 180 of subroutine WRITE.

ADDING A NEW CRITERION

New criteria may be evaluated as long as the appropriate ship motion data are available. Implementation of the new criterion can be accomplished as follows:

1. Increase the indexing parameter IC in line A260, and assign the appropriate threshold(s) via line A264.
2. If the new motion data has a corresponding threshold in the "General" category *or* the "helicopter" category, but not both, the appropriate transfer statement should be inserted after line A496 or A516 (based on the value of the indexing parameter IC).
3. Ensure that the criterion is properly identified in line A512 and/or immediately following line A540.
4. Modify format statement 180 in subroutine WRITE as appropriate.
5. Insert the motion data in the correct format at the end of the input deck.

ADDING A NEW CATEGORY

The current SEAMON program has two *major* categories for seakeeping criteria: General and Helicopter. Adding a new category, while not overly difficult, requires a good working knowledge of the program.

The program modification is basically accomplished by adding two new arrays for the program, both dimensioned 4X13X5. One is a floating point array that stores the limiting wave heights, while the other is an integer valued array that stores the limiting criteria. Both arrays are used to store the calculated results for the various modal wave periods, ship headings, and speeds, in the manner done for the existing categories. A detailed description of how this is done is beyond the scope of this paper. However, table 9 is provided to assist the programmer in implementing the program change.

TABLE 9

STEPS REQUIRED TO ADD A NEW SEAKEEPING CATEGORY

Approximate program location	Additions or modifications
A24	Dimension arrays
A26	Increase dimension of SCORE (see A680)
A88	Add new label
A220	Initialize matrices
A260	Identify new criteria
A264	Set thresholds
A496, A516	Transfer statements?
A544	Evaluate new category
A676	Print the new category output or contours
	Calculate box score
	Combine with other categories?
A112, A680	Modify the format for the box score output
B40	Add new criteria

PRINTING THE BOX SCORE SPEED EFFECT FOR ALL CATEGORIES

The current version of SEAMON only prints the boxscores at each increment of speed for the "All Criteria" case. This was done to preclude a user from being inundated with numbers in the box score printout. However, the program can be easily modified to print a separate box score table, with all speed increments for each seakeeping category.

The simplest way to do this is by altering the output format (statement 220, line 112), as appropriate, and inserting a write command each time BOXSCR is called. Note that each time BOXSCR is called, the array SPDDEF contains the desired speed information.

DELETING THE HEAD SEA CRITERIA

Evaluation of the head sea criteria can be removed from the program by deleting the appropriate input data and the following statements:

A28, A76, A80, A236, A244-A256, A428-A484, A604-A636

Format statements 220 in SEAMON and 180 in WRITE, as well as line A680, must also be modified.

REFERENCES

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2. Center for Naval Analyses, Memorandum (CNA) 77-0442 "Motion Data Base for a Seakeeping Analysis of a 3400 Ton SWATH Ship," LCDR. S. R. Olson, USN, For Official Use Only, 6 Apr 1977

3. Center for Naval Analyses, Draft Memorandum (CNA) 77-0640, "A Seakeeping Evaluation of Four Naval Monohulls and a 3400 Ton SWATH," LCDR S. R. Olson, USN, Unclassified, 13 May 1977

4. Human Factors Research, Inc., TR 1733-2 "Motion Sickness Incidence: Exploratory Studies of Habituation, Pitch and Roll, and the Refinement of a Mathematical Model," M. E. McCauley, et al, Unclassified, Apr 1976

5. Shampine, L. F., and Allen, R. C., Jr., "Numerical Computing: An Introduction," W. B. Saunders Co., Philadelphia, 1973 (ISBN 0-7216-8150-6, LCC#72-93122)

6. Commander, Naval Weather Service Command, "NAVAIR 50-1C-528, "U.S. Navy Marine Climatic Atlas of the World: Volume 1, North Atlantic Ocean," J. M. Meserv, Unclassified, Dec 1974

7. Ochi, M. K., and Bolton, W. E., "Statistics for the Prediction of Ship Performance in a Seaway," a paper published in three parts by the International Shipbuilding Progress, Vol. 20: #222 (Feb 1973), #224 (Apr 1973), #229 (Sep 1973)

8. Comstock, J. P. (Ed) "Principles of Naval Architecture," Society of Naval Architects and Marine Engineers, New York, 1967 (LCCN 67-20738)

9. Michel, W. H., "Sea Spectra Simplified," *Marine Technology*, Jan 1968, pp. 17-30

APPENDIX A

PROGRAM LISTING

```
      PROGRAM SEAMON
      EXTERNAL CALMSI
      INTEGER PERIOD,TITLE
      DIMENSION LIMFAC(4,13,5), WAVMAT(4,13,5)
      DIMENSION NSROC(4,13,5), BAILIM(4,13,5)
      DIMENSION RMSVEC(4), ENCVEC(4)
      DIMENSION SCORE(4,2), SPDEFF(5,2)
      DIMENSION SONAR(5), SLAM(5), WET(5), PLATE(5)
      DIMENSION TITLE(11),LABEL1(11),LABEL2(11),LABEL3(11),LABEL4(11)
      COMMON /BLOCK1/ IPER
      COMMON /BLOCK2/ WAVDAT(7,4,2),WAVES(7)
      COMMON /BLOCK3/ FLOG,RMS
      COMMON /BLOCK4/ WAVMAX,SPDMAX
      COMMON /BLOCK6/ CONMAT(4,13,5)
      DATA (WAVMAX=32.0)
      DATA (SPDMAX=28.0)
      DATA((LABEL1(J),J=2,8)= 56H GENERAL CRITERIA ONLY
     1     ( 1 - 6 )                         )
      DATA((LABEL1(J),J=10,11)=16HWAVE PERIOD)     )
      DATA((LABEL2(J),J=2,8)= 56H GENERAL AND HELICOPTER CRITERIA
     1     ( 1 - 9 )                         )
      DATA((LABEL2(J),J=10,11)=16HWAVE PERIOD)     )
      DATA((LABEL3(J),J=2,8)= 56H GENERAL AND DOME EMERGENCE CRITERIA
     1  ( 1 - 6, 10 )                        )
      DATA((LABEL3(J),J=10,11)=16HWAVE PERIOD)     )
      DATA((LABEL4(J),J=2,8)= 56H ALL SEAKEEPING CRITERIA
     1     ( 1 - 10 )                        )
      DATA((LABEL4(J),J=10,11)=16HWAVE PERIOD)     )
120   FORMAT (8F10.0)
140   FORMAT (7F5.0)
160   FORMAT (10A8)
180   FORMAT (20X,5F10.0)
200   FORMAT (17X,I2,I5,4(1X,F4.3,1X,F3.1,1X))
  220 FORMAT (1H1,/////,36X,A8,* BOX SCORES*,/,36X,19(1H*),  //, 66X,
     C   *NORTH ATLANTIC*,  /, 66X, 14(1H*), //, 64X, * SUMMER      WINTE
     CR*,  /, 65X, 17H******       ******    , //,4(/,10X,7A8,F4.2,7X,F4.2,
     C   //), 40X, * 5  KNOTS *, 16X,F4.2, 7X, F4.2, //,
     C          40X, *10  KNOTS *, 16X,F4.2, 7X, F4.2, //,
     C          40X, *15  KNOTS *, 16X,F4.2, 7X, F4.2, //,
     C          40X, *20  KNOTS *, 16X,F4.2, 7X, F4.2, //,
     C          40X, *25  KNOTS *, 16X,F4.2, 7X, F4.2, /, 1H1)
C
C     READ IN SEGREGATION LEVELS FOR WAVE HEIGHTS
C
      READ (60,140) (WAVES(I),I=1,7)
C
C     READ IN WAVE HEIGHT DISTRIBUTIONS
C     K=1, SUMMER
C     K=2, WINTER
C     J=1,  7 SECOND MODAL WAVE PERIOD
C     J=2,  9 SECOND MODAL WAVE PERIOD
C     J=3, 11 SECOND MODAL WAVE PERIOD
C     J=4, 13 SECOND MODAL WAVE PERIOD
C     I=1,7--DISTRIBUTION BY WAVE HEIGHT ACCORDING TO *WAVES*.
C
```

```
C       NOTE...IN THE CURRENT PROGRAM THE NUMBERS READ IN FOR EACH
C       ELEMENT IN *WAVDAT* ARE ACTUALLY IN UNITS OF
C       (FRACTION OF OCCURANCE (EG 0.05)) TIMES 1600.
C       (SEE LINES D124 AND D132 IN SUBROUTINE *BOXSCR*.)
C
        READ (60,140) (((WAVDAT(I,J,K),I=1,7),J=1,4),K=1,2)
        ICSHIP=0
240     CONTINUE
        ICSHIP=ICSHIP+1
C
C       INITIALIZE THE FOUR PRIMARY DATA MATRICES
C
C       *LIMFAC* WILL IDENTIFY THE GENERAL LIMITING CRITERION
C       FOR EACH SPEED, HEADING, AND WAVE PERIOD.
C
        DO 260 ISPD=1,5
        DO 260 IHED=1,13
        DO 260 MODW=1,4
260     LIMFAC(MODW,IHED,ISPD)=0
C
C       *WAVMAT* STORES MAXIMUM ALLOWABLE WAVE HEIGHTS FOR GENERAL CRITERIA
C       FOR EACH SPEED, HEADING, AND WAVE PERIOD.
C
        DO 280 ISPD=1,5
        DO 280 IHED=1,13
        DO 280 MODW=1,4
280     WAVMAT(MODW,IHED,ISPD)=WAVMAX
C
C       *NSRDC* WILL IDENTIFY THE HELICOPTER LIMITING CRITERION
C       FOR EACH SPEED, HEADING, AND WAVE PERIOD.
C
        DO 300 ISPD=1,5
        DO 300 IHED=1,13
        DO 300 MODW=1,4
300     NSRDC(MODW,IHED,ISPD)=0
C
C       *BAITIS* STORES MAXIMUM WAVE HEIGHTS IMPOSED BY HELICOPTER CRITERIA
C       FOR EACH SPEED, HEADING, AND WAVE PERIOD.
C
        DO 320 ISPD=1,5
        DO 320 IHED=1,13
        DO 320 MODW=1,4
320     BAILIM(MODW,IHED,ISPD)=WAVMAX
C
C       READ THE SHIP IDENTIFICATION FOR THE DATA SET
C
        READ (60,160) (TITLE(I),I=1,8)
        LABEL1(1)=TITLE(1)
        LABEL2(1)=TITLE(1)
        LABEL3(1)=TITLE(1)
        LABEL4(1)=TITLE(1)
C
C       READ IN THE LIMITING WAVE HEIGHTS FOR SPEEDS OF 5, 10, 15,
C       20, AND 25 KNOTS FOR THE CRITERIA ALREADY EVALUATED WITH
C       THE YF-17 SHIP MOTION DATA IN HEAD SEAS.
```

```
C
      READ (60,180) (PLATE(I),I=1,5)                                    A 244
      READ (60,180) (SLAM(I),I=1,5)                                     A 248
      READ (60,180) (WET(I),I=1,5)                                      A 252
      READ (60,180) (SONAR(I),I=1,5)                                    A 256
C
C     THIS STARTS THE INTERNAL SEQUENCE OF LOOPS THAT READ
C     AND EVALUATE THE DATA FROM THE BRETSCHNEIDER SPECTRA.
C
      DO 700 IC=1,4                                                     A 260
C
C     THE CONVENTION USED IN THIS PROGRAM IS-
C     IC=1, RMS ROLL DATA (DEGREES)
C     IC=2, RMS PITCH DATA (DEGREES)
C     IC=3, RMS VERTICAL ACCELERATION AT  THE CG (G'S * 100)
C     IC=4, RMS VERTICAL VELOCITY AT THE HELO PAD (FT/SEC)
C
C     NOTE THAT OTHER SHIP MOTION VARIABLES MAY EASILY BE ADDED BY
C     CHANGING *A260* AND ESTABLISHING APPROPRIATE THRESHOLDS VIA *A264*
C
C     WHEN DOING THIS, ENSURE *A512* AND/OR *A540* IDENTIFY THE CRITERIA.
C     ALSO ENSURE THAT NEW CRITERIA ARE PROPERLY IDENTIFIED
C     IN FORMAT STATEMENT 180 IN SUBROUTINE WRITE.
C
      GO TO (340,360,400,380), IC                                       A 264
C
C     THE APPROPRIATE THRESHOLDS ARE ESTABLISHED NEXT.
C     *THRESH* IS THE GENERAL THRESHOLD, AND
C     *BAITIS* IS THE HELICOPTER THRESHOLD.
C
C     THE MSI THRESHOLD IS A COMPLEX FUNCTION NOT
C     EXPLICITLY DEFINED BY A MOTION THRESHOLD.
C
C     ALL THRESHOLDS ARE STATED IN RMS.
C
C     ENSURE THAT ANY CHANGE IN A CRITERION IS
C     IDENTIFIED IN FORMAT 180 OF SUBROUTINE WRITE.
C
340   THRESH=9.6                                                        A 268
      BAITIS=3.2                                                        A 272
      GO TO 400                                                         A 276
360   THRESH=2.4                                                        A 280
      BAITIS=1.5                                                        A 284
      GO TO 400                                                         A 288
380   BAITIS=3.5                                                        A 292
400   CONTINUE                                                          A 296
C
C     THE DATA IS READ IN INCREASING ORDER OF SHIP SPEED.
C     EG,   5, 10, 15, 20, 25,  KNOTS
C
      DO 700 ISPD =1,5                                                  A 300
C
C     FOR EACH SPEED, THE DATA IS READ FOR EACH 15 DEGREE
C     INCREMENT OF HEADING ANGLE STARTING WITH 180
C     AND DECREASING TO 000
```

```
C
C     IF IT IS DESIRED TO READ IN DATA IN A HEADING ANGLE
C     SEQUENCE STARTING WITH 000, CHANGE *A308* TO READ
C                               **** IHED = IREVRS ****
C
      DO 700 IREVRS=1,13                                                A 304
      IHED=14-IREVRS                                                    A 308
C
C     EACH CARD CONTAINS THE RMS RESPONSE AND MODAL
C     ENCCUNTER PERIOD FOR WAVE MODAL PERIODS OF 7, 9, 11, 13
C     SECONDS FOR THE SPECIFIED SPEED AND HEADING.
C
      READ (60,200) ICHK1,ICHK2,((RMSVEC(J),ENCVEC(J)),J=1,4)           A 312
      IF (ICHK1.EQ.(ISPD*5).AND.ICHK2.EQ.(15*(IHED-1))) GO TO 440       A 316
C
C     EACH INPUT CARD IS CHECKED TO BE SURE IT IS IN THE CORRECT
C     SEQUENCE.  IF IT IS NOT, AN ERROR MESSAGE IS PRINTED
C     AND THE RUN IS TENRMINATED.
C
      WRITE (61,420) ISPD,ICHK1,IHED,ICHK2                              A 320
420   FORMAT (1X,*INPUT CARD ERROR*,4I10)                               A 324
      STOP                                                              A 328
440   CONTINUE                                                          A 332
C
C     THE DATA FOR EACH WAVE MODAL PERIOD IS NOW PROCESSED.
C
      DO 700 MODW=1,4                                                   A 336
      RMS=RMSVEC(MODW)                                                  A 340
      IF (RMS.LT.0.0001) GO TO 700                                      A 344
C
C     THE CURRENT PROGRAM HAS NO GENERAL CRITERIA
C     BASED ON VERTICAL VELOCITY AT THE HELO DECK.
C
      IF (IC.EQ.4) GO TO 680                                            A 348
C
C     UNLESS THE MSI IS BEING CALCULATED PROCEEED TO NORMAL
C     CRITERIA EVALUATION SEQUENCE.
C
      IF (IC.NE.3) GO TO 660                                            A 352
      RMS=RMS/100.0                                                     A 356
C
C     THE SPECIFIC MSI THRESHOLD IS STATED IN LINES F100 AND F112
C     OF FUNCTION  *CALMSI* .  IF THE THRESHOLD IS CHANGED,
C     BE SURE TO CHANGE THE LABEL IN FORMAT 180 OF SUBROUTINE *WRITE*.
C
C     FUNCTION CALMSI CALCULATES THE DIFFERENCE BETWEEN THE MSI
C     AT A SPECIFIED FREQUENCY AND ACCELERATION LEVEL,
C     AND THE SPECIFIED THRESHOLD.  *CALMSI* WILL THEREFORE EQUAL
C     ZERO WHEN THE THRESHOLD IS EXACTLY MET.
C
C     THE MSI IS A COMPLEX FUNCTION AND IS EVALUATED
C     USING A SEARCH ALGORITHM *ZEROIN*.
C
C     THE SEARCH SEEKS THE WAVE HEIGHT MULTIPLIER , WHICH,
C     WHEN MULTIPLIED BY THE RMS VERTICAL ACCELERATION RESPONSE
```

```
C     FOR A UNIT WAVE HEIGHT (AT THE SPECIFIED FREQUENCY LEVEL)
C     CAUSES *CALMSI* TO BE EXACTLY ZERO.
C
C     THE SEARCH ROUTINE *ZEROIN* REQUIRES A HIGH AND LOW
C     ESTIMATE TO START THE SEARCH.
C
      FLOG=ALOG10((1.0/ENCVEC(MODW)))
      FLOG=0.87+FLOG*(4.36+(2.73*FLOG))
      DO 460 IGES=10,35,5
      GESHI=FLOAT(IGES)
460   IF (CALMSI(GESHI).GT.0.0) GO TO 480
      GO TO 560
480   CONTINUE
      DO 500 IGES=1,9
      GESLO=10.0-FLOAT(IGES)
500   IF (CALMSI(GESLO).LT.0.0) GO TO 520
      WAVMAT(MODW,IHED,ISPD)=1.0
      GO TO 540
520   CALL ZEROIN (CALMSI,GESHI,GESLO,IFLAG,IKOUNT)
      IF (WAVMAT(MODW,IHED,ISPD).LT.GESHI) GO TO 560
      WAVMAT(MODW,IHED,ISPD)=AMIN1(WAVMAX,GESHI)
540   LIMFAC(MODW,IHED,ISPD)=3
560   CONTINUE
      IF (IHED.LT.12) GO TO 640
C
C     IF THE HEADING IS WITHIN 22.5 DEGREES OF THE BOW,
C     CHECK TO SEE IF ANY OF THE PREDETERMINED HEAD SEA
C     CRITERIA ARE LIMITING.
C
      X=WAVMAT(MODW,IHED,ISPD)
      IF (X.LT.PLATE(ISPD)) GO TO 580
      X=PLATE(ISPD)
      LIMFAC(MODW,IHED,ISPD)=4
580   CONTINUE
      IF (X.LT.SLAM(ISPD)) GO TO 600
      X=SLAM(ISPD)
      LIMFAC(MODW,IHED,ISPD)=5
600   CONTINUE
      IF (X.LT.WET(ISPD)) GO TO 620
      X=WET(ISPD)
      LIMFAC(MODW,IHED,ISPD)=6
620   CONTINUE
      WAVMAT(MODW,IHED,ISPD)=X
640   CONTINUE
      GO TO 700
660   CONTINUE
C
C     EVALUATE THE GENERAL  CRITERION.
C
      X=THRESH/RMS
      IF (X.GT.WAVMAT(MODW,IHED,ISPD)) GO TO 680
      WAVMAT(MODW,IHED,ISPD)=X
      LIMFAC(MODW,IHED,ISPD)=IC
680   CONTINUE
C
```

```
C      EVALUATE THE HELICOPTER CRITERION.
C
       X=BAITIS/RMS                                                    A 520
       IF (X.GT.BAILIM(MODW,IHED,ISPD)) GO TO 700                      A 524
       BAILIM(MODW,IHED,ISPD)=X                                        A 528
       IF (IC.EQ.1) NSRDC(MODW,IHED,ISPD)=7                            A 532
       IF (IC.EQ.2) NSRDC(MODW,IHED,ISPD)=8                            A 536
       IF (IC.EQ.4) NSRDC(MODW,IHED,ISPD)=9                            A 540
700    CONTINUE                                                        A 544
C
C      THIS COMPLETES THE ACTUAL SEAKEEPING CALCULATIONS
C      WITH THE EXCEPTION OF THE DOME EMERGENCE CRITERION
C      THE REMAINDER OF THE PROGRAM PROCESSES AND PRINTS THE OUTPUT
C
C      PRINT THE GENERAL CRITERIA TABLES FOR MODAL PERIODS OF
C      7, 9, 11, AND 13 SECONDS.
C
       CALL WRITE (LABEL1,WAVMAT,LIMFAC)                               A 556
C
       CALL CONTUR (0,WAVMAT,LABEL1)
C
C      CALCULATE THE BOX SCORE.
C
       CALL BOXSCR (WAVMAT,SCORE(1,1),SCORE(1,2),SPDEFF)               A 560
C
C      COMBINE THE GENERAL AND HELICOPTER CRITERIA AND
C      PRINT THE APPROPRIATE TABLES FOR MODAL PERIODS OF
C      7, 9, 11, AND 13 SECONDS.
C
       DO 760 ISPD=1,5                                                 A 564
       DO 760 IHED=1,13                                                A 568
       DO 760 M=1,4                                                    A 572
       X=WAVMAT(M,IHED,ISPD)                                           A 576
       IF (X.GT.BAILIM(M,IHED,ISPD)) GO TO 760                         A 580
       BAILIM(M,IHED,ISPD)=X                                           A 584
       NSRDC(M,IHED,ISPD)=LIMFAC(M,IHED,ISPD)                          A 588
760    CONTINUE                                                        A 592
       CALL WRITE (LABEL2,BAILIM,NSRDC)                                A 596
C
C      CALCULATE THE BOX SCORE.
C
       CALL BOXSCR (BAILIM,SCORE(2,1),SCORE(2,2),SPDEFF)               A 600
C
C      COMBINE THE GENERAL AND DOME EMERGENCE CRITERIA AND
C      PRINT THE APPROPRIATE TABLES FOR MODAL PERIODS OF
C      7, 9, 11, AND 13 SECONDS.
C
       DO 780 ISPD=1,5                                                 A 604
       DO 780 IHED=12,13                                               A 608
       DO 780 M=1,4                                                    A 612
       IF (SONAR(ISPD).GT.WAVMAT(M,IHED,ISPD)) GO TO 780               A 616
       WAVMAT(M,IHED,ISPD)=SONAR(ISPD)                                 A 620
       LIMFAC(M,IHED,ISPD)=10                                          A 624
780    CONTINUE                                                        A 628
       CALL WRITE (LABEL3,WAVMAT,LIMFAC)                               A 632
```

```
C
C     CALCULATE THE BOX SCORE.
C
      CALL BOXSCR (WAVMAT,SCORE(3,1),SCORE(3,2),SPDEFF)                 A 636
C
C     COMBINE ALL OF THE CRITERIA AND
C     PRINT THE APPROPRIATE TABLES FOR MODAL PERIODS OF
C     7, 9, 11, AND 13 SECONDS,
C
      DO 800 I=1,5                                                      A 640
      DO 800 J=1,13                                                     A 644
      DO 800 M=1,4                                                      A 648
      X=BAILIM(M,J,I)                                                   A 652
      IF (X.GE.WAVMAT(M,J,I)) GO TO 800                                 A 656
      WAVMAT(M,J,I)=X                                                   A 660
      LIMFAC(M,J,I)=NSRDC(M,J,I)                                        A 664
800   CONTINUE                                                          A 668
      CALL WRITE (LABEL4,WAVMAT,LIMFAC)                                 A 672
C
      CALL CONTUR (0,WAVMAT,LABEL4)
C
C     CALCULATE THE BOX SCORE.
C
      CALL BOXSCR (WAVMAT,SCORE(4,1),SCORE(4,2),SPDEFF)                 A 676
C
C     PRINT THE BOX SCORES.
C     NOTE...EVERYTIME *BOXSCR* IS CALLED, *SPDEFF*
C     RETURNS THE BOXSCORE BREAKDOWN BY SPEEDS FOR THE INPUT MATRICES.
C     HOWEVER, THE CURRENT PROGRAM ONLY PRINTS THESE CALCULATIONS
C     FOR THE *ALL CRITERIA* CASE.
C
      WRITE (61,220) TITLE(1),(LABEL1(I),I=2,8),(SCORE(1,J),J=1,2),(LABE A 680
     1L2(I),I=2,8),(SCORE(2,J),J=1,2),(LABEL3(I),I=2,8),(SCORE(3,J),J=1, A 684
     22),(LABEL4(I),I=2,8),(SCORE(4,J),J=1,2),((SPDEFF(I,J),J=1,2),I=1,5 A 688
     3)                                                                 A 692
C
C     IF MORE THAN 1 SHIP IS BEING PROCESSED, CHECK THE *ICSHIP*
C     COUNTER .
C
      IF (ICSHIP.GE.1) GO TO 820                                        A 700
      GO TO 240                                                         A 704
820   CONTINUE                                                          A 708
      STOP                                                              A 712
      END                                                               A 716-
```

* MULTI-BANK COMPILATION.

```
      SUBROUTINE WRITE (LABEL,OUTMAT,LIMMAT)
      DIMENSION LABEL(11), OUTMAT(4,13,5), LIMMAT(4,13,5)
      COMMON /BLOCK4/ WAVMAX,SPDMAX
120   FORMAT (*1*,11X,*LIMITING FACTORS  *,A8,5X,5A8,/,50X,2A8,/,42X,F5.
     11,* SECOND MODAL WAVE PERIOD*,//)
140   FORMAT (12X,17HSHIP  * FOLLOWING,20X,*BEAM*,25X,*HEAD*,/,12X,14HSP
     1EED *    SEA,23X,*SEA*,26X,*SEA*,/,11X,8H(KNOTS)*,/,18X,1H*,I2,12I
     25,/,12X,70(1H*))
160   FORMAT (18X, 1H*, /, 11X, I5, 2X, 1H*, I2, 12I5 )
180   FORMAT (// ,11X, *LIMITING SEAKEEPING FACTORS* /,
     C /,21X, *0      NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH*
     C /,27X, *SIGNIFICANT HEIGHTS UP TO *, F5.1, * FEET*,/,
     C /,21X,      *1      12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL*, /
     C /,21X,       *2      3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH*,/
     C /,21X, *3      MOTION SICKNESS INDICATOR*,/
     C  27X, *(20 PERCENT OF LABORATORY SUBJECTS*,/
     C  27X, *EXPERIENCE EMESIS WITHIN 2 HOURS)*,/
     C /, 21X, *4      BOTTOM PLATE DAMAGE*, /
     C /, 21X, *5      3 SLAMS IN 100 MOTION CYCLES*,/
     C /, 21X,  *6      ONE DECK WETNESS EVERY TWO MINUTES*, /
     C /, 21X,  *7      12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL*,/
     C /, 21X,  *8      6.0  DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH*,/
     C/,21X,*9      7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK*, /
     C /, 20X,*10      SONAR DOME EMERGENCE CRITERION*, /
     C    27X, *(3/5 DETECTION OPPORTUNITIES)*      )
200   FORMAT (//,23X,*ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)*,/,23X,4
     11(1H*),//,29X,*SHIP HEADING ANGLE IN DEGREES*,/,12X,*SHIP*,/,12X,*
     2SPEED*,1X,13I4,/,11X,*(KNOTS)*)
220   FORMAT (11X,I4,3X,13F4.0)
      DO 280 IP=7,13,2
      N=(IP-5)/2
      PERIOD=FLOAT(IP)
      WRITE (61,120) (LABEL(J),J=1,8),PERIOD
      WRITE (61,140) 0,(I,I=15,180,15)
      DO 240 K=1,5
      NSPD=5*K
240   WRITE (61,160) NSPD,(LIMMAT(N,J,K),J=1,13)
      WRITE (61,180) WAVMAX
      WRITE (61,200) 0,(I,I=15,180,15)
      DO 260 K=1,5
      NSPD=5*K
260   WRITE (61,220) NSPD,(OUTMAT(N,J,K),J=1,13)
280   CONTINUE
      RETURN
      END
```

* MULTI-BANK COMPILATION.

```
      SUBROUTINE CONTUR (PERIOD,SEAMAT,TITLE)
C
C     PRINT THE CONTOUR SPECIFIED BY *PERIOD*.
C     IF *PERIOD*=0, PRINT CONTOURS FOR ALL FOUR WAVE MODAL PERIODS.
C
      EXTERNAL WAVLIM
      INTEGER PERIOD,TITLE
      DIMENSION SEAMAT(4,13,5), TITLE(11)
      COMMON /BLOCK1/ IPER
      COMMON /BLOCK4/ WAVMAX,SPDMAX
      COMMON /BLOCK6/ CONMAT(4,13,5)
      DO 120 I=1,5
      DO 120 J=1,13
      DO 120 M=1,4
120   CONMAT(M,J,I)=SEAMAT(M,J,I)
      SH=SPDMAX+2.0
      SL=-SH
      ZH=35.0
      IPERLO=PERIOD
      IPERHI=PERIOD
      INC=1
      IF (PERIOD.NE.0) GO TO 140
      IPERLO=7
      IPERHI=13
      INC=2
140   CONTINUE
      DO 160 M=IPERLO,IPERHI,INC
      IF (M.EQ.7) TITLE(9)=8H(  7 SEC
      IF (M.EQ.9) TITLE(9)=8H(  9 SEC
      IF (M.EQ.11) TITLE(9)=8H( 11 SEC
      IF (M.EQ.13) TITLE(9)=8H( 13 SEC
      IPER=(M-5)/2
      CALL PLOT3D (SL,SH,30.0,SL,SH,30.0,0.0,ZH,5.0,TITLE,88,WAVLIM,60.0
     1,30.0)
160   CONTINUE
      RETURN
      END

*    MULTI-BANK COMPILATION.
```

```
      SUBROUTINE BOXSCR (X,SUMSCR,WINSCR,S)
      DIMENSION X(4,13,5), S(5,2), SCORE(2)
      COMMON /BLOCK2/ WAVDAT(7,4,2),WAVES(7)
      COMMON /BLOCK4/ WAVMAX,SPDMAX
      DO 220 IS=1,2
C
C     IS = 1,  SUMMER
C     IS = 2,  WINTER
C
      B=0.0
      WLIM=AMIN1(WAVMAX,WAVES(7))
      DO 200 I=1,5
C
C     I = SPEED COUNTER
C
      C=0.0
      DO 180 J=1,13
C
C     J = HEADING COUNTER
C
      A=2.0
C
C     DUE TO SYMMETRY OF SEAKEEPING MATRIX.
C     ALL HEADINGS EXCEPT BOW AND STERN ARE COUNTED TWICE
C
      IF (J.EQ.1.OR.J.EQ.13) A=1.0
      DO 180 M=1,4
C
C     M = MODAL WAVE PERIOD COUNTER
C
C     LINEARLY INTERPOLATE TO FIND THE PERCENT OF TIME
C     THAT THE OBSERVED WAVE HEIGHTS ARE LESS THAN THE LIMITING
C     WAVE HEIGHT IN A SPECIFIED CELL.
C
      Y=X(M,J,I)
      IF (Y.GE.WLIM) GO TO 140
      DO 120 KWT=2,7
      K=KWT
120   IF (WAVES(K).GT.Y) GO TO 160
140   D=A*WAVDAT(7,M,IS)
      B=B+D
      C=C+D
      GO TO 180
160   KM1=K-1
      Y1=WAVDAT(KM1,M,IS)
      Y2=WAVDAT(K,M,IS)
      Y=Y1+(Y-WAVES(KM1))*(Y2-Y1)/(WAVES(K)-WAVES(KM1))
      D=A*AMAX1(0.0,Y)
      B=B+D
      C=C+D
180   CONTINUE
C
C     NOTE...IN THE CURRENT PROGRAM THE NUMBERS READ IN FOR EACH
C     ELEMENT IN *WAVDAT* ARE ACTUALLY IN UNITS OF
C     *FRACTION OF OCCURANCE (EG 0.05)* TIMES 1000.
```

```
C
C      NOTE ALSO THAT THERE ARE 24 BEARING SECTORS IN EACH SPEED RING.
C
       S(I,IS)=C/38400.0
 200   CONTINUE
       B=B/192000.0
       SCORE(IS)=B
 220   CONTINUE
       SUMSCR=SCORE(1)
       MINSCR=SCORE(2)
       RETURN
       END
```

* MULTI-BANK COMPILATION.

```
      FUNCTION WAVLIM (X,Y)
C
C     WAVLIM IS SET UP TO RECEIVE X AND Y IN CARTESIAN COORDINATES
C     AND CONVERT THESE DATA TO A SPEED AND HEADING ANGLE.
C
C     THE LIMITING WAVE HEIGHT AT THAT SPEED AND HEADING IS THEN
C     CALCULATED FOR THE MODAL WAVE PERIOD SPECIFIED BY *IPER*
C
      INTEGER SEKTOR,SEKADJ,BELL,BELADJ
      COMMON /BLOCK1/ IPER
      COMMON /BLOCK4/ WAVMAX,SPDMAX
      COMMON /BLOCK6/ CONMAT(4,13,5)
      YABS=ABS(Y)
      XABS=ABS(X)
      R=SQRT((YABS**2.0)+(XABS**2.0))
      IF (R.LT.SPDMAX) GO TO 120
      WAVLIM=0.0
      RETURN
  120 CONTINUE
      BELL=MAX0(INT((R+2.5)/5.0),1)
      BELL=MIN0(BELL,5)
      SPDDIF=R-BELL*5.0
      IF (R.GT.3.0) GO TO 140
C
C     IF THE SPEED IS LESS THAN 3 KNOTS, IT IS PRESUMED
C     THAT THE SHIP WILL BROACH INTO BEAM SEAS.
C
      WAVLIM=CONMAT(IPER,7,1)-((SPDDIF/5.0)*(CONMAT(IPER,7,2)-CONMAT(IPE
     1R,7,1)))
      RETURN
  140 CONTINUE
C
C     ONCE THE CELL FOR THE SPECIFIED SPEED (*BELL*) AND
C     HEADING (*SEKTOR*) IS IDENTIFIED, THE ADJACENT CELLS
C     ARE ALSO IDENTIFIED.
C
      THETA=ATAN(YABS/XABS)*57.295779
      IF (X.GT.0.0) THETA=180-THETA
      SEKTOR=((THETA+7.5)/15.0)+1
      DEGDIF=THETA+7.5-15.0*SEKTOR
      Z=1.0
      SEKADJ=SEKTOR+INT(SIGN(1.1,DEGDIF))
      IF (SEKADJ.EQ.0) SEKADJ=2
      IF (SEKADJ.EQ.14) SEKADJ=12
      BELADJ=BELL+INT(SIGN(1.1,SPDDIF))
      IF (BELADJ.NE.0) GO TO 160
      BELADJ=2
      Z=-1.0
      GO TO 180
  160 CONTINUE
      IF (BELADJ.NE.6) GO TO 180
      BELADJ=4
      Z=-1.0
  180 CONTINUE
      Z=Z*ABS(SPDDIF)/5.0
```

```
      D=ABS(DEGDIF)/15.6                                                E 160
C
C     CALCULATE A FOUR POINT MULTIPLE LINEAR INTERPOLATION FOR THE
C     EXACT POINT SPECIFIED BY X AND Y.
C
      BNSN=CONMAT(IPER,SEKTOR,BELL)                                     E 164
      BNSA=CONMAT(IPER,SEKTOR,BELADJ)                                   E 168
      BASN=CONMAT(IPER,SEKADJ,BELL)                                     E 172
      BASA=CONMAT(IPER,SEKADJ,BELADJ)                                   E 176
      A=BNSN+D*(BASN-BNSN)                                              E 180
      B=BNSA+D*(BASA-BNSA)                                              E 184
      WAVLIM=A+Z*(B-A)                                                  E 188
C
C     WAVLIM IS FINALLY CHECKED TO BE SURE IT IS IN BOUNDS BEFORE BEING
C     PASSED TO *PLOT3D*.
C
      WAVLIM=AMIN1(WAVLIM,WAVMAX)                                       E 192
      WAVLIM=AMAX1(WAVLIM,0.0)                                          E 196
      RETURN                                                            E 200
      END                                                               E 204-

*    MULTI-CANK CCMPILATION.
```

```
      FUNCTION CALMSI (WH)                                              F   4
C
C     FUNCTION CALMSI CALCULATES THE DIFFERENCE BETWEEN THE MSI
C     AT A SPECIFIED FREQUENCY AND ACCELERATION LEVEL,
C     AND THE SPECIFIED THRESHOLD.  *CALMSI* WILL THEREFORE EQUAL
C     ZERO WHEN THE THRESHOLD IS EXACTLY MET.
C
C     THE SPECIFIC MSI THRESHOLD IS STATED IN LINES F100 AND F112
C     OF FUNCTION  *CALMSI* .  IF THE THRESHOLD IS CHANGED,
C     BE SURE TO CHANGE THE LABEL IN FORMAT 180 OF SUBROUTINE *WRITE*.
C
C     REF...HUMAN FACTORS RESEARCH , INC., TECHNICAL REPORT 1733-2,
C          *MOTION SICKNESS INCIDENCE-EXPLORATORY STUDIES OF HABITUATION,
C     PITCH AND ROLL, AND THE REFINEMENT OF A MATHEMATICAL MODEL,*
C     M.E. MCCAULEY ET AL, APRIL 1976
C
      COMMON /BLOCK3/ FLOG,RMS                                          F   8
      DIMENSION Z(2)                                                    F  12
C                                                                  F  16
C     EVALUATE ZA                                                  F  20
C                                                                  F  24
      Z(1)=(ALOG10((WH*RMS))-FLOG)/0.47                                 F  28
C                                                                  F  32
C     EVALUATE ZTP FOR A 120 MINUTE PERIOD                         F  36
C                                                                  F  40
      Z(2)=1.231729+(1.133893*Z(1))                                     F  44
C                                                                  F  48
C     APPROXIMATE THE NORMAL FUNCTION AT ZA AND ZTP                F  52
C                                                                  F  56
      DO 140 I=1,2                                                      F  60
      AZ=ABS(Z(I))                                                      F  64
      W=1.0/(1.0+0.2316419*AZ)                                          F  68
      D=0.3989423*EXP(-AZ*AZ/2.0)                                       F  72
      STOPHI=1.0-D*((((1.330274*W-1.821256)*W+1.781478)*W-0.3565638)*W+0F  76
     1.3193815)*W                                                       F  80
      IF (Z(I)) 120,140,140                                             F  84
120   STOPHI=1.0-STOPHI                                                 F  88
140   Z(I)=STOPHI                                                       F  92
C                                                                  F  96
C     CALCULATE THE ZERO FUNCTION FOR A 20 PERCENT MSI             F 100
C                                       **********                 F 104
C                                                                  F 108
      CALMSI=(Z(1)*Z(2))-0.20                                           F 112
C                         ****
      RETURN                                                            F 120
      END                                                               F 124-

*    MULTI-BANK COMPILATION.
```

```
      SUBROUTINE ZEROIN (F,B,C,IFLAG,IKOUNT)
C
C           THIS SUBROUTINE CALCULATES THE ROOT OF A CONTINUOUS
C        FUNCTION USING A COMBINATION OF THE BISECTION AND SECANT
C        METHODS AFTER  SHAMPINE AND ALLEN.
C
C           THE ABSOLUTE ERROR IS FIXED AT  0.00001
C           THE RELATIVE ERROR IS FIXED AT  0.00001
C           A MAXIMUM OF 50 ITERATIONS IS PERMITTED
C
C     REF...SHAMPINE,L.F., AND C.A. ALLEN, "NUMERICAL COMPUTING,"
C        W.B. SAUNDERS CO., PHILADELPHIA, 1973, (ISBN 0-7216-8150-6)
C
      IC=0
      ACBS=ABS(B-C)
      A=C
      FB=F(B)
      FA=F(A)
      FC=FA
      KOUNT=2
      FX=AMAX1(ABS(FB),ABS(FC))
20    IF (ABS(FC).GE.ABS(FB)) GO TO 40
      A=B
      FA=FB
      B=C
      FB=FC
      C=A
      FC=FA
40    CMB=0.5*(C-B)
      ACMB=ABS(CMB)
      TOL=0.00001*ABS(B)+0.00001
      IF (ACMB.LE.TOL) GO TO 160
      IF (KOUNT.GE.50) GO TO 240
      P=(B-A)*FB
      Q=FA-FB
      IF (P.GE.0.0) GO TO 60
      P=-P
      Q=-Q
60    A=B
      FA=FB
      IC=IC+1
      IF (IC.LT.4) GO TO 80
      IF (8.0*ACMB.GE.ACBS) GO TO 120
      IC=0
      ACBS=ACMB
80    IF (P.GT.ABS(Q)*TOL) GO TO 100
      B=B+SIGN(TOL,CMB)
      GO TO 140
100   IF (P.GE.CMB*Q) GO TO 120
      B=B+P/Q
      GO TO 140
120   B=0.5*(C+B)
140   FB=F(B)
      IF (FB.EQ.0.0) GO TO 160
      KOUNT=KOUNT+1
```

```
      IF (SIGN(1.0,FB).NE.SIGN(1.0,FC)) GO TO 20
      C=A
      FC=FA
      GO TO 20
160   IF (SIGN(1.0,FB).EQ.SIGN(1.0,FC)) GO TO 220
      IF (ABS(FB).GT.FX) GO TO 200
      IFLAG=1
      RETURN
180   IFLAG=2
      RETURN
200   IFLAG=3
      RETURN
220   IFLAG=4
      RETURN
240   IFLAG=5
      RETURN
      END
```

* MULTI-BANK COMPILATION.

APPENDIX B

DATA INPUT FOR THE FFG 7

2.5	5.7	9.0	12.3	18.9	25.4	32.0
197	799	1037	1094	1105	1106	1107
4	103	243	286	310	311	312
2	24	67	92	113	120	121
0	8	25	45	58	59	60
55	287	493	589	627	638	642
2	55	221	329	415	446	456
2	9	75	157	245	274	291
0	13	45	93	151	186	211

FFG 7 SEAKEEPING AND SHIP MOTION DATA

FFG7 PLATE DAMAGE	45.0	45.0	45.0	45.0	45.0
FFG7 3 SLAMS/100	45.0	32.92	18.66	14.54	12.95
FFG7 2 MIN WETNESS	45.0	45.0	32.25	21.0	15.0
FFG7 3/5 SONAR	20.4	15.1	12.74	11.53	10.5

3	FFG 7	ROLL	5	180	000/000	000/000	000/000	000/000
3	FFG 7	ROLL	5	165	068/087	192/090	228/090	209/090
3	FFG 7	ROLL	5	150	134/087	327/087	378/090	344/090
3	FFG 7	ROLL	5	135	212/085	441/090	487/090	436/090
3	FFG 7	ROLL	5	120	301/085	534/090	558/090	489/090
3	FFG 7	ROLL	5	105	354/087	566/090	566/090	487/090
3	FFG 7	ROLL	5	090	379/087	573/090	551/090	465/090
3	FFG 7	ROLL	5	075	570/087	723/090	647/090	529/090
3	FFG 7	ROLL	5	060	682/087	804/090	692/092	556/092
3	FFG 7	ROLL	5	045	577/090	654/092	554/092	443/092
3	FFG 7	ROLL	5	030	375/092	397/092	333/092	267/092
3	FFG 7	ROLL	5	015	213/090	203/090	165/090	131/090
3	FFG 7	ROLL	5	000	000/087	000/087	000/087	000/087
3	FFG 7	ROLL	10	180	000/000	000/000	000/000	000/000
3	FFG 7	ROLL	10	165	032/079	118/101	178/101	181/101
3	FFG 7	ROLL	10	150	070/079	197/101	275/101	275/101
3	FFG 7	ROLL	10	135	124/079	284/095	361/095	349/101
3	FFG 7	ROLL	10	120	194/081	360/095	411/095	381/098
3	FFG 7	ROLL	10	105	260/087	431/092	455/092	404/095
3	FFG 7	ROLL	10	090	331/087	488/090	473/090	403/090
3	FFG 7	ROLL	10	075	634/087	700/090	598/092	481/092
3	FFG 7	ROLL	10	060	805/090	765/092	614/092	480/092
3	FFG 7	ROLL	10	045	441/095	391/095	320/095	257/095
3	FFG 7	ROLL	10	030	122/121	144/126	136/128	119/131
3	FFG 7	ROLL	10	015	044/128	058/128	058/140	053/143
3	FFG 7	ROLL	10	000	000/134	000/140	000/143	000/146
3	FFG 7	ROLL	15	180	000/000	000/000	000/000	000/000
3	FFG 7	ROLL	15	165	020/077	064/101	108/112	122/112
3	FFG 7	ROLL	15	150	046/077	121/101	182/105	197/112
3	FFG 7	ROLL	15	135	083/077	181/101	247/105	254/105
3	FFG 7	ROLL	15	120	133/077	238/095	290/105	283/105
3	FFG 7	ROLL	15	105	190/083	302/095	332/098	307/101
3	FFG 7	ROLL	15	090	273/085	388/090	381/092	330/092
3	FFG 7	ROLL	15	075	643/087	633/090	522/092	416/092
3	FFG 7	ROLL	15	060	571/101	513/105	412/105	326/105
3	FFG 7	ROLL	15	045	163/143	194/143	181/143	157/143

3	FFG 7	ROLL	15	030	068/175	095/175	097/175	088/175
3	FFG 7	ROLL	15	015	028/196	040/196	043/196	040/196
3	FFG 7	ROLL	15	000	000/203	000/203	000/203	000/203
3	FFG 7	ROLL	20	180	000/000	000/000	000/000	000/000
3	FFG 7	ROLL	20	165	015/075	045/112	086/112	110/112
3	FFG 7	ROLL	20	150	034/075	088/101	146/112	173/112
3	FFG 7	ROLL	20	135	062/075	132/101	190/112	208/116
3	FFG 7	ROLL	20	120	107/077	196/098	254/105	259/108
3	FFG 7	ROLL	20	105	163/081	263/098	303/101	287/101
3	FFG 7	ROLL	20	090	265/085	373/090	367/092	318/092
3	FFG 7	ROLL	20	075	780/090	691/092	547/092	427/092
3	FFG 7	ROLL	20	060	321/134	323/134	277/134	228/134
3	FFG 7	ROLL	20	045	121/190	153/190	148/190	130/190
3	FFG 7	ROLL	20	030	086/262	090/233	087/233	079/233
3	FFG 7	ROLL	20	015	024/331	036/273	039/262	037/262
3	FFG 7	ROLL	20	000	000/370	000/299	000/273	000/273
3	FFG 7	ROLL	25	180	000/000	000/000	000/000	000/000
3	FFG 7	ROLL	25	165	012/077	032/101	070/126	099/126
3	FFG 7	ROLL	25	150	027/075	064/101	112/112	143/126
3	FFG 7	ROLL	25	135	050/073	104/095	156/116	182/116
3	FFG 7	ROLL	25	120	086/075	153/098	203/108	216/116
3	FFG 7	ROLL	25	105	135/081	219/098	261/101	255/108
3	FFG 7	ROLL	25	090	251/085	350/090	345/092	301/095
3	FFG 7	ROLL	25	075	930/090	749/092	571/092	439/092
3	FFG 7	ROLL	25	060	253/170	264/165	232/165	194/165
3	FFG 7	ROLL	25	045	116/299	142/242	137/242	121/242
3	FFG 7	ROLL	25	030	072/571	085/393	085/299	078/299
3	FFG 7	ROLL	25	015	039/073	042/571	042/393	038/331
3	FFG 7	ROLL	25	000	000/077	000/077	000/077	000/349
3	FFG 7	PITCH	5	180	047/070	082/081	096/090	095/101
3	FFG 7	PITCH	5	165	050/071	084/081	096/090	095/101
3	FFG 7	PITCH	5	150	059/071	090/079	098/087	094/101
3	FFG 7	PITCH	5	135	074/068	098/077	098/085	089/095
3	FFG 7	PITCH	5	120	096/063	102/071	092/081	079/090
3	FFG 7	PITCH	5	105	096/057	083/065	067/073	054/083
3	FFG 7	PITCH	5	090	013/045	009/048	006/048	004/048
3	FFG 7	PITCH	5	075	086/065	074/075	060/083	049/092
3	FFG 7	PITCH	5	060	074/081	082/090	077/101	068/112
3	FFG 7	PITCH	5	045	056/092	077/101	081/112	077/121
3	FFG 7	PITCH	5	030	043/101	071/108	081/121	080/131
3	FFG 7	PITCH	5	015	037/105	066/112	080/121	081/134
3	FFG 7	PITCH	5	000	035/105	084/116	079/126	081/134
3	FFG 7	PITCH	10	180	049/070	088/081	101/090	100/098
3	FFG 7	PITCH	10	165	052/070	090/081	102/090	100/098
3	FFG 7	PITCH	10	150	061/067	095/079	103/087	098/101
3	FFG 7	PITCH	10	135	078/068	103/077	102/085	093/092
3	FFG 7	PITCH	10	120	098/063	105/071	094/081	081/090
3	FFG 7	PITCH	10	105	092/057	081/063	066/075	054/083
3	FFG 7	PITCH	10	090	012/045	008/045	006/045	004/045
3	FFG 7	PITCH	10	075	080/070	069/079	057/087	047/108

3	FFG	7	PITCH	10	060	067/092	076/105	072/112	064/121
3	FFG	7	PITCH	10	045	051/112	072/121	076/128	073/134
3	FFG	7	PITCH	10	030	039/126	066/134	076/140	076/146
3	FFG	7	PITCH	10	015	033/134	061/140	074/150	076/157
3	FFG	7	PITCH	10	000	031/140	059/143	074/150	076/161
3	FFG	7	PITCH	15	180	050/071	092/079	106/090	104/098
3	FFG	7	PITCH	15	165	053/071	094/079	107/090	104/098
3	FFG	7	PITCH	15	150	062/071	099/079	107/087	102/101
3	FFG	7	PITCH	15	135	078/068	106/075	105/085	096/092
3	FFG	7	PITCH	15	120	096/063	105/071	095/081	082/090
3	FFG	7	PITCH	15	105	089/057	080/063	066/075	053/083
3	FFG	7	PITCH	15	090	011/045	008/045	005/045	004/045
3	FFG	7	PITCH	15	075	075/077	065/085	054/092	045/112
3	FFG	7	PITCH	15	060	062/108	072/116	069/121	062/131
3	FFG	7	PITCH	15	045	046/143	067/143	072/143	069/150
3	FFG	7	PITCH	15	030	035/175	060/175	071/175	071/175
3	FFG	7	PITCH	15	015	029/196	056/196	069/196	071/196
3	FFG	7	PITCH	15	000	028/203	054/203	068/203	071/203
3	FFG	7	PITCH	20	180	048/073	093/079	108/090	107/098
3	FFG	7	PITCH	20	165	051/073	095/079	109/087	106/098
3	FFG	7	PITCH	20	150	060/071	100/079	109/087	103/101
3	FFG	7	PITCH	20	135	075/068	105/075	106/085	097/092
3	FFG	7	PITCH	20	120	092/065	104/071	095/081	082/090
3	FFG	7	PITCH	20	105	085/057	078/063	065/070	053/083
3	FFG	7	PITCH	20	090	011/045	007/045	005/045	004/045
3	FFG	7	PITCH	20	075	070/083	062/090	052/105	043/116
3	FFG	7	PITCH	20	060	059/134	069/134	066/134	060/134
3	FFG	7	PITCH	20	045	042/190	062/190	067/190	064/190
3	FFG	7	PITCH	20	030	033/251	056/233	065/233	066/233
3	FFG	7	PITCH	20	015	028/314	053/262	065/262	067/262
3	FFG	7	PITCH	20	000	027/349	052/273	065/273	068/273
3	FFG	7	PITCH	25	180	044/073	092/081	109/087	108/098
3	FFG	7	PITCH	25	165	047/073	094/081	109/087	107/098
3	FFG	7	PITCH	25	150	056/071	098/079	109/085	104/101
3	FFG	7	PITCH	25	135	071/068	104/077	106/083	097/095
3	FFG	7	PITCH	25	120	087/067	102/071	094/077	082/090
3	FFG	7	PITCH	25	105	082/063	077/063	064/070	052/083
3	FFG	7	PITCH	25	090	010/045	007/045	006/045	005/140
3	FFG	7	PITCH	25	075	068/087	061/092	051/108	043/121
3	FFG	7	PITCH	25	060	055/165	065/165	063/165	057/165
3	FFG	7	PITCH	25	045	040/273	051/242	062/242	060/242
3	FFG	7	PITCH	25	030	033/524	054/331	063/299	063/299
3	FFG	7	PITCH	25	015	032/098	054/483	064/349	065/331
3	FFG	7	PITCH	25	000	029/000	052/524	063/370	065/349
3	FFG	7	HEAVE	5	180	144/052	168/085	181/092	179/108
3	FFG	7	HEAVE	5	165	152/052	176/083	188/092	185/101
3	FFG	7	HEAVE	5	150	179/048	204/083	211/092	202/101
3	FFG	7	HEAVE	5	135	234/068	259/079	254/090	233/101
3	FFG	7	HEAVE	5	120	368/063	369/075	331/085	286/092
3	FFG	7	HEAVE	5	105	703/052	587/057	471/075	379/085

3	FFG	7	HEAVE	5	090	886/052	684/057	526/070	413/079
3	FFG	7	HEAVE	5	075	389/070	366/079	315/090	266/105
3	FFG	7	HEAVE	5	060	146/085	189/095	191/108	178/116
3	FFG	7	HEAVE	5	045	068/098	112/108	131/116	132/128
3	FFG	7	HEAVE	5	030	040/105	077/116	100/126	106/131
3	FFG	7	HEAVE	5	015	030/112	061/121	084/131	093/143
3	FFG	7	HEAVE	5	000	027/112	067/121	080/134	089/143
3	FFG	7	HEAVE	10	180	217/052	267/079	274/090	259/101
3	FFG	7	HEAVE	10	165	226/052	276/079	282/090	265/101
3	FFG	7	HEAVE	10	150	257/065	309/077	307/087	283/101
3	FFG	7	HEAVE	10	135	333/063	379/073	356/083	316/092
3	FFG	7	HEAVE	10	120	516/057	509/063	441/079	370/090
3	FFG	7	HEAVE	10	105	842/052	700/057	554/057	441/079
3	FFG	7	HEAVE	10	090	883/052	682/057	524/070	412/079
3	FFG	7	HEAVE	10	075	329/075	314/085	275/095	235/112
3	FFG	7	HEAVE	10	060	108/095	146/108	153/116	145/126
3	FFG	7	HEAVE	10	045	045/116	081/126	098/134	101/143
3	FFG	7	HEAVE	10	030	023/131	052/140	070/146	077/153
3	FFG	7	HEAVE	10	015	016/128	039/146	057/157	065/165
3	FFG	7	HEAVE	10	000	014/143	035/150	053/161	062/170
3	FFG	7	HEAVE	15	180	272/070	394/073	407/077	375/090
3	FFG	7	HEAVE	15	165	287/070	409/073	417/077	381/090
3	FFG	7	HEAVE	15	150	341/067	457/071	448/075	400/087
3	FFG	7	HEAVE	15	135	463/064	547/068	503/068	433/083
3	FFG	7	HEAVE	15	120	684/063	680/063	578/063	476/065
3	FFG	7	HEAVE	15	105	974/057	815/057	641/057	507/057
3	FFG	7	HEAVE	15	090	881/052	681/057	523/070	411/079
3	FFG	7	HEAVE	15	075	275/081	268/092	239/105	207/116
3	FFG	7	HEAVE	15	060	080/112	113/121	121/131	117/140
3	FFG	7	HEAVE	15	045	028/143	055/150	070/157	075/165
3	FFG	7	HEAVE	15	030	012/175	032/175	046/175	053/185
3	FFG	7	HEAVE	15	015	007/196	022/196	022/196	043/196
3	FFG	7	HEAVE	15	000	006/203	020/203	032/203	040/203
3	FFG	7	HEAVE	20	180	343/071	569/075	593/077	537/079
3	FFG	7	HEAVE	20	165	368/071	589/073	604/077	542/077
3	FFG	7	HEAVE	20	150	450/071	651/071	637/075	559/075
3	FFG	7	HEAVE	20	135	601/068	746/068	684/070	580/073
3	FFG	7	HEAVE	20	120	845/063	863/063	731/067	597/067
3	FFG	7	HEAVE	20	105	1097/057	928/057	730/057	575/057
3	FFG	7	HEAVE	20	090	881/052	680/057	523/070	411/079
3	FFG	7	HEAVE	20	075	227/087	228/101	207/112	182/121
3	FFG	7	HEAVE	20	060	056/134	084/134	094/146	093/153
3	FFG	7	HEAVE	20	045	016/190	035/190	047/190	053/190
3	FFG	7	HEAVE	20	030	006/233	017/233	028/233	035/233
3	FFG	7	HEAVE	20	015	007/273	012/262	020/262	027/262
3	FFG	7	HEAVE	20	000	006/299	010/273	018/273	024/273
3	FFG	7	HEAVE	25	180	413/073	766/077	814/079	735/081
3	FFG	7	HEAVE	25	165	441/073	787/077	823/079	737/079
3	FFG	7	HEAVE	25	150	538/071	850/075	847/077	742/077
3	FFG	7	HEAVE	25	135	723/068	952/073	881/073	746/073

3	FFG	7	HEAVE	25	120	985/065	1045/067	890/067	724/067
3	FFG	7	HEAVE	25	105	1212/057	1042/057	820/063	644/063
3	FFG	7	HEAVE	25	090	882/052	680/057	523/070	411/079
3	FFG	7	HEAVE	25	075	185/095	194/108	180/116	160/128
3	FFG	7	HEAVE	25	060	036/165	059/165	070/165	072/165
3	FFG	7	HEAVE	25	045	008/242	020/242	030/242	037/242
3	FFG	7	HEAVE	25	030	011/063	011/299	017/299	022/299
3	FFG	7	HEAVE	25	015	014/067	010/349	012/331	016/331
3	FFG	7	HEAVE	25	000	016/068	011/370	011/349	015/349
3	FFG	7	VELBUL	5	180	112/ 70	167/ 79	184/ 87	179/ 98
3	FFG	7	VELBUL	5	165	117/ 70	171/ 79	186/ 87	180/ 98
3	FFG	7	VELBUL	5	150	134/ 67	186/ 77	194/ 85	184/ 92
3	FFG	7	VELBUL	5	135	168/ 64	209/ 75	206/ 83	188/ 95
3	FFG	7	VELBUL	5	120	228/ 63	239/ 71	217/ 81	191/105
3	FFG	7	VELBUL	5	105	282/ 57	251/ 70	214/ 87	184/108
3	FFG	7	VELBUL	5	090	237/ 63	211/ 79	184/ 98	161/116
3	FFG	7	VELBUL	5	075	261/ 64	228/ 79	194/101	167/116
3	FFG	7	VELBUL	5	060	171/ 79	181/ 87	169/105	153/121
3	FFG	7	VELBUL	5	045	112/ 90	142/101	146/112	139/126
3	FFG	7	VELBUL	5	030	081/ 98	118/108	130/116	129/131
3	FFG	7	VELBUL	5	015	066/105	104/112	121/121	122/134
3	FFG	7	VELBUL	5	000	062/105	100/116	117/126	120/134
3	FFG	7	VELBUL	10	180	121/ 70	188/ 79	207/ 87	200/ 98
3	FFG	7	VELBUL	10	165	126/ 70	192/ 79	209/ 87	201/ 98
3	FFG	7	VELBUL	10	150	144/ 67	206/ 77	216/ 85	203/ 92
3	FFG	7	VELBUL	10	135	181/ 64	229/ 75	225/ 83	205/ 92
3	FFG	7	VELBUL	10	120	241/ 63	255/ 71	231/ 83	203/ 95
3	FFG	7	VELBUL	10	105	288/ 57	258/ 70	221/ 87	189/108
3	FFG	7	VELBUL	10	090	235/ 63	209/ 70	182/ 18	160/116
3	FFG	7	VELBUL	10	075	221/ 70	198/ 85	173/108	151/121
3	FFG	7	VELBUL	10	060	130/ 92	145/105	141/116	131/134
3	FFG	7	VELBUL	10	045	080/108	110/121	117/128	114/143
3	FFG	7	VELBUL	10	030	054/126	087/131	100/140	102/153
3	FFG	7	VELBUL	10	015	042/128	074/140	091/150	095/157
3	FFG	7	VELBUL	10	000	039/137	070/143	088/150	093/161
3	FFG	7	VELBUL	15	180	124/ 70	203/ 79	226/ 87	219/ 98
3	FFG	7	VELBUL	15	165	131/ 70	208/ 79	228/ 87	219/ 98
3	FFG	7	VELBUL	15	150	153/ 67	224/ 77	235/ 87	221/ 92
3	FFG	7	VELBUL	15	135	195/ 64	248/ 73	243/ 83	221/ 95
3	FFG	7	VELBUL	15	120	258/ 63	273/ 70	247/ 83	216/ 95
3	FFG	7	VELBUL	15	105	299/ 57	270/ 65	230/ 87	196/108
3	FFG	7	VELBUL	15	090	232/ 63	207/ 79	180/ 98	158/116
3	FFG	7	VELBUL	15	075	186/ 77	172/ 90	154/112	137/128
3	FFG	7	VELBUL	15	060	100/108	118/116	118/128	112/143
3	FFG	7	VELBUL	15	045	056/143	083/143	092/143	093/157
3	FFG	7	VELBUL	15	030	034/175	061/175	075/175	079/175
3	FFG	7	VELBUL	15	015	025/196	050/196	065/196	072/196
3	FFG	7	VELBUL	15	000	023/203	047/203	062/203	069/203
3	FFG	7	VELBUL	20	180	135/ 70	227/ 77	250/ 87	240/ 98
3	FFG	7	VELBUL	20	165	143/ 70	233/ 77	253/ 87	241/ 98

3	FFG 7	VELBUL	20	150	169/ 67	251/ 75	260/ 85	242/ 92
3	FFG 7	VELBUL	20	135	216/ 64	276/ 70	268/ 83	241/ 95
3	FFG 7	VELBUL	20	120	280/ 63	298/ 67	268/ 83	232/ 95
3	FFG 7	VELBUL	20	105	314/ 57	285/ 63	242/ 85	205/108
3	FFG 7	VELBUL	20	090	231/ 63	206/ 79	179/ 98	157/116
3	FFG 7	VELBUL	20	075	157/ 85	150/105	138/116	125/134
3	FFG 7	VELBUL	20	060	077/134	095/134	098/134	096/134
3	FFG 7	VELBUL	20	045	036/190	059/190	070/190	073/190
3	FFG 7	VELBUL	20	030	021/242	040/233	053/233	060/233
3	FFG 7	VELBUL	20	015	016/299	032/262	045/262	052/262
3	FFG 7	VELBUL	20	000	015/314	030/273	043/273	050/273
3	FFG 7	VELBUL	25	180	147/ 73	262/ 77	287/ 79	272/ 90
3	FFG 7	VELBUL	25	165	156/ 71	268/ 75	289/ 79	272/ 90
3	FFG 7	VELBUL	25	150	186/ 71	286/ 73	295/ 77	272/ 81
3	FFG 7	VELBUL	25	135	238/ 68	312/ 70	301/ 73	268/ 75
3	FFG 7	VELBUL	25	120	304/ 63	329/ 67	295/ 67	253/ 95
3	FFG 7	VELBUL	25	105	333/ 57	304/ 63	257/ 85	217/101
3	FFG 7	VELBUL	25	090	229/ 63	204/ 79	178/ 98	155/116
3	FFG 7	VELBUL	25	075	134/ 87	132/108	124/126	114/140
3	FFG 7	VELBUL	25	060	056/165	074/165	080/165	080/165
3	FFG 7	VELBUL	25	045	022/262	040/242	051/242	056/242
3	FFG 7	VELBUL	25	030	017/419	026/314	037/299	043/299
3	FFG 7	VELBUL	25	015	019/571	021/393	029/331	037/331
3	FFG 7	VELBUL	25	000	019/ 83	019/419	027/349	034/349

APPENDIX C

PROGRAM OUTPUT FOR THE FFG 7

LIMITING FACTORS FFG 7 GENERAL CRITERIA ONLY

(1 - 6)

7.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA 0	15	30	45	60	75	BEAM SEA 90	105	120	135	150	165	HEAD SEA 180
5	0	0	1	1	1	1	3	3	3	3	0	0	0
10	0	0	0	1	1	1	3	3	3	3	3	0	0
15	0	0	0	0	1	1	3	3	3	3	3	5	5
20	0	0	0	0	1	1	3	3	3	3	3	5	5
25	0	0	0	0	0	1	3	3	3	3	3	5	5

LIMITING SEAKEEPING FACTORS

0	NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
1	12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
2	3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
3	MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
4	BOTTOM PLATE DAMAGE
5	3 SLAMS IN 100 MOTION CYCLES
6	ONE DECK WETNESS EVERY TWO MINUTES
7	12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
8	6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
9	7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
10	SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	32	32	26	17	14	17	8	11	19	31	32	32	32
10	32	32	32	22	12	15	8	9	14	21	28	32	32
15	32	32	32	32	17	15	8	7	10	15	21	19	19
20	32	32	32	32	30	12	8	7	8	12	16	15	15
25	32	32	32	32	32	10	8	6	7	10	14	13	13

LIMITING FACTORS FFG 7 GENERAL CRITERIA ONLY
(1 - 6)
9.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 (FOLLOWING SEA)	15	30	45	60	75	90 (BEAM SEA)	105	120	135	150	165	180 (HEAD SEA)
5	2	0	1	1	1	1	3	3	1	1	2	2	2
10	0	0	0	1	1	1	3	3	3	3	3	2	2
15	0	0	0	0	1	1	3	3	3	3	3	3	3
20	0	0	0	0	1	1	3	3	3	3	3	3	3
25	0	0	0	0	0	1	3	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY TWO MINUTES

7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	29	32	24	15	12	13	11	12	18	22	27	29	29
10	32	32	32	25	13	14	11	10	14	19	24	27	27
15	32	32	32	32	19	15	11	9	11	13	16	18	19
20	32	32	32	32	30	14	11	8	8	10	11	12	13
25	32	32	32	32	32	13	11	7	7	8	9	10	10

LIMITING FACTORS FFG 7 GENERAL CRITERIA ONLY
(1 - 6)
11.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA						BEAM SEA						HEAD SEA
	0	15	30	45	60	75	90	105	120	135	150	165	180
5	2	2	1	1	1	1	3	3	1	1	2	2	2
10	0	0	2	1	1	1	3	3	3	3	2	2	2
15	0	0	0	0	1	1	3	3	3	3	3	3	3
20	0	0	0	0	0	1	3	3	3	3	3	3	3
25	0	0	0	0	0	1	3	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

0	NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
1	12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
2	3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
3	MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
4	BOTTOM PLATE DAMAGE
5	3 SLAMS IN 100 MOTION CYCLES
6	ONE DECK WETNESS EVERY TWO MINUTES
7	12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
8	6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
9	7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
10	SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	30	30	29	17	14	15	14	16	17	20	24	25	25
10	32	32	32	30	16	16	14	13	17	22	23	24	24
15	32	32	32	32	23	18	14	11	12	14	17	18	18
20	32	32	32	32	32	18	14	10	10	11	12	12	13
25	32	32	32	32	32	17	14	9	8	8	9	9	9

LIMITING FACTORS FFG 7 GENERAL CRITERIA ONLY
(1 - 6)
13.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 FOLLOWING SEA	15	30	45	60	75	90 BEAM SEA	105	120	135	150	165	180 HEAD SEA
5	2	2	2	1	1	1	3	1	1	1	2	2	2
10	2	2	2	0	1	1	3	3	3	2	2	2	2
15	0	0	0	0	1	1	3	3	3	3	3	5	5
20	0	0	0	0	0	1	3	3	3	3	3	3	3
25	0	0	0	0	0	1	3	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

- 0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
- 1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
- 2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
- 3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
- 4 BOTTOM PLATE DAMAGE
- 5 3 SLAMS IN 100 MOTION CYCLES
- 6 ONE DECK WETNESS EVERY TWO MINUTES
- 7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
- 8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
- 9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
- 10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	30	30	30	22	17	18	18	20	20	22	26	25	25
10	32	32	32	32	20	20	18	17	23	26	24	24	24
15	32	32	32	32	29	23	19	14	15	18	20	19	19
20	32	32	32	32	32	22	19	13	12	13	13	14	14
25	32	32	32	32	32	22	19	11	10	10	10	10	11

LIMITING FACTORS FFG 7 GENERAL AND HELICOPTER CRITERIA

(1 - 9)

7.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 (FOLLOWING SEA)	15	30	45	60	75	90 (BEAM SEA)	105	120	135	150	165	180 (HEAD SEA)
5	0	7	7	7	7	7	3	7	7	7	7	9	9
10	0	0	7	7	7	7	3	3	3	8	9	9	9
15	0	0	0	7	7	7	3	3	3	3	3	5	5
20	0	0	0	7	7	7	3	3	3	3	3	5	5
25	0	0	0	7	7	7	3	3	3	3	3	5	5

LIMITING SEAKEEPING FACTORS

0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY TWO MINUTES

7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	32	15	9	6	5	6	8	9	11	15	24	30	31
10	32	32	26	7	4	5	8	9	14	19	24	28	29
15	32	32	32	20	6	5	8	7	10	15	21	19	19
20	32	32	32	26	10	4	8	7	8	12	16	15	15
25	32	32	32	28	13	3	8	6	7	10	14	13	13

LIMITING FACTORS FFG 7 GENERAL AND HELICOPTER CRITERIA
(1 - 9)
9.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 (FOLLOWING SEA)	15	30	45	60	75	90 (BEAM SEA)	105	120	135	150	165	180 (HEAD SEA)
5	8	7	7	7	7	7	7	7	7	7	7	7	8
10	8	8	7	7	7	7	7	7	7	7	8	8	8
15	8	8	8	7	7	7	7	3	3	3	8	8	8
20	8	8	8	7	7	7	7	3	3	3	3	3	3
25	8	8	8	7	7	7	7	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY TWO MINUTES

7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	18	16	8	5	4	4	6	6	6	7	10	17	18
10	25	25	22	8	4	5	7	7	9	11	16	17	17
15	28	27	25	16	6	5	8	9	11	13	15	16	16
20	29	28	27	21	10	5	9	8	8	10	11	12	13
25	29	28	28	23	12	4	9	7	7	8	9	10	10

LIMITING FACTORS FFG 7 GENERAL AND HELICOPTER CRITERIA
(1 - 9)
11.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 (FOLLOWING SEA)	15	30	45	60	75	90 (BEAM SEA)	105	120	135	150	165	180 (HEAD SEA)
5	8	8	7	7	7	7	7	7	7	7	7	7	8
10	8	8	8	7	7	7	7	7	7	7	7	8	8
15	8	8	8	7	7	7	7	7	7	7	8	8	8
20	8	8	8	7	7	7	7	3	3	3	3	3	3
25	8	8	8	7	7	7	7	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

0	NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
1	12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
2	3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
3	MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
4	BOTTOM PLATE DAMAGE
5	3 SLAMS IN 100 MOTION CYCLES
6	ONE DECK WETNESS EVERY TWO MINUTES
7	12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
8	6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
9	7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
10	SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	19	19	10	6	5	5	6	6	6	7	8	14	16
10	20	20	20	10	5	5	7	7	8	9	12	15	15
15	22	22	21	18	8	6	8	10	11	13	14	14	14
20	23	23	23	22	12	6	9	10	10	11	12	12	13
25	24	23	24	23	14	6	9	9	8	8	9	9	9

LIMITING FACTORS FFG 7 GENERAL AND HELICOPTER CRITERIA

(1 - 9)

13.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA						BEAM SEA						HEAD SEA
	0	15	30	45	60	75	90	105	120	135	150	165	180
5	8	8	7	7	7	7	7	7	7	7	7	7	8
10	8	8	8	7	7	7	7	7	7	7	7	8	8
15	8	8	8	7	7	7	7	7	7	7	8	8	8
20	8	8	8	8	7	7	7	7	3	3	3	3	8
25	8	8	8	8	7	7	7	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

- 0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
- 1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
- 2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
- 3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
- 4 BOTTOM PLATE DAMAGE
- 5 3 SLAMS IN 100 MOTION CYCLES
- 6 ONE DECK WETNESS EVERY TWO MINUTES
- 7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
- 8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
- 9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
- 10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	19	19	12	7	6	6	7	7	7	7	9	15	16
10	20	20	20	12	7	7	8	8	8	9	12	15	15
15	21	21	21	20	10	8	10	10	11	13	15	14	14
20	22	22	23	23	14	7	10	11	12	13	13	14	14
25	23	23	24	25	16	7	11	11	10	10	10	10	11

LIMITING FACTORS FFG 7 GENERAL AND DOME EMERGENCE CRITERIA

(1 - 6, 10)

7.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA						BEAM SEA						HEAD SEA
	0	15	30	45	60	75	90	105	120	135	150	165	180
5	0	0	1	1	1	1	3	3	3	3	0	10	10
10	0	0	0	1	1	1	3	3	3	3	3	10	10
15	0	0	0	0	1	1	3	3	3	3	3	10	10
20	0	0	0	0	1	1	3	3	3	3	3	10	10
25	0	0	0	0	0	1	3	3	3	3	3	10	10

LIMITING SEAKEEPING FACTORS

- 0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
- 1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
- 2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
- 3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
- 4 BOTTOM PLATE DAMAGE
- 5 3 SLAMS IN 100 MOTION CYCLES
- 6 ONE DECK WETNESS EVERY TWO MINUTES
- 7 12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
- 8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
- 9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
- 10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	32	32	26	17	14	17	8	11	19	31	32	20	20
10	32	32	32	22	12	15	8	9	14	21	28	15	15
15	32	32	32	32	17	15	8	7	10	15	21	13	13
20	32	32	32	32	30	12	8	7	8	12	16	12	12
25	32	32	32	32	32	10	8	6	7	10	14	11	11

LIMITING FACTORS FFG 7 GENERAL AND DOME EMERGENCE CRITERIA
(1 - 6, 10)
9.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA 0	15	30	45	60	75	BEAM SEA 90	105	120	135	150	165	HEAD SEA 180
5	2	0	1	1	1	1	3	3	1	1	2	10	10
10	0	0	0	1	1	1	3	3	3	3	3	10	10
15	0	0	0	0	1	1	3	3	3	3	3	10	10
20	0	0	0	0	1	1	3	3	3	3	3	10	10
25	0	0	0	0	0	1	3	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY TWO MINUTES

7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	29	32	24	15	12	13	11	12	18	22	27	20	20
10	32	32	32	25	13	14	11	10	14	19	24	15	15
15	32	32	32	32	19	15	11	9	11	13	16	13	13
20	32	32	32	32	30	14	11	8	8	10	11	12	12
25	32	32	32	32	32	13	11	7	7	8	9	10	10

LIMITING FACTORS FFG 7 GENERAL AND DOME EMERGENCE CRITERIA
(1 - 6, 10)
11.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA						BEAM SEA						HEAD SEA
	0	15	30	45	60	75	90	105	120	135	150	165	180
5	2	2	1	1	1	1	3	3	1	1	2	10	10
10	0	0	2	1	1	1	3	3	3	3	2	10	10
15	0	0	0	0	1	1	3	3	3	3	3	10	10
20	0	0	0	0	0	1	3	3	3	3	3	10	10
25	0	0	0	0	0	1	3	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

- 0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
- 1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
- 2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
- 3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
- 4 BOTTOM PLATE DAMAGE
- 5 3 SLAMS IN 100 MOTION CYCLES
- 6 ONE DECK WETNESS EVERY TWO MINUTES
- 7 12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
- 8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
- 9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
- 10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	30	30	29	17	14	15	14	16	17	20	24	20	20
10	32	32	32	30	16	16	14	13	17	22	23	15	15
15	32	32	32	32	23	18	14	11	12	14	17	13	13
20	32	32	32	32	32	18	14	10	10	11	12	12	12
25	32	32	32	32	32	17	14	9	8	8	9	9	9

LIMITING FACTORS FFG 7

GENERAL AND DOME EMERGENCE CRITERIA
(1 - 6, 10)
13.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 (FOLLOWING SEA)	15	30	45	60	75	90 (BEAM SEA)	105	120	135	150	165	180 (HEAD SEA)
5	2	2	2	1	1	1	3	1	1	1	2	10	10
10	2	2	2	0	1	1	3	3	3	2	2	10	10
15	0	0	0	0	1	1	3	3	3	3	3	10	10
20	0	0	0	0	0	1	3	3	3	3	3	10	10
25	0	0	0	0	0	1	3	3	3	3	3	3	10

LIMITING SEAKEEPING FACTORS

0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY TWO MINUTES

7 12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	30	30	30	22	17	18	18	20	20	22	26	20	20
10	32	32	32	32	20	20	18	17	23	26	24	15	15
15	32	32	32	32	29	23	19	14	15	18	20	13	13
20	32	32	32	32	32	22	19	13	12	13	13	12	12
25	32	32	32	32	32	22	19	11	10	10	10	10	11

LIMITING FACTORS FFG 7   ALL SEAKEEPING CRITERIA
(1 - 10)
7.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA 0	15	30	45	60	75	BEAM SEA 90	105	120	135	150	165	HEAD SEA 180
5	0	7	7	7	7	7	3	7	7	7	7	10	10
10	0	0	7	7	7	7	3	3	3	8	9	10	10
15	0	0	0	7	7	7	3	3	3	3	3	10	10
20	0	0	0	7	7	7	3	3	3	3	3	10	10
25	0	0	0	7	7	7	3	3	3	3	3	10	10

LIMITING SEAKEEPING FACTORS

0   NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1   12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2   3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3   MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4   BOTTOM PLATE DAMAGE

5   3 SLAMS IN 100 MOTION CYCLES

6   ONE DECK WETNESS EVERY TWO MINUTES

7   12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8   6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9   7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10   SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	32	15	9	6	5	6	8	9	11	15	24	20	20
10	32	32	26	7	4	5	8	9	14	19	24	15	15
15	32	32	32	20	6	5	8	7	10	15	21	13	13
20	32	32	32	26	10	4	8	7	8	12	16	12	12
25	32	32	32	28	13	3	8	6	7	10	14	11	11

LIMITING FACTORS FFG 7 ALL SEAKEEPING CRITERIA

(1 - 10)

9.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 FOLLOWING SEA	15	30	45	60	75	90 BEAM SEA	105	120	135	150	165	180 HEAD SEA
5	8	7	7	7	7	7	7	7	7	7	7	7	8
10	8	8	7	7	7	7	7	7	7	7	8	10	10
15	8	8	8	7	7	7	7	3	3	3	8	10	10
20	8	8	8	7	7	7	7	3	3	3	3	10	10
25	8	8	8	7	7	7	7	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

0	NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
1	12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
2	3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
3	MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
4	BOTTOM PLATE DAMAGE
5	3 SLAMS IN 100 MOTION CYCLES
6	ONE DECK WETNESS EVERY TWO MINUTES
7	12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
8	6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
9	7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
10	SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	10	16	8	5	4	4	6	6	6	7	10	17	18
10	25	25	22	8	4	5	7	7	9	11	16	15	15
15	28	27	25	16	6	5	8	9	11	13	15	13	13
20	29	28	27	21	10	5	9	8	8	10	11	12	12
25	29	28	28	23	12	4	9	7	7	8	9	10	10

LIMITING FACTORS FFG 7 ALL SEAKEEPING CRITERIA
(1 - 10)
11.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	FOLLOWING SEA						BEAM SEA						HEAD SEA
	0	15	30	45	60	75	90	105	120	135	150	165	180
5	8	8	7	7	7	7	7	7	7	7	7	7	8
10	8	8	8	7	7	7	7	7	7	7	7	8	8
15	8	8	8	7	7	7	7	7	7	7	8	10	10
20	8	8	8	7	7	7	7	3	3	3	3	10	10
25	8	8	8	7	7	7	7	3	3	3	3	3	3

LIMITING SEAKEEPING FACTORS

0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET

1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL

2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH

3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)

4 BOTTOM PLATE DAMAGE

5 3 SLAMS IN 100 MOTION CYCLES

6 ONE DECK WETNESS EVERY TWO MINUTES

7 12.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL

8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH

9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK

10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	19	19	10	6	5	5	6	6	6	7	8	14	16
10	20	20	20	10	5	5	7	7	8	9	12	15	15
15	22	22	21	18	8	6	8	10	11	13	14	13	13
20	23	23	23	22	12	6	9	10	10	11	12	12	12
25	24	23	24	23	14	6	9	9	8	8	9	9	9

LIMITING FACTORS FFG 7 — ALL SEAKEEPING CRITERIA (1 - 10)

13.0 SECOND MODAL WAVE PERIOD

SHIP SPEED (KNOTS)	0 (FOLLOWING SEA)	15	30	45	60	75	90 (BEAM SEA)	105	120	135	150	165	180 (HEAD SEA)
5	8	8	7	7	7	7	7	7	7	7	7	7	8
10	8	8	8	7	7	7	7	7	7	7	7	8	8
15	8	8	8	7	7	7	7	7	7	7	8	10	10
20	8	8	8	8	7	7	7	7	3	3	3	10	10
25	8	8	8	8	7	7	7	3	3	3	3	3	10

LIMITING SEAKEEPING FACTORS

- 0 NO SEAKEEPING THRESHOLD EXCEEDED FOR WAVES WITH SIGNIFICANT HEIGHTS UP TO 32.0 FEET
- 1 12.0 DEGREE SINGLE AMPLITUDE AVERAGE ROLL
- 2 3.0 DEGREE SINGLE AMPLITUDE AVERAGE PITCH
- 3 MOTION SICKNESS INDICATOR (20 PERCENT OF LABORATORY SUBJECTS EXPERIENCE EMESIS WITHIN 2 HOURS)
- 4 BOTTOM PLATE DAMAGE
- 5 3 SLAMS IN 100 MOTION CYCLES
- 6 ONE DECK WETNESS EVERY TWO MINUTES
- 7 12.8 DEGREE DOUBLE AMPLITUDE SIGNIFICANT ROLL
- 8 6.0 DEGREE DOUBLE AMPLITUDE SIGNIFICANT PITCH
- 9 7.0 FT/SEC SIG VERTICAL VELOCITY AT THE HELO DECK
- 10 SONAR DOME EMERGENCE CRITERION (3/5 DETECTION OPPORTUNITIES)

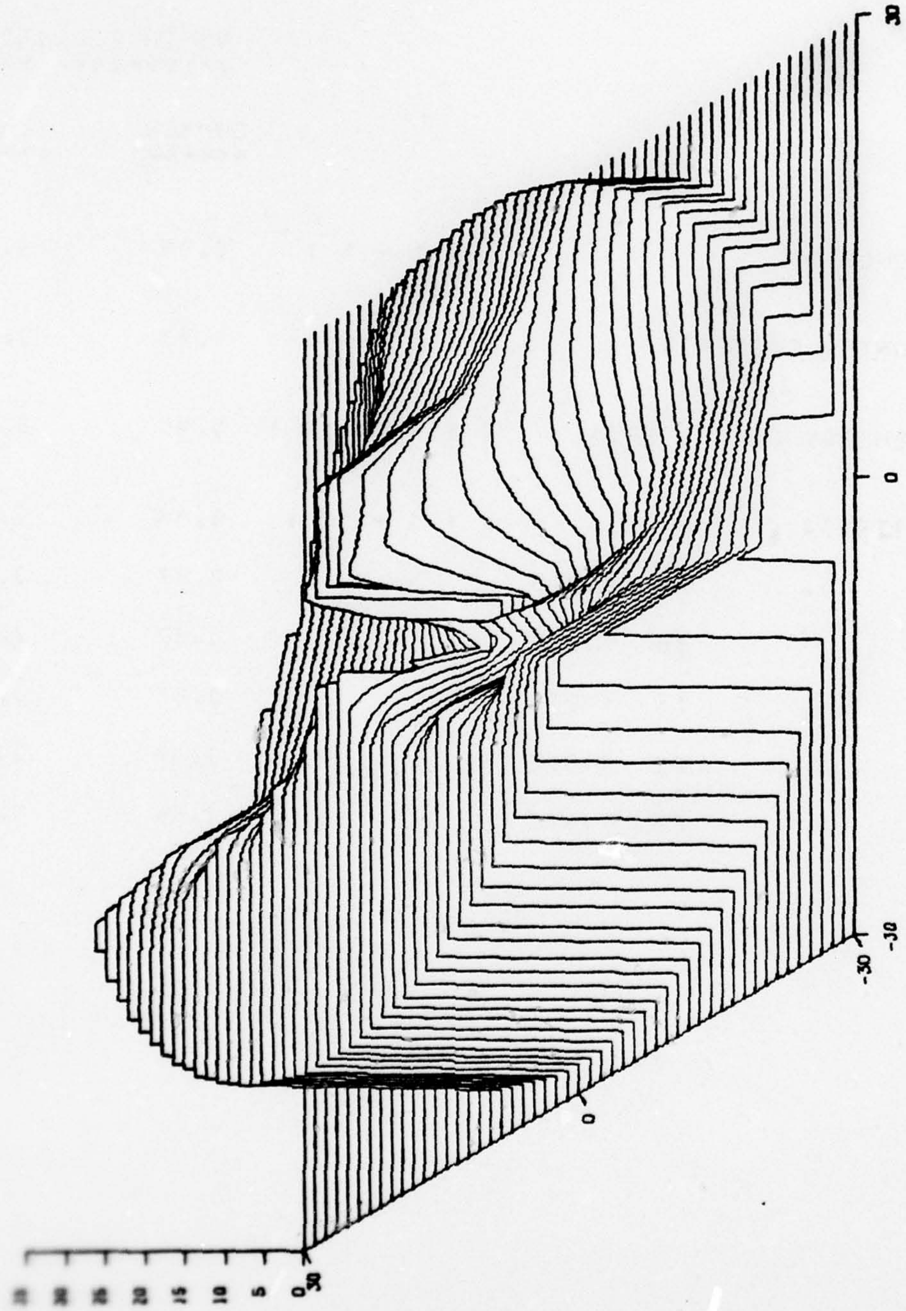
ACCEPTABLE SIGNIFICANT WAVE HEIGHT (FEET)

SHIP HEADING ANGLE IN DEGREES

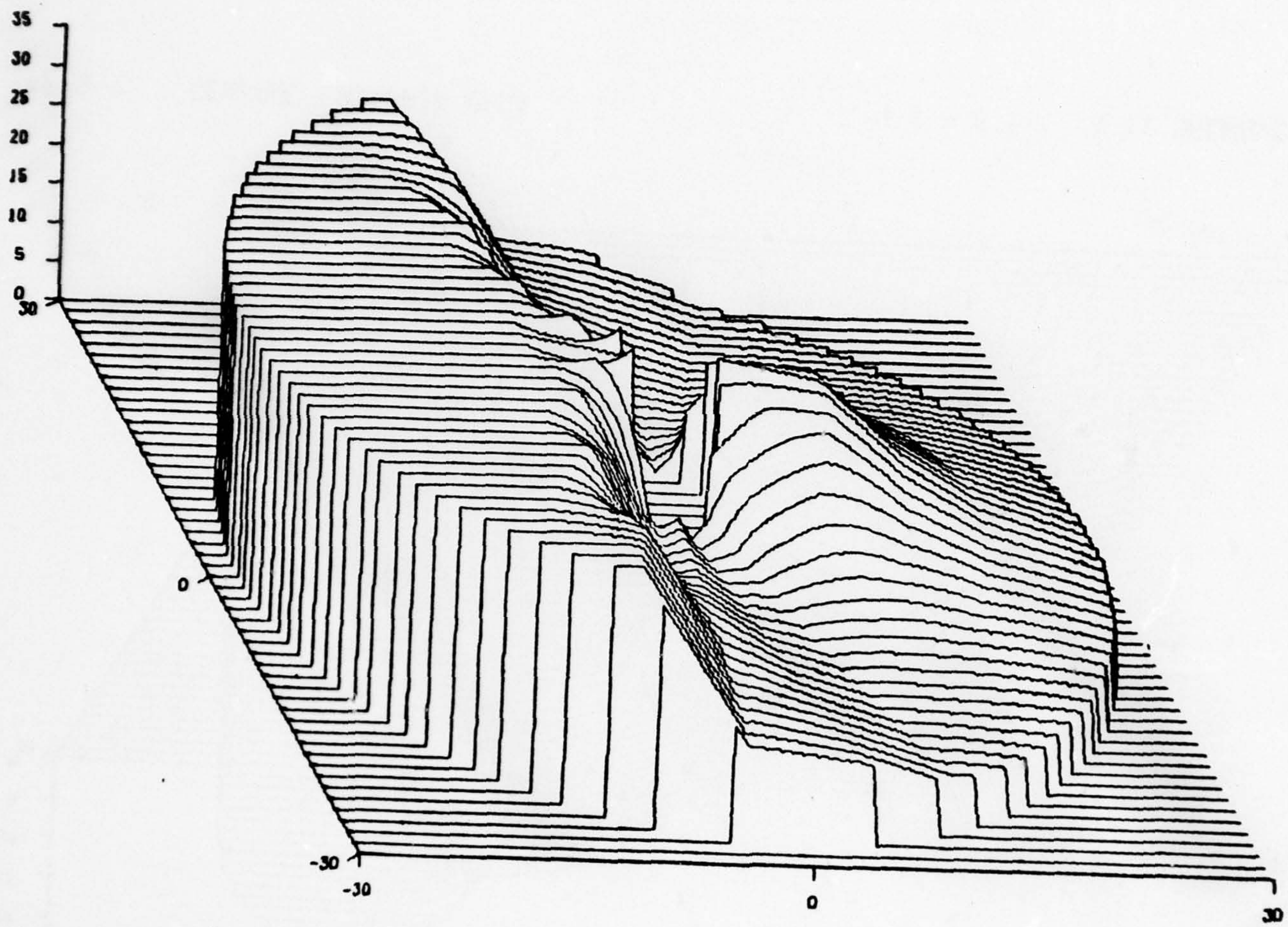
SHIP SPEED (KNOTS)	0	15	30	45	60	75	90	105	120	135	150	165	180
5	19	19	12	7	6	6	7	7	7	7	9	15	16
10	20	20	20	12	7	7	8	8	8	9	12	15	15
15	21	21	21	20	10	8	10	10	11	13	15	13	13
20	22	22	23	23	14	7	10	11	12	13	13	12	12
25	23	23	24	25	16	7	11	11	10	10	10	10	11

FFG 7 BOX SCORES

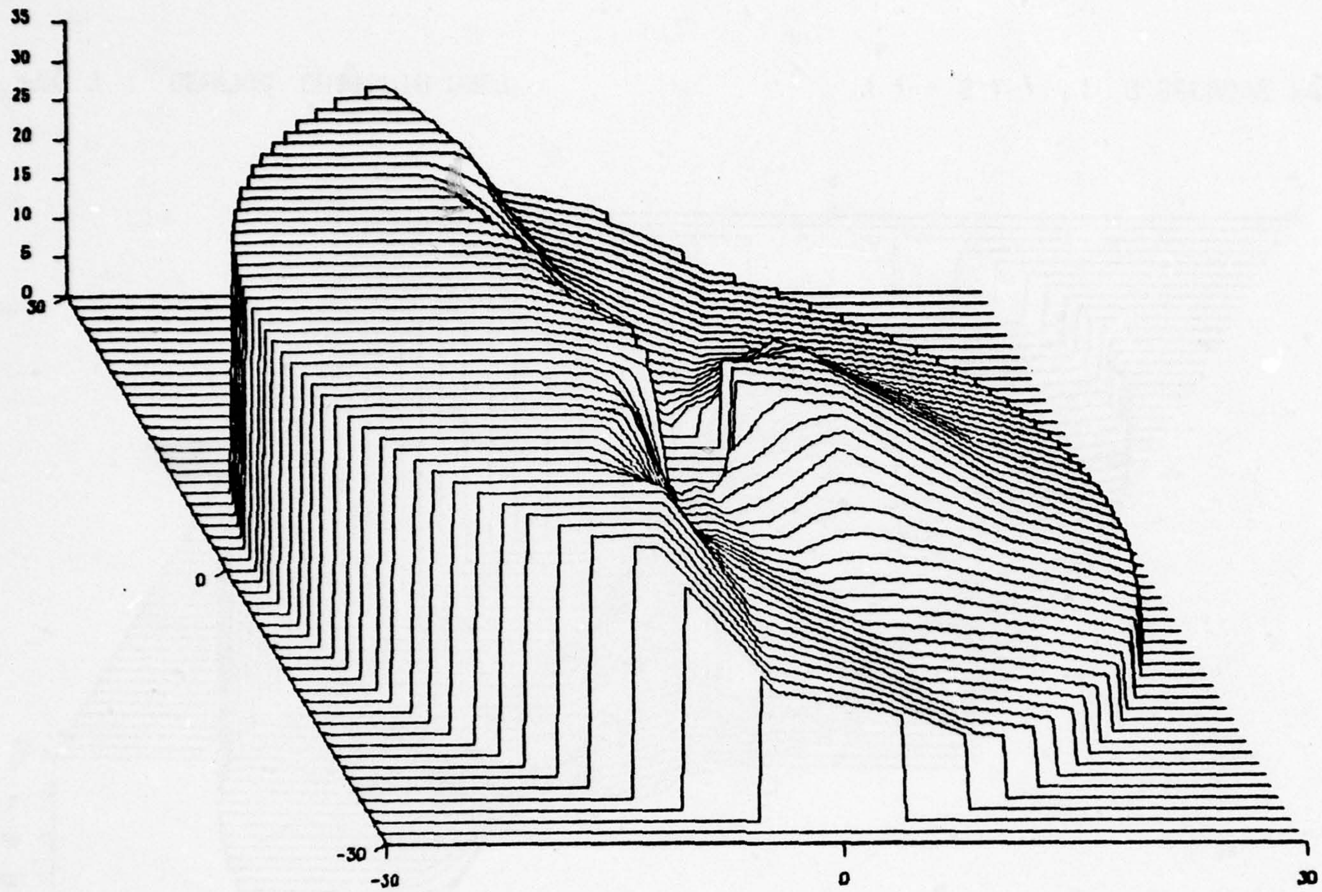
		NORTH ATLANTIC	
		SUMMER	WINTER
GENERAL CRITERIA ONLY	(1 - 6)	0.95	0.62
GENERAL AND HELICOPTER CRITERIA	(1 - 9)	0.83	0.61
GENERAL AND DOME EMERGENCE CRITERIA	(1 - 6, 10)	0.95	0.61
ALL SEAKEEPING CRITERIA	(1 - 10)	0.83	0.61
5 KNOTS		0.77	0.49
10 KNOTS		0.82	0.59
15 KNOTS		0.87	0.67
20 KNOTS		0.87	0.66
25 KNOTS		0.84	0.62



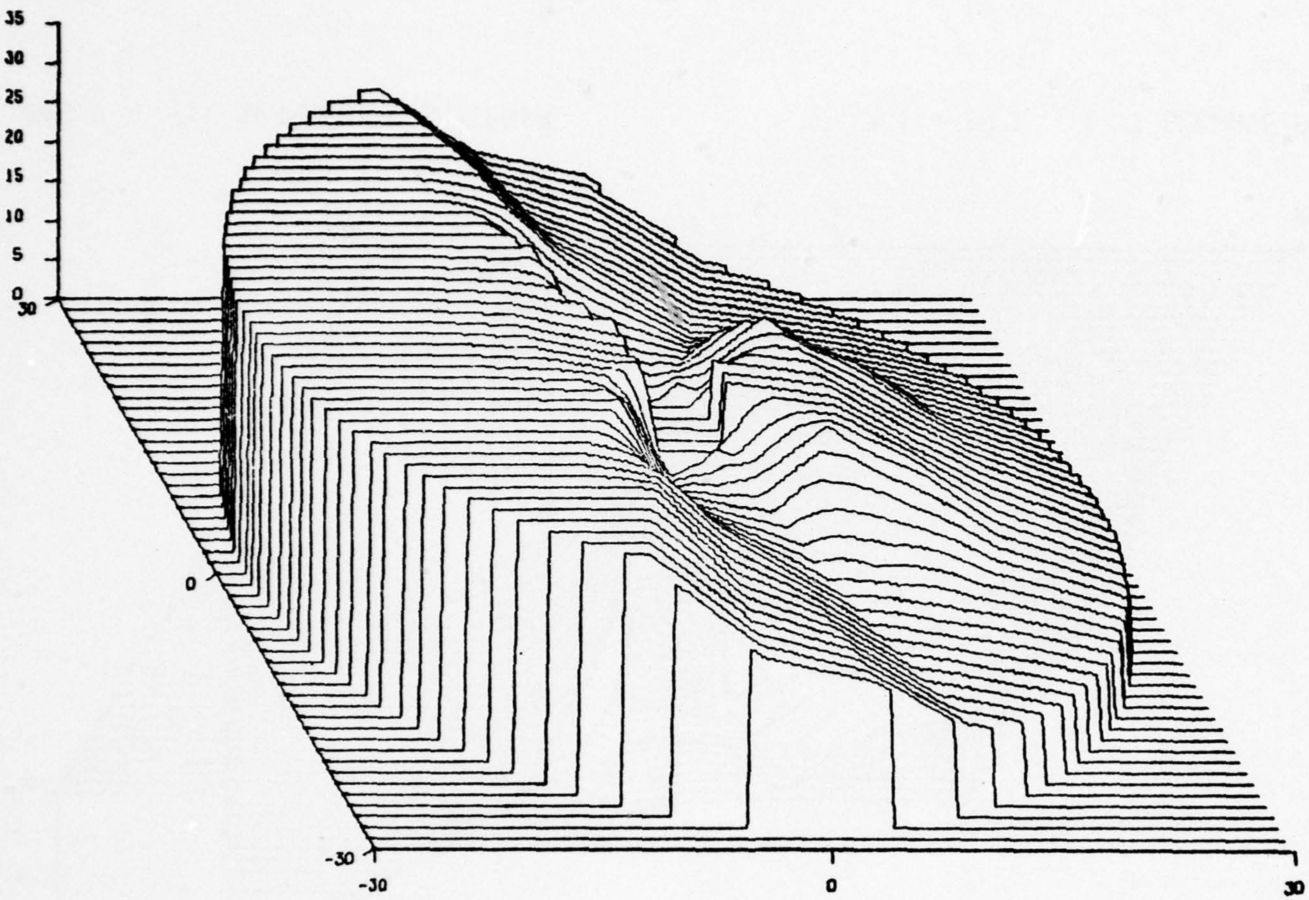
FFG 7 GENERAL CRITERIA ONLY (1 - 6) (7 SECWAVE PERIOD)



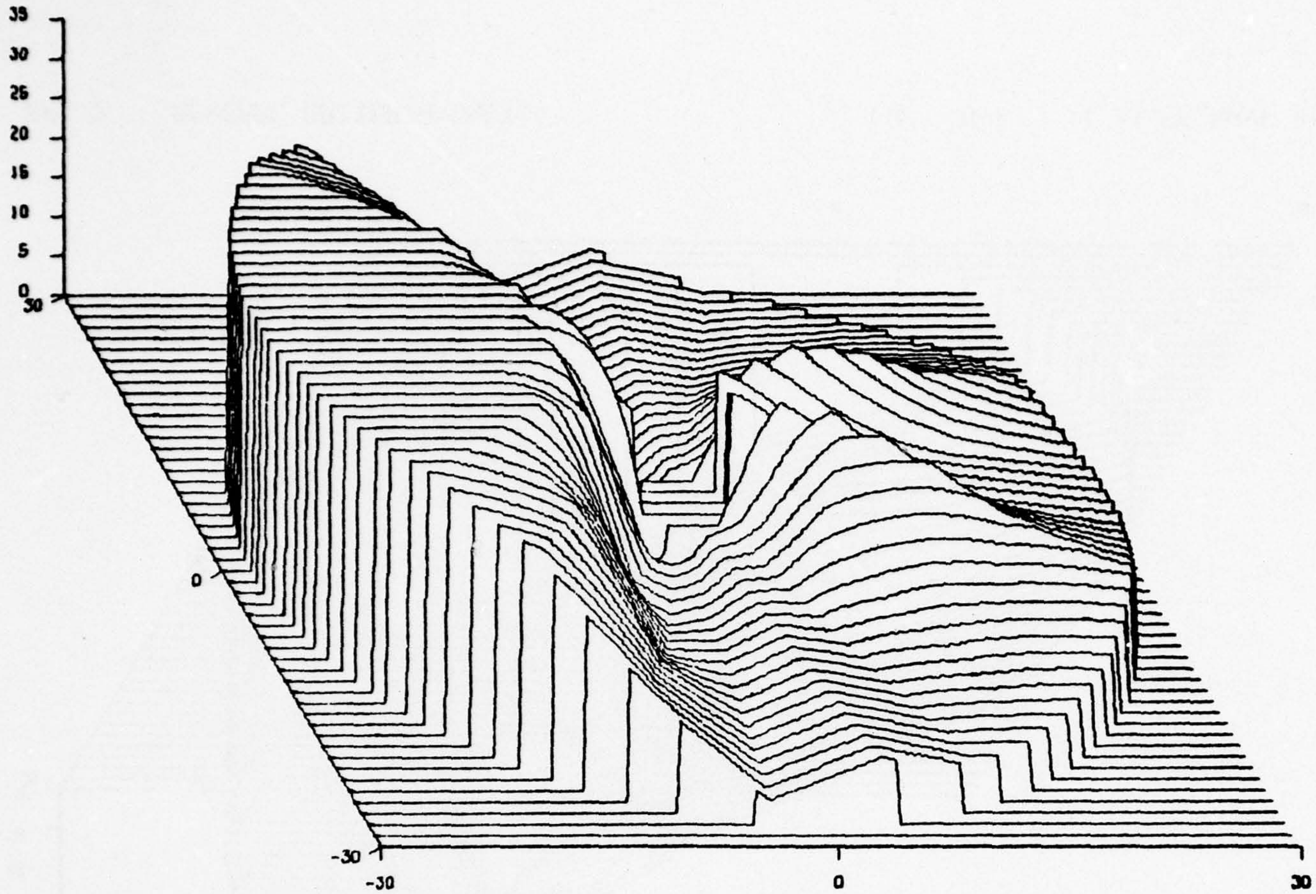
FFG 7 GENERAL CRITERIA ONLY (1 - 6) (9 SECWAVE PERIOD)



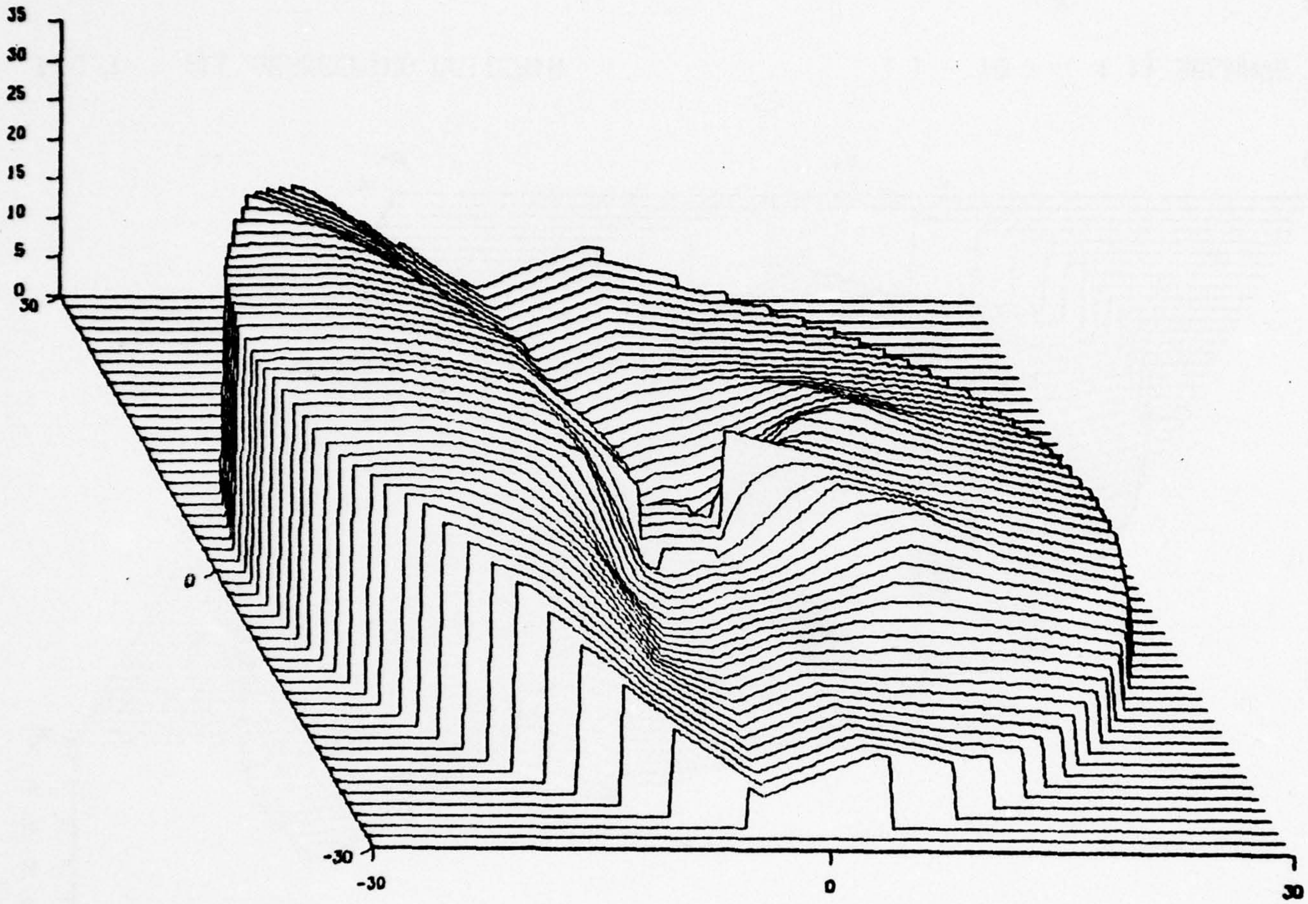
FFG 7 GENERAL CRITERIA ONLY (1 - 6) (11 SECWAVE PERIOD)



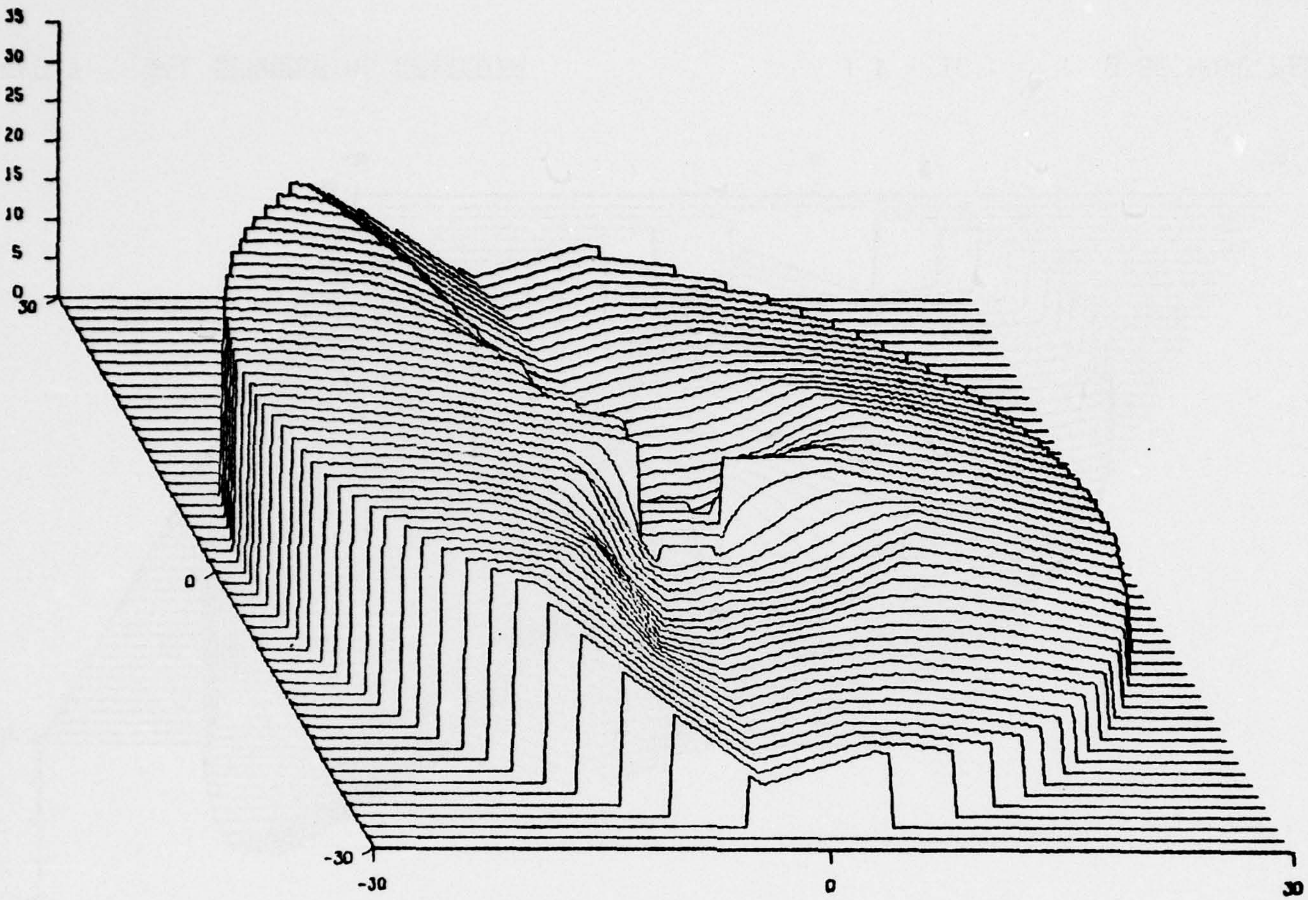
FFG 7 GENERAL CRITERIA ONLY (1 - 6) (13 SECWAVE PERIOD)



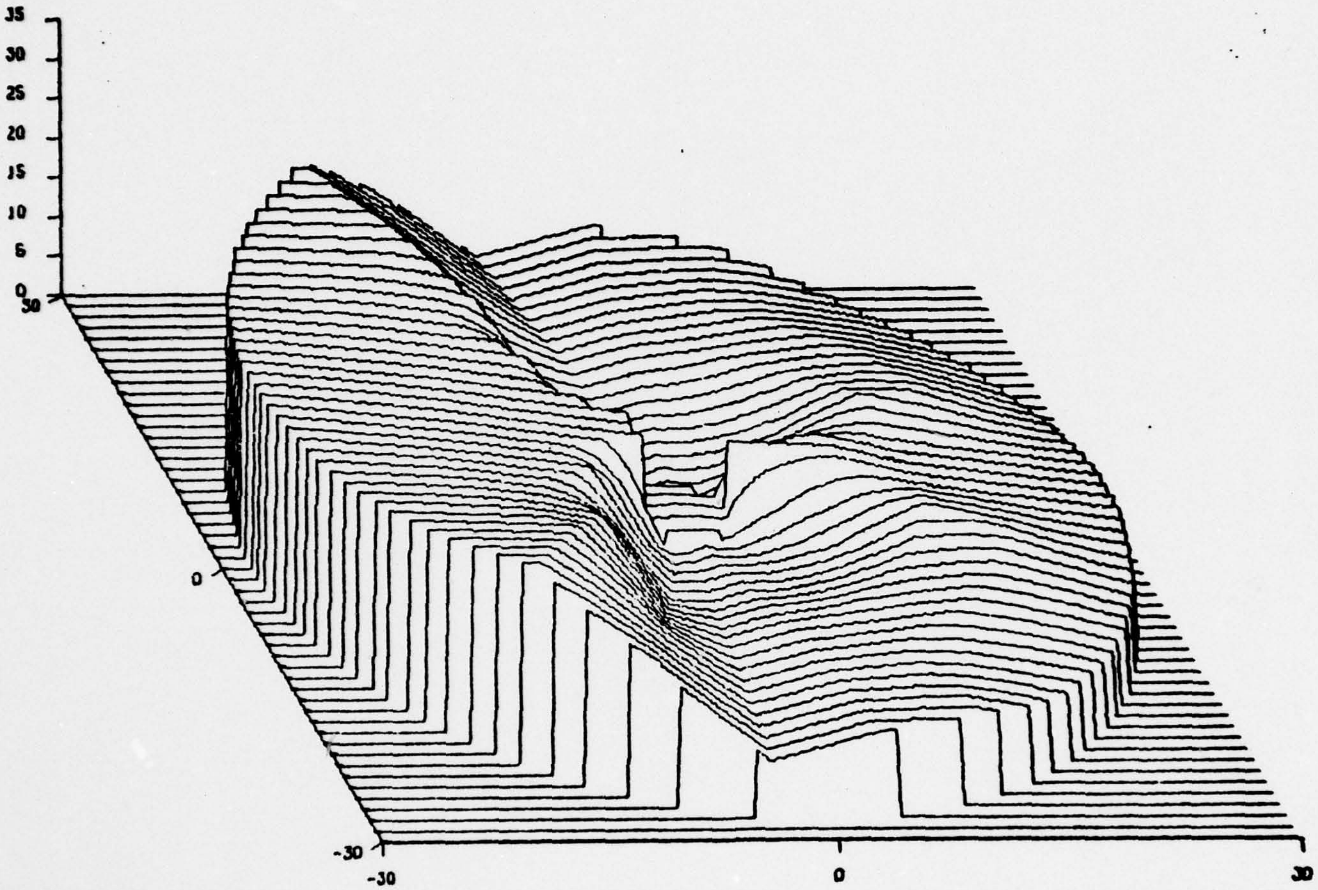
FFG 7 ALL SEAKEEPING CRITERIA (1 - 10) (7 SECWAVE PERIOD)



FFG 7 ALL SEAKEEPING CRITERIA (1 - 10) (9 SECWAVE PERIOD)



FFG 7 ALL SEAKEEPING CRITERIA (1 - 10) (11 SECWAVE PERIOD)



FFG 7 ALL SEAKEEPING CRITERIA (1 - 10) (13 SECWAVE PERIOD)

APPENDIX D

PLOT3D PROGRAM LISTING

PLOT3D

CNA PROGRAM 27-73S

CALL PLOT3D (XMIN,XMAX,DX,YMIN,YMAX,DY,ZMIN,ZMAX,DZ,TITLE,NC,F,DABOVEXY, DLEFTXY)

XMIN = Minimum value labelled on the X-axis

XMAX = Maximum value labelled on the X-axis

DX = Value between tic marks on X-axis

YMIN = Minimum value labelled on the Y-axis

YMAX = Maximum value labelled on the Y-axis

DY = Value between tic marks on Y-axis. Because of the Y-axis scaling algorithm, the values at the tic marks will be "reasonable" only if MOD (YMAX-YMIN), 50) = Ø.

ZMIN = Minimum value labelled on the Z-axis

ZMAX = Maximum value labelled on the Z-axis

DZ = Value between tic marks on Z-axis

TITLE = Name of array of BCD words to be used as graph title.

NC = Number of characters in TITLE. If NC = 0, no graph title will be plotted. If NC = 1, the X, Y, Z-axes will not be drawn or labelled. (NC < 88)

F = The name of a continuous function in the form: Z = F(X,Y)

The calling program must use:

EXTERNAL F

if the function is not a statement function.

DABOVEXY = Degrees above the XY plane for the viewing eye. -90.<DABOVEXY<90.

DLEFTXY = Degrees to the left of the XY plane for the viewing eye. 0.<DLEFTXY<90.

The suggested viewing angle is:

DABOVEXY = 60.0
DLEFTXY = 30.0

```
      SUBROUTINE PLOT3D (XMIN,XMAX,DX,YMIN,YMAX,DY,ZMIN,ZMAX,DZ,TI,NC,F,
     *                   DABOVEXY,DLEFTXY)
      DIMENSION X(250),Y(250),XG(1000),G(1000),XH(1000),H(1000),
     *          XG1(1000),G1(1000),TI(1)
      CALL NEW PLOT
      ZZ=90.-DABOVEXY
      ZLNTH=(ZZ*6)/90.
      ZZNTH=ZLNTH  $  IF (ABSF(ZLNTH).GT.6)  ZZNTH=ABSF(ZLNTH)-6.
      IF (DLEFTXY.LT.90) XLNTH=TANF(DLEFTXY*.0174532925)*ABSF(6.-ZZNTH)
      IF (DLEFTXY.GE.90)  XLNTH=9
      XLNTH=9-XLNTH
      NG=0  $  NG1=-3
      N=250  $  N1=-N
C     NFNS=50  $  MAXDIM=1000
      NFNS=51  $  MAXDIM=1000
      CN=NC $ XLNTH=SIGNF(XLNTH,CN) $ ZLNTH=SIGNF(ZLNTH,CN)
      DELTAX=(XMAX-XMIN)/ABSF(XLNTH)
      DELTAZ=(ZMAX-ZMIN)/ABSF(ZZNTH)
C     VDX=(XMAX-XMIN)/250.  $  VDY=(YMAX-YMIN)/50. $ IDY=DY/VDY+.999
      VDX=(XMAX-XMIN)/250.  $  VDY=(YMAX-YMIN)/(NFNS-1)
      DO 500 I=1,1000
  500 XG(I)=G(I)=XH(I)=H(I)=XG1(I)=G1(I)=0
      V=XMIN  $  LX=N  $  DO 10 I=1,LX  $  X(I)=V
   10 V=V+VDX  $  LY=NFNS  $  V=YMIN  $  DO 3 I=1,LY  $  YY=V $ V=V+VDY
      DO 12 J=1,LX
      Y(J)=F(X(J),YY)
   12 CONTINUE
      CALL HIDE(X,Y,XG,G,XH,H,NG,MAXDIM,N,NFNS,TI,XLNTH,ZLNTH,XMIN,
C    *          DELTAX,ZMIN,DELTAZ,1,XMIN,XMAX,DX,YMIN,YMAX,VDY,IDY,ZMIN,
     *          DELTAX,ZMIN,DELTAZ,1,XMIN,XMAX,DX,YMIN,YMAX,VDY, DY,ZMIN,
     *           ZMAX,DZ,NC)
      CALL HIDE (X,Y,XG1,G1,XH,H,NG1,MAXDIM,N1,0,6HNOTTLE,XLNTH,ZLNTH,
C    *     XMIN,DELTAX,ZMIN,DELTAZ,0,XMIN,XMAX,DX,YMIN,YMAX,VDY,IDY,ZMIN,
     *     XMIN,DELTAX,ZMIN,DELTAZ,0,XMIN,XMAX,DX,YMIN,YMAX,VDY, DY,ZMIN,
     *           ZMAX,DZ,NC)
    3 CONTINUE  $  CALL PLOT OFF (ABSF(ZLNTH))   $  END
```

```
      SUBROUTINE HIDE (X,Y,XG,G,XH,H,NG,MAXDIM,N1,NFNS,TITLE,XLNTH,
     *               YYYYLNTH,XMIN,DELTAX,YMIN,DELTAY,ITOPBOT,XXMIN,XXMAX,
C    *                      XDX,YYMIN,YYMAX,YDY,IYDY,ZZMIN,ZZMAX,ZDZ,NCTITLE)
     *                      XDX,YYMIN,YYMAX,YDY,  DY,ZZMIN,ZZMAX,ZDZ,NCTITLE)
      DATA (EPS1=.0000000001),(NOTTLE=6HNOTTLE)
      DIMENSION X(1),Y(1),XG(1),G(1),H(1),XH(1),TITLE(1)
      INTEGER TITLE
      EQUIVALENCE (K1,IWHICH),(K2,SLOPE),(FNSM1,Z1),(IGGP1,K1),(K1,N2)
      F(XX,XI,YI,XIP1,YIP1)=YI+(XX-XI)*(YIP1-YI)/(XIP1-XI)
      YLNTH=YYYYLNTH
      IF (ABSF(YYYYLNTH).GT.6) YLNTH=SIGNF(ABSF(YYYYLNTH)-6.,YYYYLNTH)
      IF (MAXDIM.LE.0)  RETURN
      DO 71 I=2,N1
      IF (X(I-1).LT.X(I))  GO TO 71
      MAXDIM=0  $  GO TO 75
   71 CONTINUE
      IFPLOT=1
      IF (N1.GT.0)  GO TO 76
      N1=-N1
      IFPLOT=0
   76 IF(NG.GT.0) GO TO 5000
      IF(N1+4.LE.MAXDIM) GO TO 74
      MAXDIM = -MAXDIM
   75 RETURN
   74 SIGN = 1.
      IF(NG.LT.-1) SIGN = -1.
      IF(NFNS.LE.0) GO TO 46
      FNSM1 = NFNS-1
      DXIN = (9.-ABS(XLNTH))*DELTAX/FNSM1
      DYIN = (6.-ABS(YLNTH))*DELTAY/FNSM1
      IF (ABSF(YYYYLNTH).GT.6) DYIN=-DYIN
   46 IF(NG.EQ.-1.OR.NG.EQ.-3) GO TO 41
      CALL PLOTZ8Z4 (11.,0.,2)
      CALL PLOTZ8Z4 (11.,8.5,1)
      CALL PLOTZ8Z4 (0.,8.5,1)
      CALL PLOTZ8Z4 (0.,0.,1)
      IF (ABSF(YYYYLNTH).LE.6)  CALL PLOTZ8Z4 (1.,2.0,-3)
      IF (ABSF(YYYYLNTH).GT.6)  CALL PLOTZ8Z4 (1.,5.0,-3)
   41 IF(TITLE(1).NE.NOTTLE.AND.NCTITLE.GT.0)  CALL PSYMB (-.28,-1.,.14,
     *TITLE,0.,NCTITLE)
      IF(XLNTH.LT.0.) GO TO 42
      IF (ITOPBOT.NE.1)  GO TO 42
      IF (XLNTH.EQ.0.)  GO TO 4040
      CALL PAXIS (9.-XLNTH,0.,XLNTH,00.,XXMIN,XXMAX,XDX)
 4040 IF(YLNTH.LT.0.) GO TO 43
      IF (ITOPBOT.NE.1)  GO TO 43
      IF (XLNTH.EQ.9.0.AND.YLNTH.EQ.6.0)  GO TO 42
      IF (XLNTH.EQ.0.OR.YLNTH.EQ.0)  GO TO 42
C     CALL PAXISY (9.-XLNTH,0.,0.,6.-YYYYLNTH,NFNS,YYMIN,YDY,IYDY)
      CALL PAXISY (9.-XLNTH,0.,0.,6.-YYYYLNTH,NFNS,YYMIN,YDY,  DY)
   42 IF(YLNTH.LT.0.) GO TO 43
      IF (ITOPBOT.NE.1)  GO TO 43
      IF (YLNTH.EQ.0.)  GO TO 43
      CALL PAXIS (0.,6.-YYYYLNTH,YLNTH,90.,ZZMIN,ZZMAX,ZDZ)
   43 INDEXT=3
```

```
      DO 3 J = 1,N1
      XG(INDEXT) = X(J)
      G(INDEXT) = SIGN*Y(J)
    3 INDEXT = INDEXT+1
      EPS = EPS1*(ABS(XMIN)+ABS(DELTAX))
      NG = N1+4
      XG(1) = -FNSM1*DXIN+XMIN-ABS(XMIN)-ABS(XG(3))-1.
      XG(2) = XG(3)-EPS
      XG(N1+3) = XG(N1+2)+EPS
      ZZ=YMIN
      IF(SIGN.LT.0.) ZZ = -YMIN-50.*DELTAY
      G(1)=G(2)=G(N1+3)=G(NG)=ZZ
      XSTART = XMIN-(9.-ABS(XLNTH))*DELTAX
      IF(IFPLCT.EQ.1) CALL POATA(X,Y,N1,0,1,XSTART,DELTAX,
     1         YMIN,DELTAY,.07,1,ITOPBOT,ABSF(YYYYLNTH))
      DXKK=DYKK=0
      RELINC = DELTAX/DELTAY
      XG(NG) = SIGN
      RETURN
 5000 SIGN=XG(NG)  $  XG(NG)=X(N1)
      IF(NFNS) 52,48,49
   49 DXKK = DXKK+DXIN
      DYKK = DYKK+DYIN
   48 DO 4 J = 1,N1
      Y(J) = SIGN* (Y(J)+DYKK)
    4 X(J) = X(J)-DXKK
   52 CALL LOOKUP (X(1),XG(1),JJ)
      IF(JJ.GE.MAXDIM) GO TO 700
      DO 31 J= 1,JJ
      XH(J) = XG(J)
   31 H(J) = G(J)
      IG = JJ+1
      XH(IG) = X(1)
      H(IG) = F(X(1),XG(JJ),G(JJ),XG(IG),G(IG))
      INDEXG = JJ
      INDEXT = 1
      Z1 = X(1)
      F1 = H(IG)-Y(1)
      IT = 2
      JJ = IG
      IF(H(IG).GE.Y(1)) GO TO 32
      IF(JJ.GE.MAXDIM) GO TO 700
      JJ = IG+1
      H(JJ) = Y(1)
      XH(JJ) = Z1+EPS
   32 LAST = 0
      X1 = Z1
 1100 IF(XG(IG).LT.X(IT)) GO TO 1001
      IWHICH = 0
      X2 = X(IT)
      F2 = F(X2,XG(IG-1),G(IG-1),XG(IG),G(IG))-Y(IT)
      IT = IT+1
      GO TO 1002
 1001 X2 = XG(IG)
      IWHICH = 1
```

```
      F2 = G(IG)-F(X2,X(IT-1),Y(IT-1),X(IT),Y(IT))
      IG = IG+1
 1002 IF(F1*F2.GT.0.) GO TO 1005
      SLOPE = (F2-F1)/(X2-X1)
      IGG = IG-1-IWHICH
      ITT =IT-2+IWHICH
      IF(ABS(SLOPE*RELINC).GT.1.E-6) GO TO 1007
      Z2 = X2
      GO TO 1006
 1007 Z2 = X1-F1/SLOPE
      GO TO 1006
 1005 X1 = X2
      F1 = F2
      IF(IT.LE.N1) GO TO 1100
 1008 LAST = 1
      Z2 = X(N1)
      CALL LOOKUP(Z2,XG(INDEXG),IGG)
      IGG = INDEXG+IGG-1
      ITT = N1-1
 1006 ZZ = .99*Z1+.01*Z2
      CALL LOOKUP(ZZ,X(INDEXT),K1)
      CALL LOOKUP(ZZ,XG(INDEXG),K2)
      K1 = K1+INDEXT-1
      K2 = K2+INDEXG-1
      IF(F(ZZ,X(K1),Y(K1),X(K1+1),Y(K1+1)).GT.
     1   F(ZZ,XG(K2),G(K2),XG(K2+1),G(K2+1))) GO TO 7
      IF(JJ+IGG-INDEXG.GE.MAXDIM) GO TO 700
      IF(INDEXG.EQ.IGG) GO TO 712
      J1 = INDEXG+1
      DO 12 I = J1,IGG
      JJ = JJ+1
      XH(JJ) = XG(I)
   12 H(JJ) = G(I)
  712 JJ = JJ+1
      XH(JJ) = Z2
      H(JJ) = F(Z2,XG(IGG),G(IGG),XG(IGG+1),G(IGG+1))
      INDEXG = IGG
      INDEXT = ITT
      GO TO 60
    7 NGRAPH = ITT-INDEXT+2
      IF (JJ+NGRAPH-1.GT.MAXDIM) GO TO 700
      N2 = JJ
      IF(NGRAPH.EQ.2) GO TO 9
      J1 = INDEXT+1
      DO 11 I = J1,ITT
      JJ = JJ+1
      XH(JJ) = X(I)
   11 H(JJ) = Y(I)
    9 JJ = JJ+1
      XH(JJ) = Z2
      H(JJ) = F(Z2,X(ITT),Y(ITT),X(ITT+1),Y(ITT+1))
      IF(IFPLOT.EQ.1) CALL PDATA(XH(N2),H(N2),NGRAPH,0,1,
     1XSTART,DELTAX,SIGN*YMIN,SIGN*DELTAY,.07,N2,ITOPBOT,ABSF(YYYYLNTH))
      INDEXT = ITT
      INDEXG = IGG
```

AD-A045 443 CENTER FOR NAVAL ANALYSES ARLINGTON VA SYSTEMS EVALUA--ETC F/G 13/10
A METHODOLOGY FOR QUANTIFYING THE OPERATIONAL EFFECTS OF SHIP S--ETC(U)
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```
 60 IF(LAST.EQ.1) GO TO 61
    X1 = X2
    F1 = F2
    Z1 = Z2
    IF(IT.LE.N1) GO TO 1100
    GO TO 1008
 61 IF(XG(NG).LE.XG(NG-1)) NG = NG-1
    IF(XG(NG).LE.X(N1)) GO TO 33
    IF(JJ+3+NG-IGG.GT.MAXDIM) GO TO 700
    XH(JJ+1) = XH(JJ)+EPS
    JJ = JJ+1
    H(JJ) = F(X(N1),XG(IGG),G(IGG),XG(IGG+1),G(IGG+1))
    IGGP1 = IGG+1
    DO 34 J = IGGP1,NG
    JJ = JJ+1
    XH(JJ) = XG(J)
 34 H(JJ) = G(J)
 33 NG = JJ+2
    IF(NG.GT.MAXDIM) GO TO 700
    DO 13 I = 1,JJ
    G(I) =H(I)
 13 XG(I) = XH(I)
    XG(JJ+1) = XG(JJ)+EPS
    G(JJ+1) = YMIN+DYKK
    IF(SIGN.LT.0.) G(JJ+1) = -YMIN-50.*DELTAY+DYKK
    G(NG) = G(JJ+1)
 66 IF(NFNS.LT.0) GO TO 53
    DO 82 I = 1, N1
    X(I) = X(I)+DXKK
 82 Y(I) = SIGN*Y(I)-DYKK
 53 XG(NG) = SIGN
    RETURN
700 MAXDIM = -MAXDIM
    GO TO 66
    END
```

```
      SUBROUTINE LOOKUP(X,XTBL,J)
      DIMENSION XTBL(1)
      J = 2
    4 IF(XTBL(J)-X) 1,2,3
    1 J = J+1
      GO TO 4
    2 RETURN
    3 J = J-1
      END
```

```
      SUBROUTINE PDATA (X,Y,N,J,L,XMIN,DX,YMIN,DY,HT,ISA,ITOPBOT,YYYLNT)
      DIMENSION X(1),Y(1)
      IF (YYYLNT.GT.6) 90,91
   91 YYMAX=6.5  $  YYMIN=-2.  $  GO TO 92
   90 YYMAX=3.5  $  YYMIN=-5.
   92 XXMAX=10. $ XXMIN=-1. $ XSCALER=YSCALER=1.
      NP=0  $  IND=3  $  DO 1 I=1,N
      Z1=(Y(I)-YMIN)/DY*YSCALER
      X1=(X(I)-XMIN)/DX*XSCALER
      IF (Z1.LT.YYMIN.OR.Z1.GT.YYMAX.OR.X1.LT.XXMIN.OR.X1.GT.XXMAX) 2,3
    2 IND=2  $  IF (NP-5)    13,12,1
   12 PRINT 60  $  GO TO 14
   60 FORMAT(*0AFTER  5 POINTS OUT OF RANGE, PRINTING IS DISCONTINUED.*)
   13 IF (NP.EQ.0)  PRINT 26
   26 FORMAT(*0  *)
      PRINT 25,X(I),Y(I),XMIN,YMIN,DX,DY
   25 FORMAT(* POINT OUT OF RANGE     X =*,E10.2,*     Y =*,E10.2,
     ** XMIN =*,E10.2,*   YMIN =*,E10.2,*   DX =*,E10.2,*   DY =*,E10.2
     **)
   14 NP=NP+1
      IF (Z1.LT.YYMIN) Z1=YYMIN $ IF (Z1.GT.YYMAX) Z1=YYMAX
      IF (X1.LT.XXMIN) X1=XXMIN $ IF (X1.GT.XXMAX) X1=XXMAX
    3 CALL PLOTZ8Z4 (X1,Z1,IND)  $  IND=2
    1 CONTINUE  $  END
```

```
      SUBROUTINE PSYMB  (X,Y,HT,T,TH,N)
      CALL SYMBOL       (X,Y,HT,T,TH,N)
      END
```

```
      SUBROUTINE PAXIS (X,Y,S,THETA,FMIN,FMAX,DF)
      DIMENSION IB(2)
      DCON=.01745329252
      XI=SINF(THETA*DCON)        $ YI=COSF(THETA*DCON)
      XX=X  $  YY=Y  $  V=FMIN  $  XIN=S/((FMAX-FMIN)/DF)
      IS = (FMAX-FMIN)/DF+1  $  ISW=1
      CALL PLOTZ8Z4 (X,Y,3)  $  CALL PLOTZ8Z4 (X,Y,2)  $  DO 1 I=1,IS
    3 CALL PLOTZ8Z4 (XX,YY,2)
      CALL PLOTZ8Z4 (XX-.10*XI,YY-.10*YI,1)  $  CALL TICVAL (V,IB,N)
      CALL SYMBOL (XX-(N/30.)*YI-(N/15.+.25)*XI,YY-.3*YI,.08,IB,0.,N)
      CALL PLOTZ8Z4 (XX,YY,3)  $  V=V+DF  $  XX=XX+YI*XIN
      YY=YY+XI*XIN  $  GO TO (1,2),ISW
    1 CONTINUE       $  IF (V-DF.GE.FMAX)  GO TO 2
      IF (XX.GT.X+S)      XX=X+S  $  V=FMAX
      IF (YY.GT.Y+S)  YY=Y+S  $  ISW=2  $  GO TO 3
    2 CALL PLOTZ8Z4 (0.,0.,3)  $  END


      SUBROUTINE PLOT OFF (Z)
      IF (Z.LE.6)  CALL PLOTZ8Z4 (-1.,-2.,-3)
      IF (Z.GT.6)  CALL PLOTZ8Z4 (-1.,-5.,-3)
      CALL PLOTZ8Z4 (0,0,0)
      END


      SUBROUTINE NEW PLOT
      DIMENSION ISEQ(2)
      DATA (ISEQ=8H SEQ NO ),(IENTRY=1)
      IF (IENTRY)  CALL SEQPL (ISEQ(2))  $  IENTRY=0
      CALL SKPFRM
      CALL SYMBOL (.25,8.5,.1,ISEQ,0.,12)
      CALL PLOTZ8Z4 (0.,0.,3)
      END


      SUBROUTINE TIC VAL (X,IBCD,NC)  $  DIMENSION IBCD(2)
      IBCD(2)=1H  $  IE=500  $  CALL GAWCODE (X,IBCD,IE,NC)
      IF (IE.EQ.0)RETURN $ EE=IE $ IEE=500 $ CALL GAWCODE(EE,IT,IEE,NCH)
      CALL MOVE(1HE,1,IBCD,NC+1,1) $ CALL MOVE(IT,1,IBCD,NC+2,NCH)
      NC=NC+NCH+1  $  END
```

```
      SUBROUTINE PAXISY(X1,Y1,X2,Y2,N,FMIN,DF,DDY)
C     SUBROUTINE PAXISY(X1,Y1,X2,Y2,N,FMIN,DF,INC)
      DIMENSION IB(2)
      DIST = SQRTF((X2-X1)**2+(Y2-Y1)**2)  $  CD=0
C     DELTA=DIST/(N-1.)*INC
      DELTA=DIST*DDY/((N-1)*DF)
      SLOPE=(Y2-Y1)/(X2-X1)  $  IF (X2.EQ.X1)  SLOPE=1E300
      XX=X1  $  YY=Y1  $  V=FMIN
      CALL PLOTZ8Z4 (XX,YY,3)  $  CALL PLOTZ8Z4 (XX,YY,2)
    3 X=XX-SQRTF(.01/((-1/SLOPE)**2+1))
      Y=YY+(-1/SLOPE)*(X-XX)
      CALL PLOTZ8Z4 (X,Y,1)  $  CALL TICVAL (V,IB,NN)
      CALL SYMBOL (X-(NN/15.+.06),Y-.06,.08,IB,0.,NN)
      CALL PLOTZ8Z4 (XX,YY,3)
C     V=V+DF*INC  $  IF (CD.GE.DIST)  GO TO 1
      V=V+DDY      $  IF (CD.GE.DIST)  GO TO 1
      CD=CD+DELTA  $  IF (CD.GT.DIST)  CD=DIST
      IF (CD.EQ.DIST)  V=FMIN+DF*(N-1)
      CALL PLCTZ8Z4 (XX,YY,2)
      XX=X1-SQRTF    (CD**2/(SLOFE**2+1))
      YY=Y1+SLOPE*(XX-X1)  $  CALL PLOTZ8Z4(XX,YY,1)  $  GO TO 3
    1 CALL PLOTZ8Z4 (0.,0.,3)  $  END
```