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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

Seakeeping Characteristics of the STRETCHED SSP

by

Alvin Gersten

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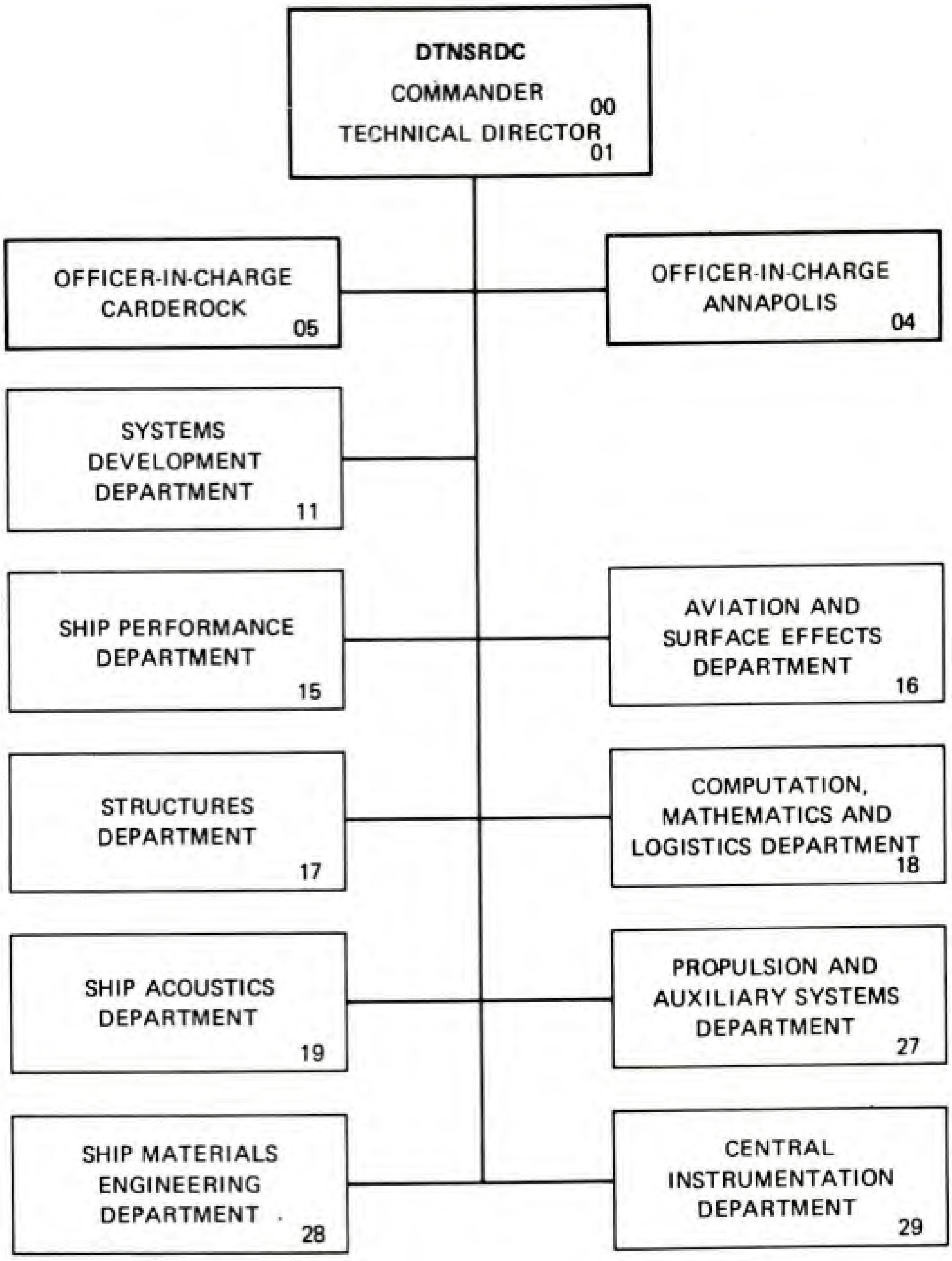

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Seakeeping experiments in calm water and regular and random waves have been conducted on a model representing a lengthened SSP KAIMALINO to evaluate its performance in severe seas. Several design modifications were examined such as large canards forward, replacement of the full-span aft stabilizer with large fins, and thick forward struts. The model was self-propelled, and incorporated manual control of speed and steering. Measurements were made of motions, accelerations and impact pressures. Significant values of measured variables and transfer functions are presented in this report. Impact induced accelerations are also given. Impact pressures are reported separately in Enclosure (4) to DTNSRDC ltr 1113:GRL Ser 3900 of 12 Mar 1981. It is determined that while the bridging structure will experience frequent impacts and the main deck will occasionally take on green water, the STRETCHED SSP appears to satisfy the requirement for survivability in extreme seas provided that: (a) the bridging structure is adequately strengthened; (b) large forward canards are installed; (c) propulsion intakes and exhausts are relocated; and (d) pilothouse windows are replaced with port holes and the structure on the forward face of the pilothouse is strengthened. In addition, it is recommended that NAVSEA issue an operator guidance document to minimize exposure of the STRETCHED SSP to operating modes with potential to cause structural damage in seas more severe than State 5.

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ABSTRACT

Seakeeping experiments in calm water and regular and random waves have been conducted on a model representing a lengthened SSP KAIMALINO to evaluate its performance in severe seas. Several design modifications were examined such as large canards forward, replacement of the full-span aft stabilizer with large fins, and thick forward struts. The model was self-propelled, and incorporated manual control of speed and steering. Measurements were made of motions, accelerations and impact pressures. Significant values of measured variables and transfer functions are presented in this report. Impact induced accelerations are also given. Impact pressures are reported separately in Encl (4) to DTNSRDC ltr 1113:GRL Ser 3900 of 12 Mar 1981. It is determined that while the bridging structure will experience frequent impacts and the main deck will occasionally take on green water, the STRETCHED SSP appears to satisfy the requirement for survivability in extreme seas provided that: (a) the bridging structure is adequately strengthened; (b) large forward canards are installed; (c) propulsion intakes and exhausts are relocated; and (d) pilothouse windows are replaced with port holes and the structure on the forward face of the pilothouse is strengthened. In addition, it is recommended that NAVSEA issue an operator guidance document to minimize exposure of the STRETCHED SSP to operating modes with potential to cause structural damage in seas more severe than State 5.

ADMINISTRATIVE INFORMATION

The investigation discussed herein was performed for NAVSEA Codes 03R12 and 3213 under the direction of the SWATH Ship Development Office in the Systems Development Department of DTNSRDC. Funding was provided under Work Unit Number 1100-500, Task Area S1332001.

INTRODUCTION

The SSP KAIMALINO, a small Waterplane Area Twin-Hull (SWATH) craft displacing 224 metric tons, is currently being operated by the Naval Ocean Systems Center (NOSC) in Hawaii. Although the seakeeping behavior of this craft is excellent, the small displacement severely limits its usefulness as a platform for evaluating heavy sensor payload equipment. In addition, the present endurance and transit range capabilities are quite limited. NOSC submitted a proposal to the Naval Sea Systems Command (NAVSEA) to remedy these limitations by lengthening the SSP in such a way that the displacement would be increased to 624 metric tons. Responsibility for the design of this modification was assigned to PMS 383 with SEA 03D48 as the Design Manager.

In May 1980 the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) was requested by SEA 03D48 and 3213 to conduct analytical studies and model tests in support of the design of the lengthened SSP. A dozen configurations designated "B" through "M" were proposed in a hydrodynamic design committee that reported their findings to SEA 03D48. At the conclusion of the study phase, configuration "Modified H" was selected for model testing. This "Modified H" configuration will henceforth be referred to in this report as the STRETCHED SSP.

NAVSEA 3213 requested that model experiments be carried out to evaluate the new design (STRETCHED SSP) in terms of seakeeping performance. Emphasis was placed on measuring slamming pressures on the cross-structure and bow, as well as model motions and accelerations, in severe seas. Sea severity up to mid-State 7 (9.15m significant wave height) was to be tested.

The experiments were conducted in the Maneuvering and Seakeeping Facility (MASK) at DTNSRDC during August 1980. In the course of these tests, several approaches to reduce motions -- particularly relative motion between the bow and oncoming waves (RBM) -- were evaluated. Reduced RBM generally leads to lower slamming loads. Devices that were evaluated include larger canards forward, large canards aft instead of a stabilizer spanning the distance between hulls, and more buoyancy forward obtained by increasing the forward strut thickness. In addition to tests in random waves simulating the expected operating environment, motion experiments were conducted in regular waves to obtain the motion transfer functions which can be used to validate/improve computerized prediction techniques. Calm water tests yielded information on natural periods and damping.

DESCRIPTION OF MODEL AND TEST EQUIPMENT

MODEL

A 1:24-scale model of STRETCHED SSP KAIMALINO was used for these experiments. Figure 1 shows a photograph of the model. Its lower hulls and struts were fabricated from sugar pine. The cross-sectional area of each hull is greatest near midship; transition cones lead to smaller diameter sections forward and aft. In the most forward region there is a bulbous "nose."

The demihulls are bridged by a flat mahogany marine plywood structure. At the forward end of the bridging structure there is a polyurethane foam deck house covered with fiberglass and epoxy. Aluminum stiffeners are mounted on the bridging structure.

Full scale dimensions of the STRETCHED SSP are given in Figure 2 and Table 1 (the latter also lists other principal characteristics of the design). The aft struts have a 42 ft-6 in. (13.0m) long parallel section joined to 8 ft (2.4m) long leading and trailing ogive sections. The forward struts have a 26 ft-6 in. (8.1m) long parallel section and 9 ft-3 in. (2.8m) long leading and trailing edges which are also ogive in shape. All struts have a maximum thickness of 4 ft (1.2m).

One D.C. electric motor was mounted in each lower hull to provide propulsive power. The motors had a rated power output of 92 watts and provided 32 oz-in. (2,304gm-cm) of torque at full load. Each motor drove a propeller mounted aft of its demihull. Propeller r.p.m. and, therefore, model speed was controlled manually from the main carriage. Manual control of the twin plexiglass rudders was also provided. Table 2 has the dimensions of all the appendages including the rudders.

With the capability of controlling both propulsion and steering from the carriage, the model was tested free-running, with no attachment to the carriage other than instrumentation cable umbilicals and light nylon safety lines (see Figure 3). The lines were kept slack during a normal run regardless of the severity of wave induced surge.

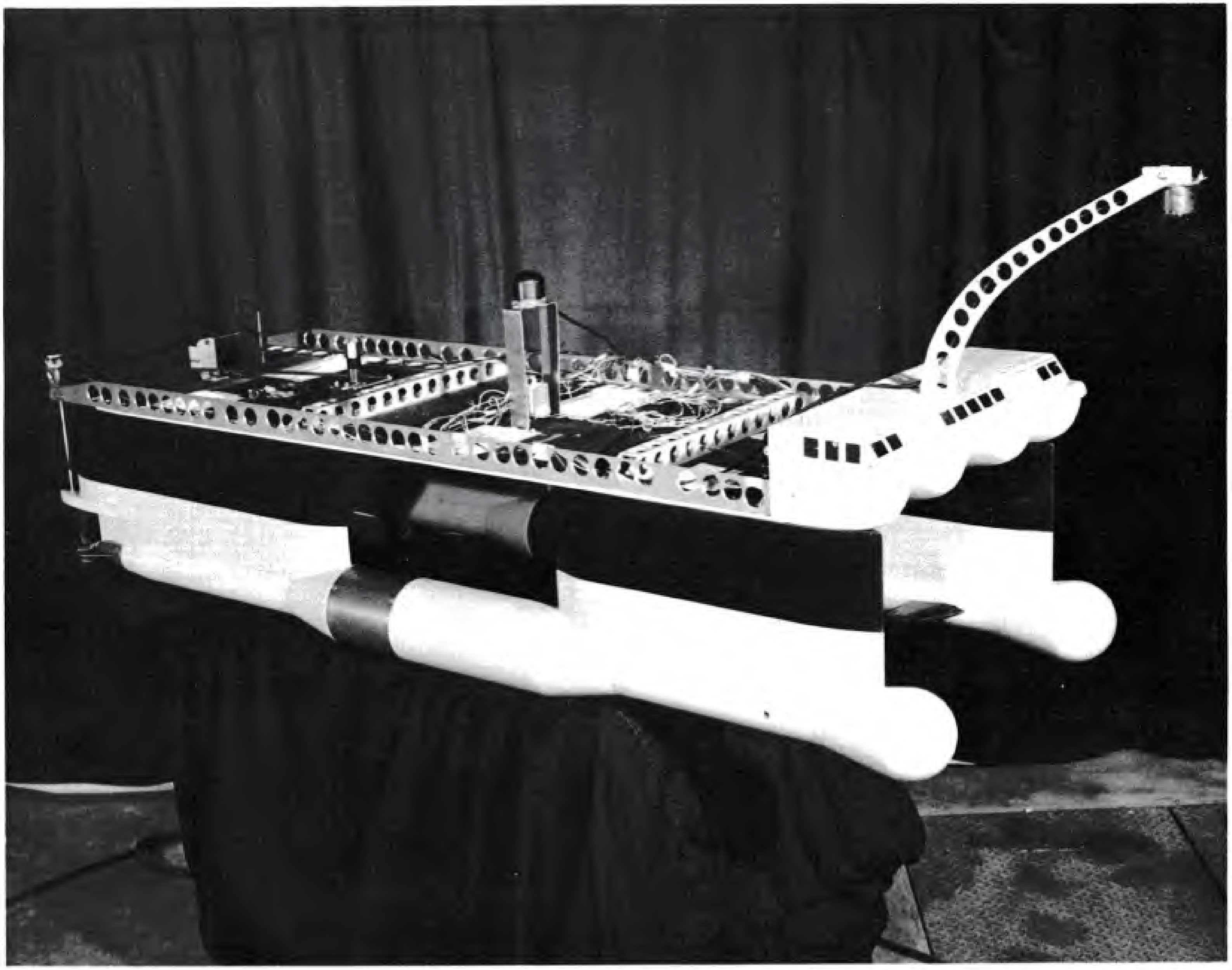


FIGURE 1—PHOTOGRAPH OF STRETCHED SSP MODEL

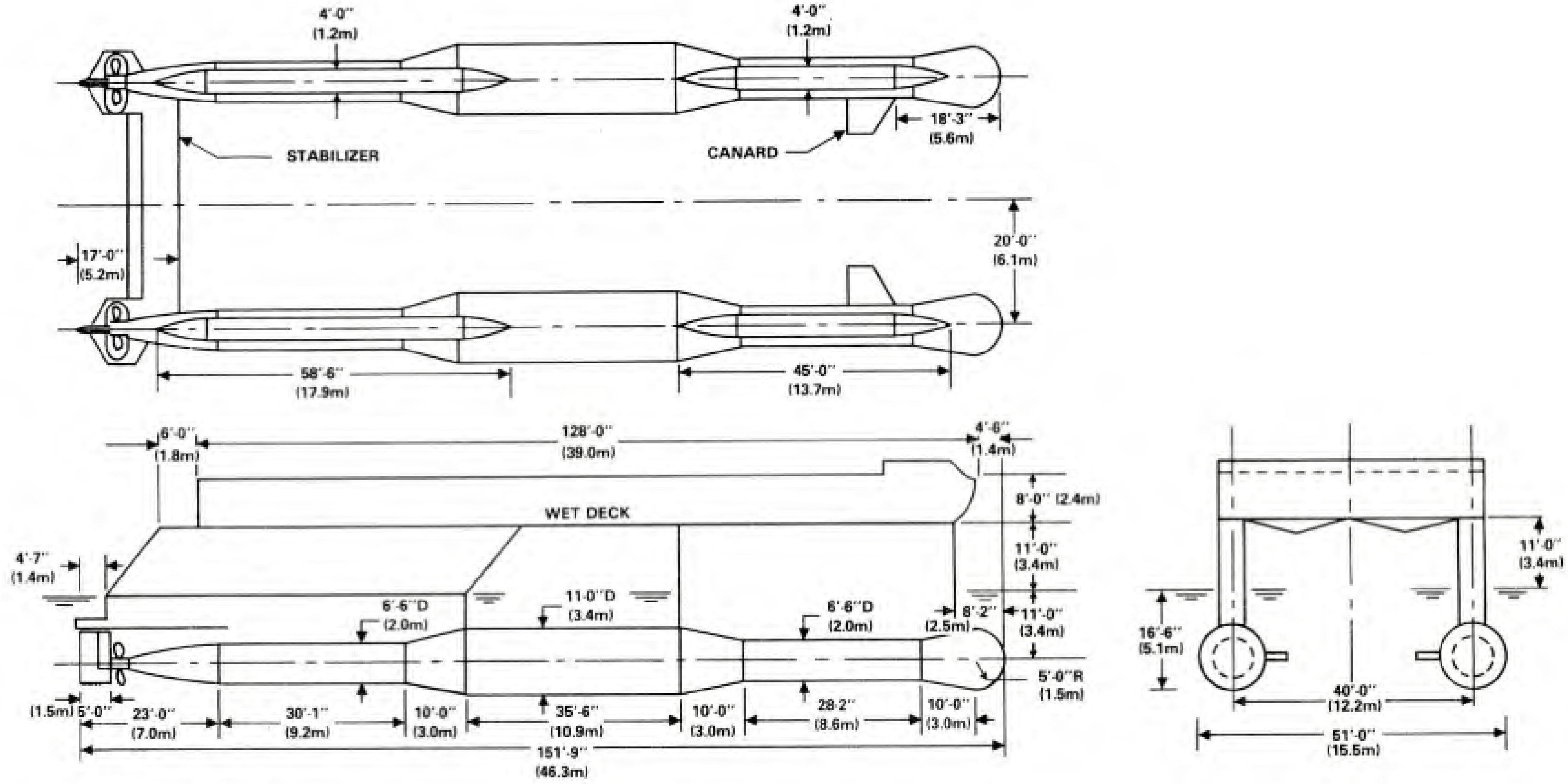


FIGURE 2 — STRETCHED SSP (FULL SCALE DIMENSIONS)

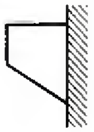
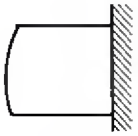
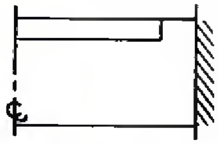
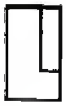
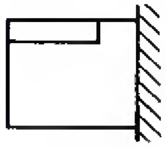
TABLE 1

PRINCIPAL STRETCHED SSP CHARACTERISTICS

	ENGLISH	METRIC
LENGTH OVERALL	149.1 ft	45.4 m
LENGTH AT THE WATERLINE	139.0 ft	42.4 m
MAXIMUM BEAM	51.0 ft	15.5 m
DRAFT	16.5 ft	5.0 m
DISTANCE BETWEEN HULL CENTERLINES	40.0 ft	12.2 m
DEPTH OF HULL CENTERLINE BELOW WL	11.0 ft	3.4 m
CROSS STRUCTURE CLEARANCE ABOVE WL	11.0 ft	3.4 m
DISPLACEMENT (DESIGN CONDITION)	614.4 long tons SW	624.2 metric tonnes
TOTAL STRUT WATERPLANE AREA	736 ft^2	68.4 m^2
LONGITUDINAL CENTER OF FLOTATION, AFT OF HULL NOSE	81.1 ft	24.7 m
LONGITUDINAL CENTER OF BUOYANCY, AFT OF HULL NOSE	71.8 ft	21.9 m
VERTICAL CENTER OF BUOYANCY, ABOVE KEEL	7.4 ft	2.3 m
TRANSVERSE $\overline{GM}$*	5.4 ft	1.6 m
LONGITUDINAL $\overline{GM}$*	50.5 ft	15.4 m
MASS DISTRIBUTION		
CG LOCATION:		
LONGITUDINAL, AFT OF LOWER HULL NOSE	72.3 ft	22.0 m
VERTICAL, ABOVE KEEL (DRY)	14.2 ft	4.3 m
LATERAL, OFF CENTERLINE	0 ft	0 m
PITCH RADIUS OF GYRATION*	40.8 ft	12.4 m
ROLL RADIUS OF GYRATION	18.5 ft	5.6 m

*AS TESTED

TABLE 2
APPENDAGE DIMENSIONS

APPENDAGE	CONFIGURATION PLATFORM	SPAN	CHORD	THICKNESS
SMALL CANARDS		6'-0" (1.8m)	8'-0"(max) (2.4m) 4'-0" (min) (1.2m)	0'-11"(max) (0.03m)
LARGE CANARDS		10'-10.6" (3.0m) - (3.2m)	9'-1" (2.8m)	1'-6"(max) (0.49m)
AFT STABILIZER		36'-0" (11.0m) FLAP: 29'-6" (9.0m)	8'-0" (2.4m) FLAP: 2'-0" (0.6m)	1'-7"(max) (0.5m)
HORN RUDDERS		9'-0" (2.7m)	5'-0" (1.5m)	0'-7" (0.02m)
SIMULATED LARGE AFT CANARDS		12'-0" (3.7 m) FLAP: 8'-9" (2.7 m)	8'-0" (2.4 m) FLAP: 2'-0" (0.6 m)	1'-7" (max) (0.5 m)

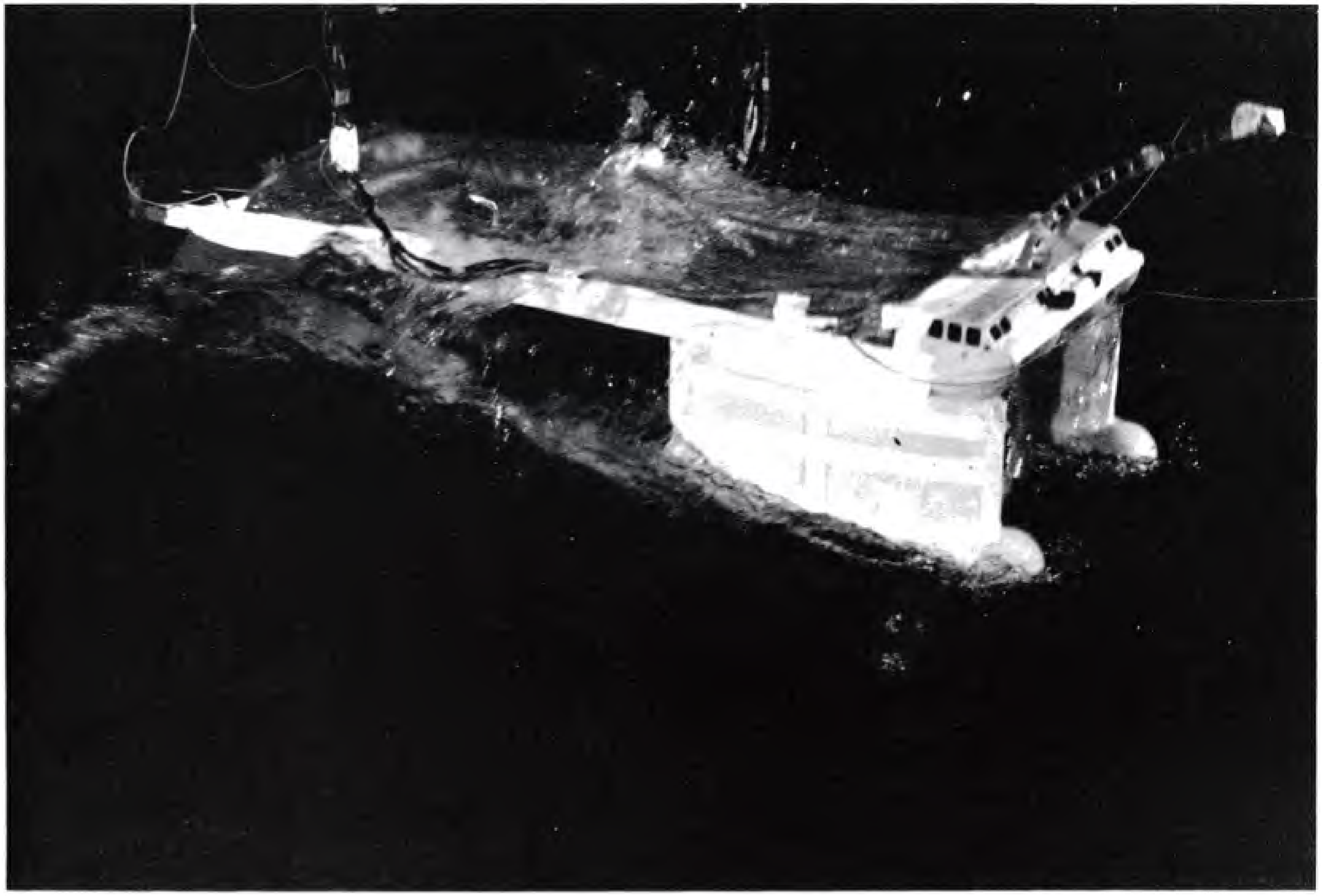


FIGURE 3 - MODEL UNDERWAY DURING A RUN

As can be seen in Figure 2, canard fins were fitted on the forward inboard side of each lower hull. Two canard sizes were investigated during the tests to determine if relative bow motion could be reduced by increasing size; their dimensions are given in Table 2. The smaller or "design" canards were used for most of the tests and were set at 0 deg. The larger canards were adjustable in angle of attack, but were usually set at 0 deg. For a few runs a 15 deg trailing edge down setting was employed. In order to stimulate turbulent flow on the canards, "Hama Triangles" were formed by cutting a sawtooth pattern on a double layer of 0.75 in. (1.9cm) wide plastic electrical tape. These were installed on each face of the canards just aft of the leading edge.

Also shown in Figure 2 is the stabilizer with an adjustable flap, that spans the distance between the tail sections of the lower hulls. The dimensions given in Table 2 are for the entire span between hulls. For runs made in the design condition, the flap was set at 5 deg trailing edge up. A few experiments were conducted with the middle one-third of the aft stabilizer span removed to, in effect, create two large canards aft. The span of each "canard" was 12 ft (3.7m). This modification was an attempt to reduce wave lift on the stern in following seas.

During all experiments, appendages such as canards and stabilizer were used passively to reduce responses of the ship to wave action, and were manually adjusted prior to running to obtain slightly bow up running trim. In the full-scale ship installation, these movable appendages could be actively controlled, and therefore used more effectively to minimize motions.

Finally, a series of experiments were performed with the forward struts made thicker by taping a styrofoam jacket 1/2 in. (1.3 cm) thick (model scale) over them. The jacket covered the full strut depth from lower hull to upper deck. This increased the full-scale strut thickness from 4 ft (1.2m) to 6 ft (1.8m), and lengthened the chord by approximately 2 ft (0.6m). It was thought that increasing buoyancy forward would reduce motions, particularly relative bow motion; however, this was not the case, as will be shown later in this report.

TEST EQUIPMENT

The experiments were carried out at DTNSRDC in the Maneuvering and Seakeeping Basin (MASK). The MASK basin is 360 ft (109.7m) long, 240 ft (73.2m) wide and 20 ft (6.1m) deep. Pneumatic-type wavemakers on adjacent sides of the tank can be electronically controlled to generate long-crested regular waves, long-crested random waves having a preprogrammed spectral shape, and programmed bi-directional or short-crested waves. Wave absorbers are installed along walls opposite the wavemakers. The length of the basin is spanned by a bridge with tracks attached to its underside, along which the controlled carriage runs. The bridge is supported on a rail system that permits it to rotate through angles up to 45 deg from the longitudinal centerline of the basin. By using combinations of change in model heading relative to the carriage, bridge rotation, and a choice of wavemaker bank -- and considering model symmetry -- all angles between the direction of craft travel and wave propagation can be investigated.

As noted previously, the model was self-propelled and steered with both systems manually controlled by personnel on the carriage. This allowed the model to have six degrees-of-freedom, and resulted in more realistic responses than would generally be obtained with a partially constrained model.

A vertical gyro containing a stabilized ± 10 G accelerometer (Kistler force-balance type) was mounted on the main deck just aft of the deck house, and used to measure pitch, roll and bow acceleration. The gyro had a resolution of 0.2 deg and an accuracy of ± 0.2 deg; the accelerometer accuracy was about 1 percent. Figure 4 shows the location of all transducers mounted on the model. Systron-Donner force-balance servo accelerometers were used to measure vertical acceleration at the CG and stern: these gages had ranges of ± 1.0 G and ± 0.75 G, respectively and an overall accuracy on the order of 0.1 percent. Rudder angle was determined by mounting a high resolution potentiometer on the rudder shaft.

One ultrasonic transducer was used to sense heave (i.e., vertical motion of the CG). A second sensed the vertical component of relative motion between a point 16.3 ft (5.0m) forward of the deck house bow and the water surface (acronym RBM for relative bow motion). The RBM probe was mounted forward of

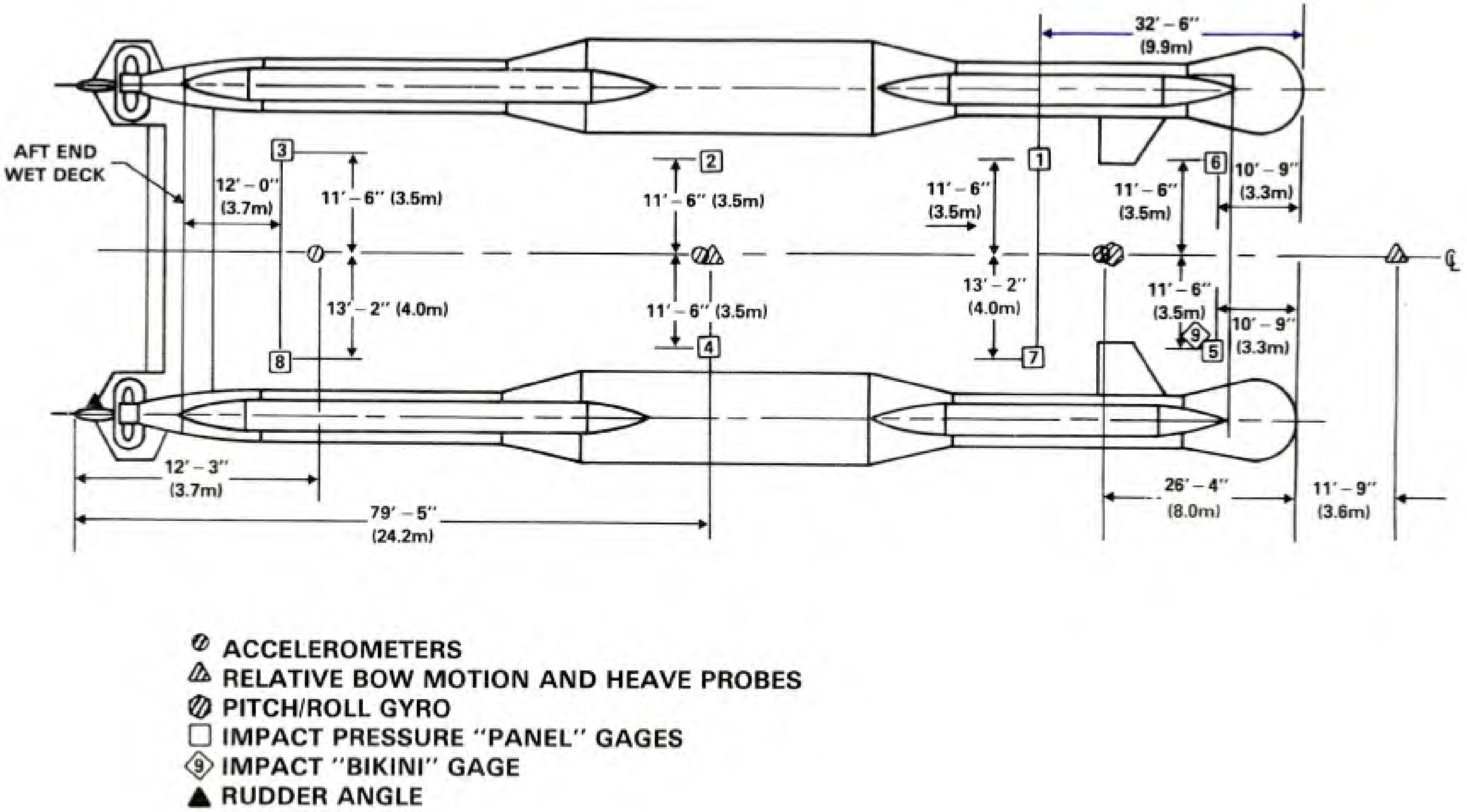


FIGURE 4—LOCATION OF MEASUREMENT TRANSDUCERS

the vessel to avoid signal dropout caused by model-generated splash -- particularly during impact. In spite of this precaution, dropout occurred during most impacts. The heave ultrasonic bounced its pulses off a target mounted above the model.

Wave height too was measured with an ultrasonic transducer. The probe was located as follows for the specified headings relative to the waves:

0°, 45°, 135°, 180°: 11 ft-6 in. (3.5m) forward of model CG if CG centered under heave target;
90°: 10 ft-0 in. (3.0m) to starboard of CG if CG in center of heave target.

All of the ultrasonics used were Wesmar Level Monitor transducers, Model LM4000. This instrument has a range of 32 in. (0.8m) with a resolution of 0.5 percent of measured range. The carrier frequency is 200 KHz, and a pulse repetition rate of 90 Hz was used for these experiments. The LM4000 generates a series of ultrasonic pulses, receives echoes from the target, and produces a d.c. output voltage proportional to the time elapsed between pulse transmission and receipt of echo. The transducers used for these experiments have a total beam angle of 16 deg.

A principal objective of this test program was to obtain data on impact pressures acting on the bow and bridging structure during operation in heavy seas. To this end, eight panel size pressure gages with bonded foil strain gage elements were installed at locations shown in Figure 4. Gages 1 through 4 have full scale dimensions 2 ft by 8 ft (0.6m by 2.4m); gages 5 through 8 are 1 ft by 4 ft (0.3m by 1.2m). Thus, their areas differ by a factor of 4. One small "bikini" gage (no. 9) with a semiconductor strain gage sensor was mounted in the bow region next to panel gage 5 to allow comparison of impact pressure sensed by large and small transducers. The circular diaphragm of the bikini gage is only 0.39 ft (0.12m) in diameter full scale and has an area only 3 percent of the area of gage 5. The natural frequency of the bikini gage exceeds 30 KHz.

For the greater part of most runs, model speed changed only a little as the model surged under the action of small and large waves. It therefore moved at the same average speed as the carriage because propulsive power was controlled to maintain the relative position of model and carriage. Speed was determined by use of a wheel on the carriage which rode on a rail and drove a tachometer generator.

All transducer signals were amplified and then directed through one of several available recording systems depending on the frequency content of the signals. High frequency transducer outputs (e.g., short rise time signals such as impact pressure) were recorded unfiltered on analog magnetic tape at a tape drive speed of 3-3/4 ips (9.5 cm/sec). This gave each channel a frequency response of 1.25 KHz. Accelerations were also recorded on analog magnetic tape; in this case a tape drive speed of 1-7/8 ips (4.8 cm/sec) was used to provide a frequency response of 625 Hz. All pressures and accelerations were later re-recorded on a light beam oscillograph type strip chart for analysis of slams. Endevco signal conditioning with 5 volt d.c. excitation was used for the strain gage bridges of the pressure channels. Signals from the Endevco units were fed to Dana amplifiers which provided a gain of 2.5K.

The inventory of recording media on the carriage included 2-14 channel Ampex CP100 tape recorders; 2-8 channel Sanborn strip chart recorders (for motions, rigid body accelerations, RBM, propeller rpm, rudder angle and model speed); a light beam oscillograph to provide real-time input on pressure gage signal quality; and an Interdata Model 70 mini-computer. All recording media carried a 1/2 volt mode signal which could be used for later time correlation of recorder outputs. The mode was also employed for designating the usable portion of each record. Its voltage source was triggered by the computer.

A sample strip chart recording of impact acceleration is given in Figure 5. It shows that impact accelerations were read from a "zero" level (only gravitational acceleration acting) to the point of maximum upward acceleration. Thus, the accelerations presented later in this report are total values, that is, the sum of rigid body acceleration at the frequency of wave encounter, and acceleration upward due to contact of the bridging structure with a wave. The latter contains a vibratory mode or "ringing" because of flexibility of the model structure.

Video tape recordings were made of all runs, and 16mm color movies and slides were taken of selected runs.

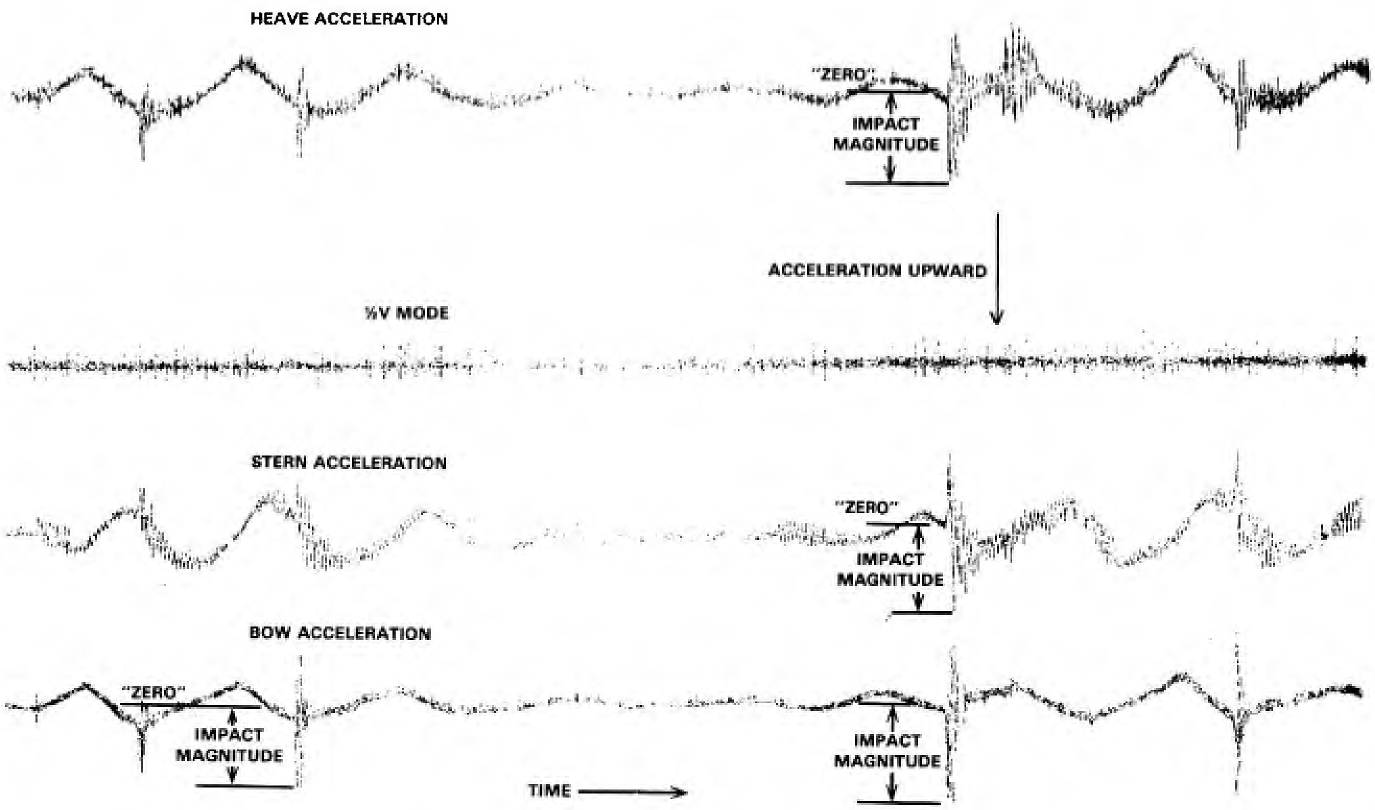


FIGURE 5—SAMPLE STRIP CHART RECORDING OF IMPACT ACCELERATION

DIGITAL DATA COLLECTION AND REDUCTION

The digital system consisted of an Interdata Model 70 computer with 64 KB memory and selector channel, one nine-track Kennedy 3110 digital tape drive, an ASR-43 teletype, an Analogic 5800 analog to digital (A to D) and D to A converter, a Versatec 1100A Matrix 600 line-per-minute line printer, and a Tridata 1024 cartridge tape recorder. This system was used to provide real-time digitization of all recorded signals, and immediate (post-run) data processing of wave input and vehicle motions and accelerations. The sample rate was 30/channel/sec during the tests (i.e., in model scale). The analog signals were passed through 6 Hz, 6 pole, Butterworth low pass filters prior to being digitized.

The sampling procedure was initiated by the computer operator who depressed a switch when experimental conditions had stabilized. During the good portion of the run a 1/2 volt signal was put out by the D to A converter and indicated on all recording devices. A "minimum" analysis (mean, standard deviation, and either $\sqrt{2}$ · standard deviation* for regular wave runs or an estimate of significant double amplitude from the standard deviation for random wave runs) was performed after each run for all channels. For regular wave runs, the frequency of wave encounter, wave slope, and wave celerity were also calculated. Signals from the regular wave runs were harmonically analyzed on the carriage, and the amplitude of the fundamental was used to calculate non-dimensional transfer functions.

After the experiments were completed, time-domain analysis was executed for random wave groupings in which several runs for the same conditions were treated as one long time-history to provide a larger statistical sample. Histograms of double amplitude model responses were calculated and used in computing statistical properties such as the largest double amplitude, second largest, etc., and the average of the largest one-third and one-tenth. Spectral analysis was performed for one sample wave trace for each wave program so that comparisons could be made with the Bretschneider and Pierson-Moskowitz spectral formulations.

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*For a sinusoidal response, $\sqrt{2}$ · standard deviation is the single amplitude.

TEST PROGRAM AND PROCEDURE

The towing tank experiments were conducted in regular waves to derive transfer functions, random waves for responses in realistic sea conditions, and calm water to obtain natural period and damping information. Headings relative to the random waves that were investigated are: 0 deg (following), 45 deg (stern quartering), 90 deg (beam), 180 deg (head) and 225 deg (bow quartering). The data for 225 deg were plotted as 135 deg to provide continuity in the data points. This could be done because of model symmetry. A heading of 225 deg was run because of the desire to obtain wave spectral shapes produced by the short bank of wavemakers. The speeds run are equivalent to 0, 3, 8, 11 and 15.5 kts full scale.

Table 3 is a listing of the random wave programs generated in the tank and gives the period of maximum energy of their associated wave spectra, i.e., modal period, and the significant wave height, $\overline{H}_{1/3}$. It can be seen that several modal periods were investigated for a given $\overline{H}_{1/3}$. This is a true simulation of what occurs in the ocean, where there is no unique relationship between sea state and modal period. The periods were selected to excite pitch and roll. To generate Program G, a short-crested or bi-directional sea, the short and long banks of wavemakers were employed simultaneously.

Samples of the spectra which represent the energy distribution of the random waves in the tank are presented in Figure 6. A typical value of significant wave height is given on each figure; however, this statistic was somewhat different for each run in a particular sea state. Bretschneider and Pierson-Moskowitz theoretical wave spectra for the same significant wave height as the measured spectrum are also plotted on each figure. The Bretschneider spectrum, having two parameters (viz. significant wave height and modal period), generally compares more closely to the measurement.

Table 4 is a complete listing of the random wave runs made including particulars of the test conditions. The column labeled Wave Program is keyed to Table 3. The values tabulated in the significant wave height ($\overline{H}_{1/3}$) column correspond to Sea States 5, 6 and 7. Wave programs were varied with heading and ship speed to simulate worst-case operating conditions. As stated

TABLE 3

WAVE PROGRAMS USED IN TANK

PROGRAM	T_{MAX}, SEC	NOMINAL $\overline{H}_{1/3}$	
		FT	M
A	13.7	10	3
B	14.0	20	6
C	14.0	30	9
D	7.0	10	3
E	6.3	10	3
F	10.0	10	3
G	10.0 & 7.0*	20	6
H	9.5	20	6
I	10.1	10	3
J	10.0	20	6

*BI-DIRECTIONAL

FIGURE 6—SAMPLES OF WAVE SPECTRA OBTAINED FROM MEASUREMENTS MADE DURING EXPERIMENTS

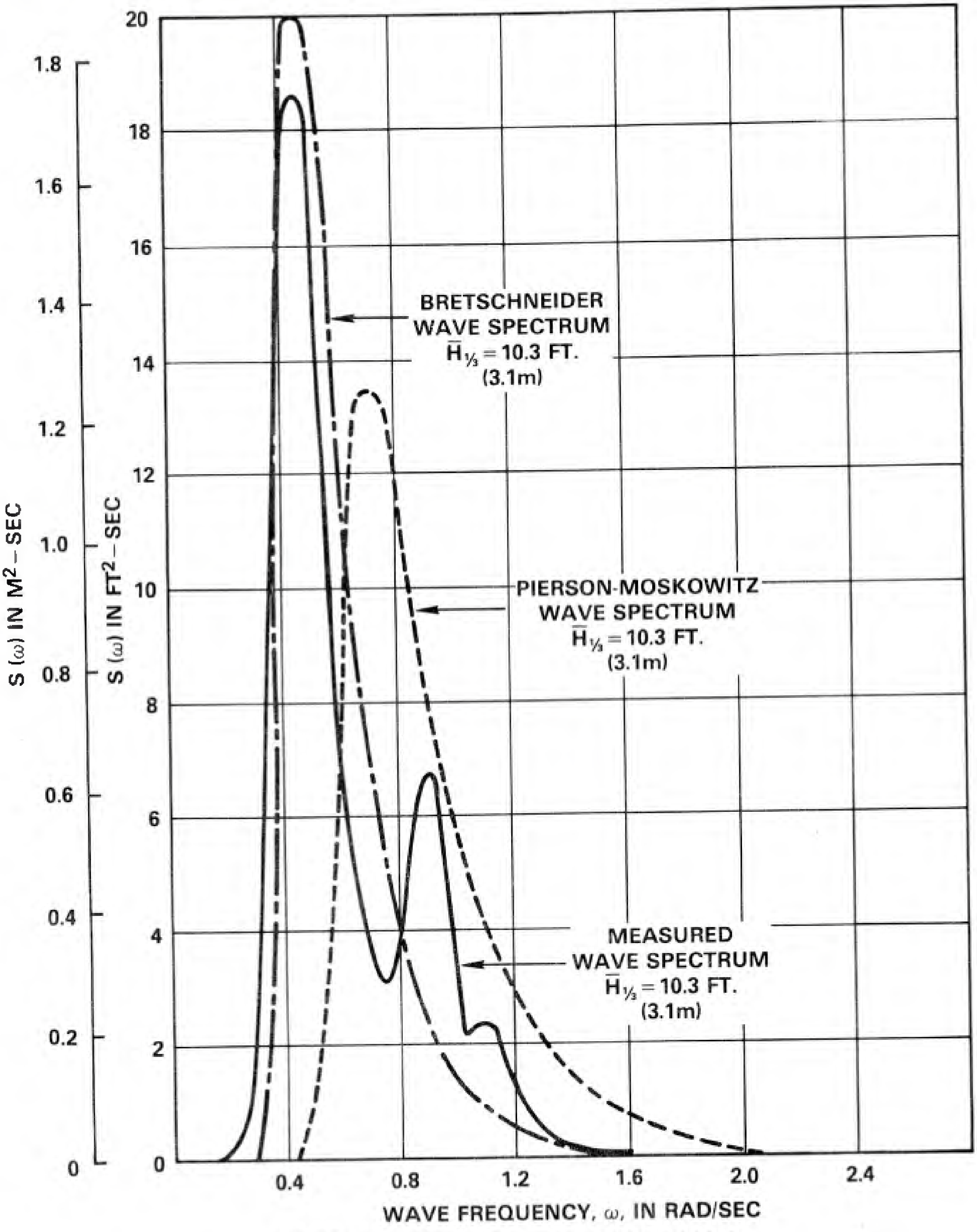

FIGURE 6a—SEA STATE 5, PROGRAM A

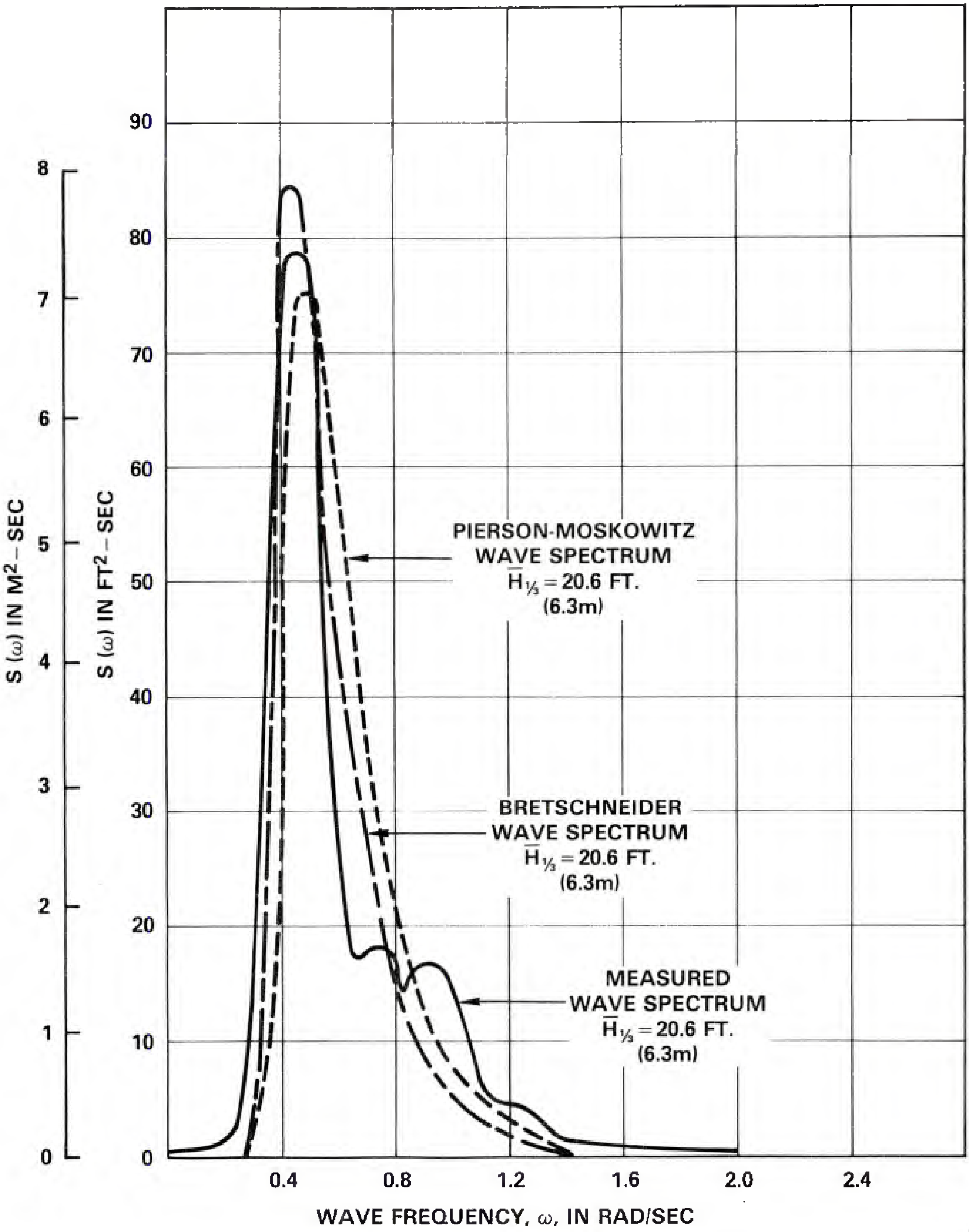

FIGURE 6b—SEA STATE 6, PROGRAM B

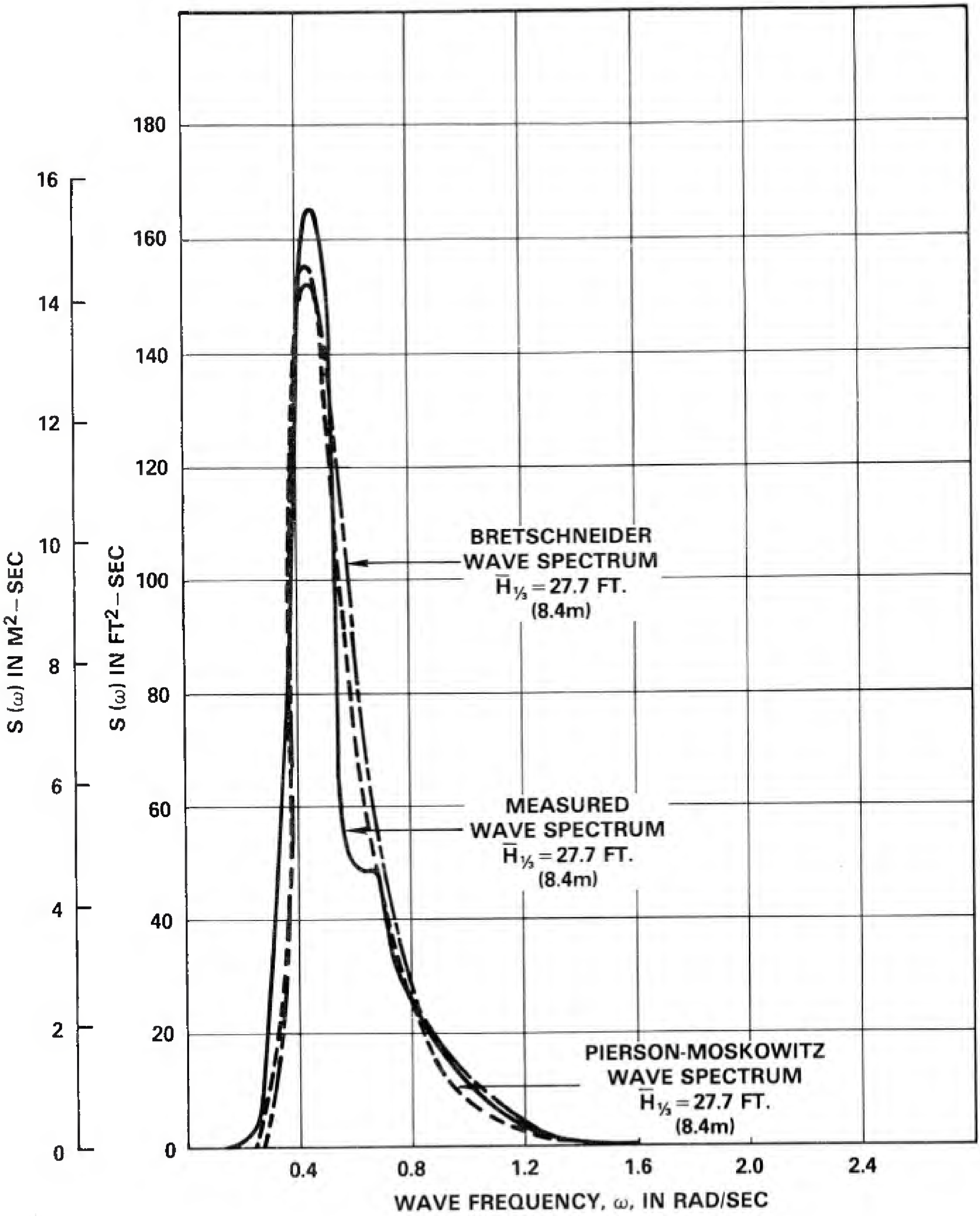

FIGURE 6c—SEA STATE 7, PROGRAM C

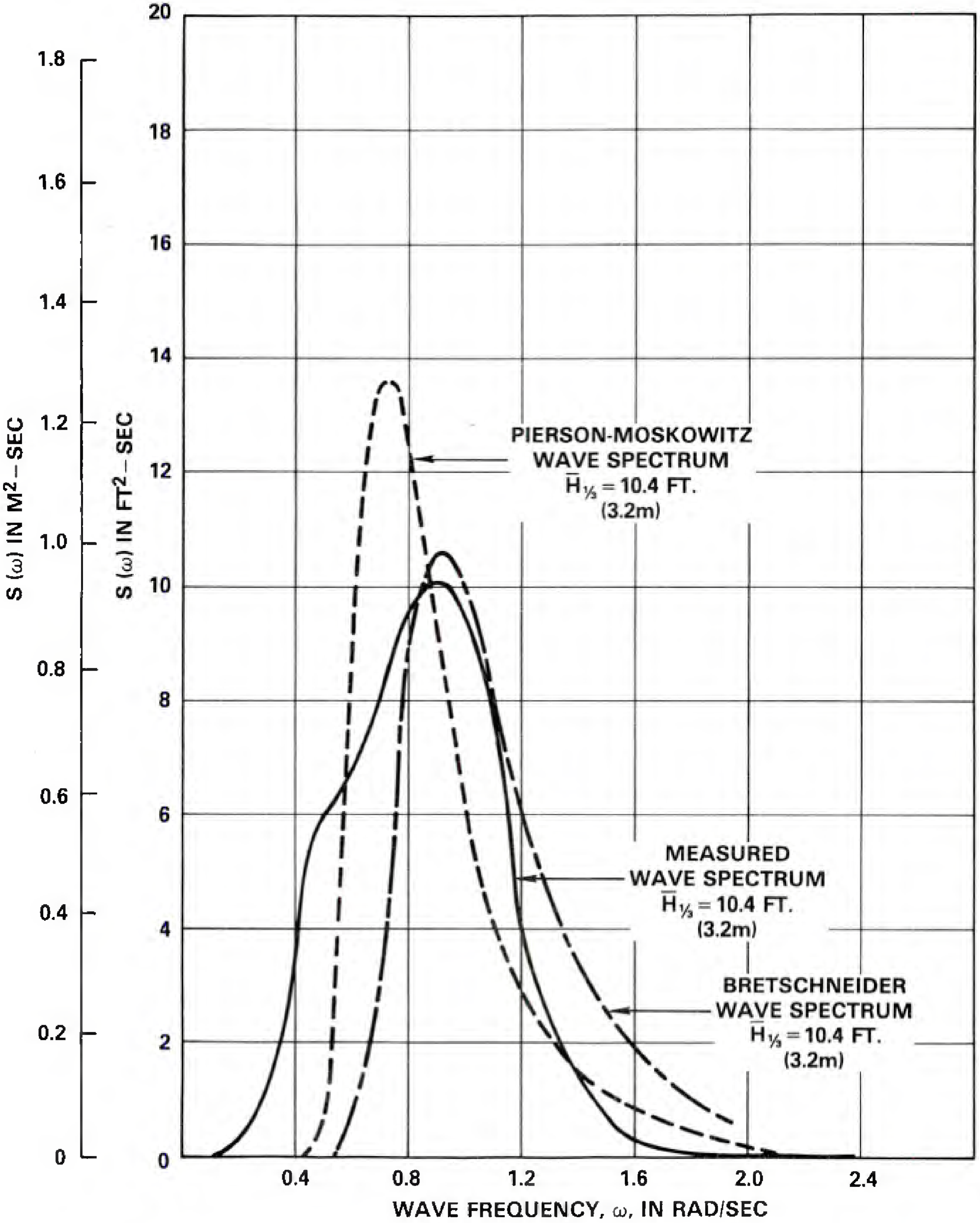

FIGURE 6d—SEA STATE 5, PROGRAM D

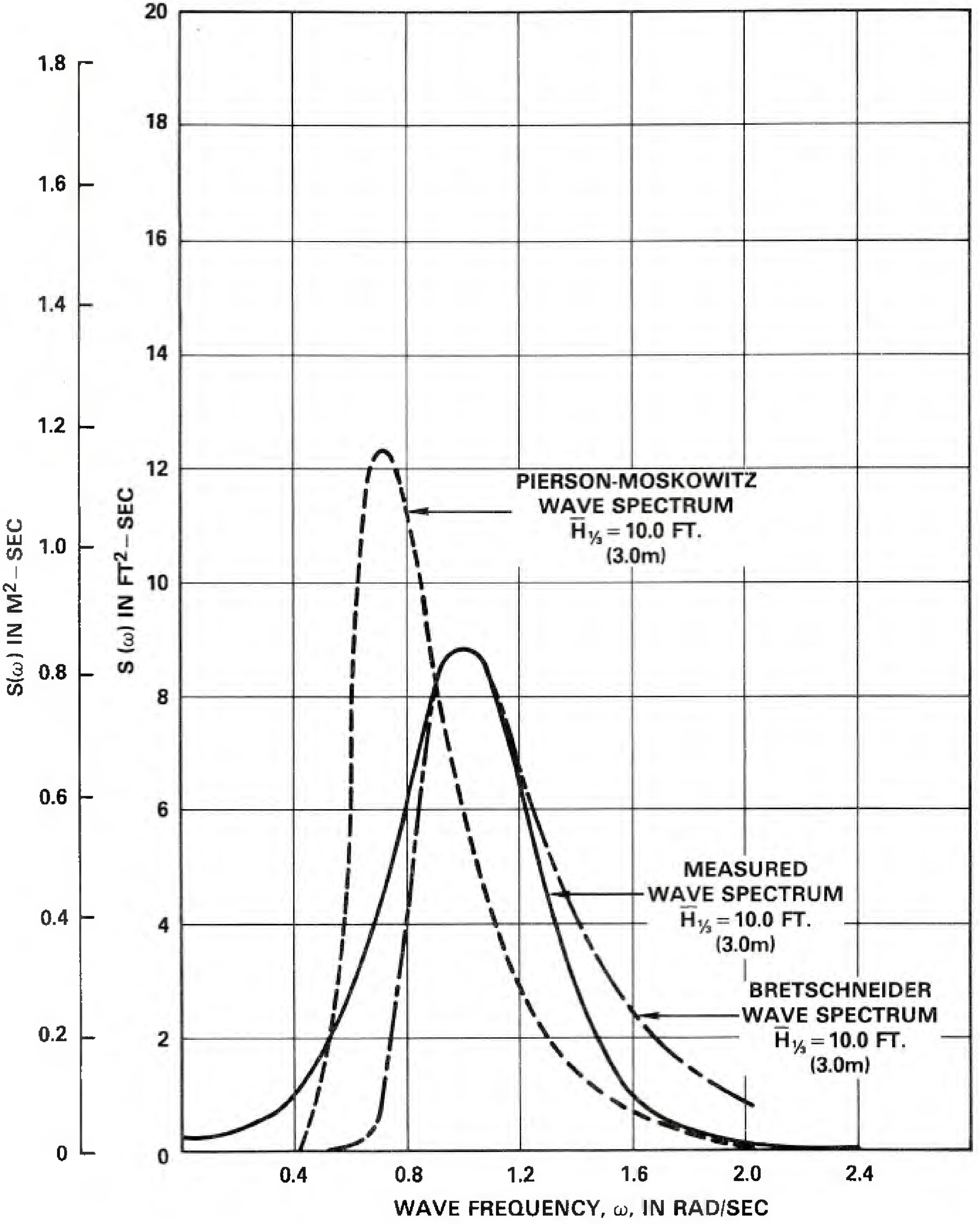

FIGURE 6e—SEA STATE 5, PROGRAM E

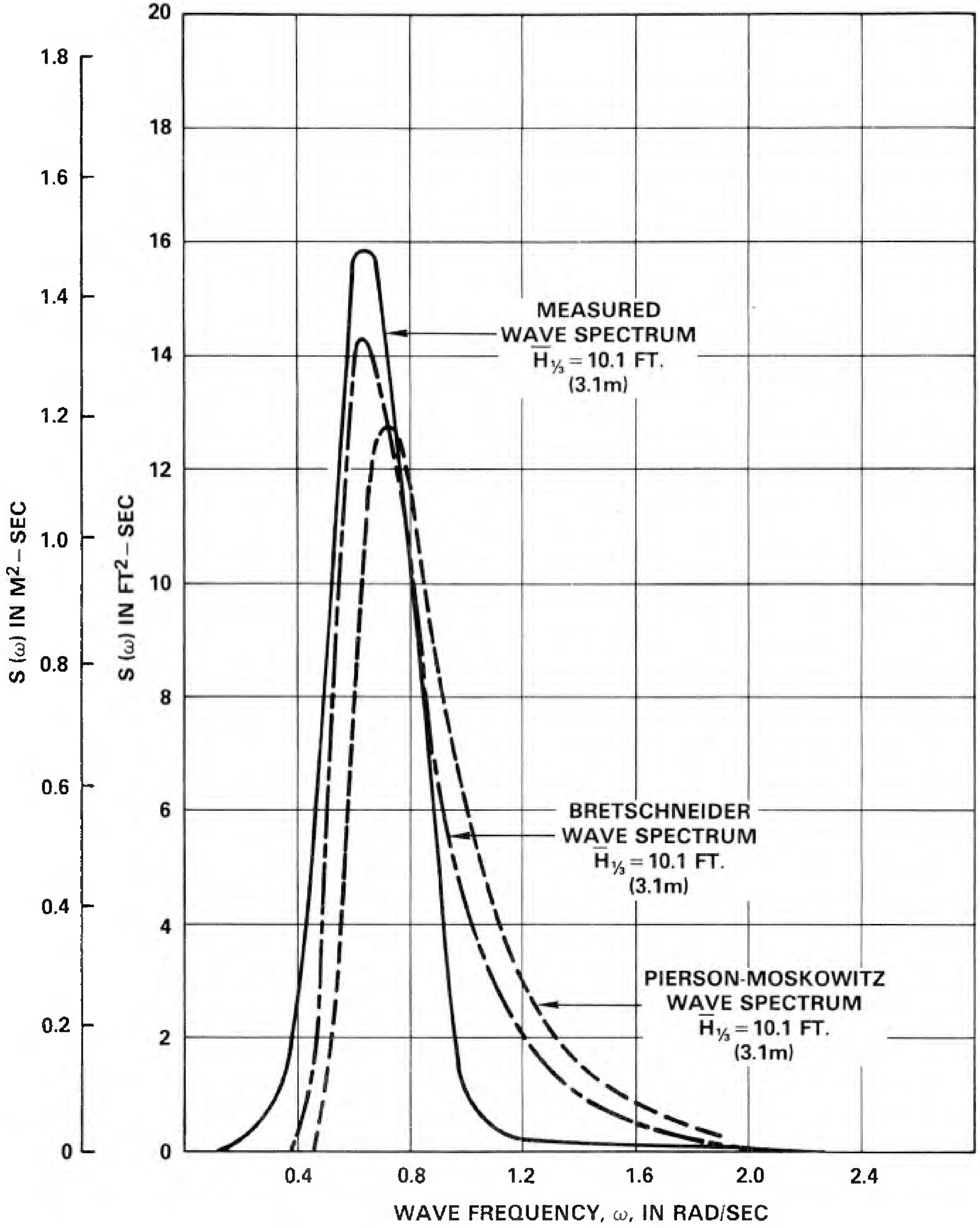

FIGURE 6f—SEA STATE 5, PROGRAM F

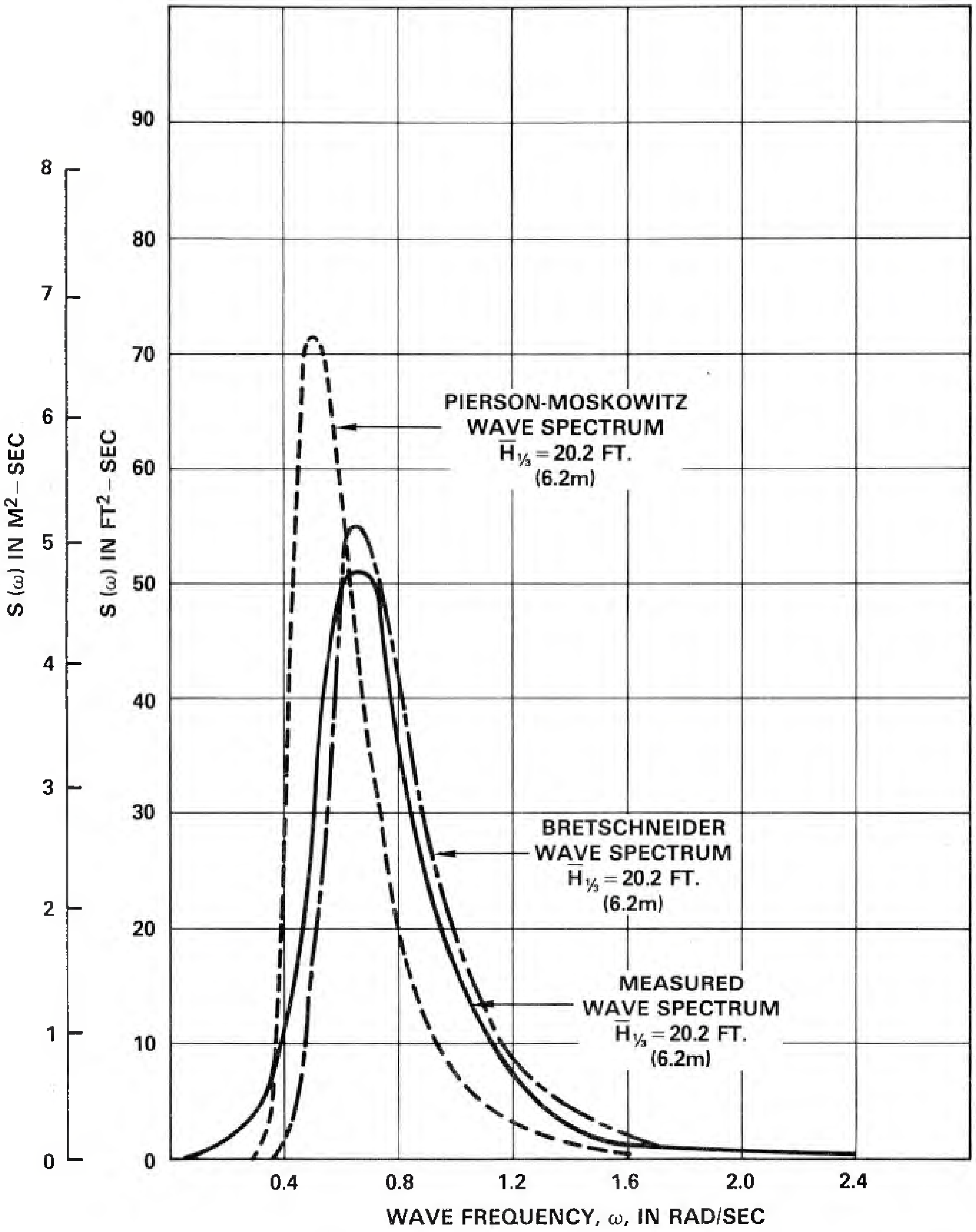

FIGURE 6g—SEA STATE 6, PROGRAM H

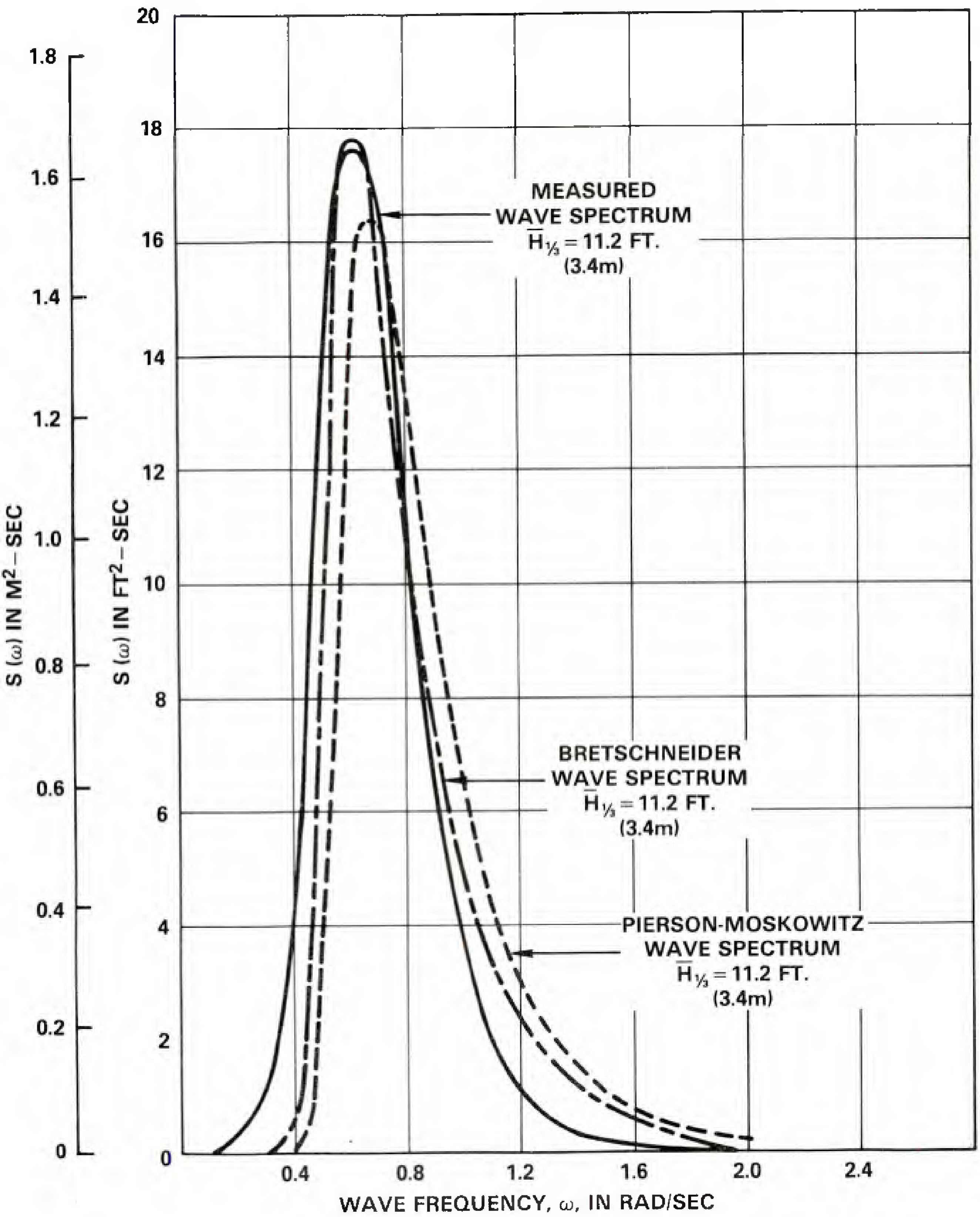

FIGURE 6h—SEA STATE 5, PROGRAM I

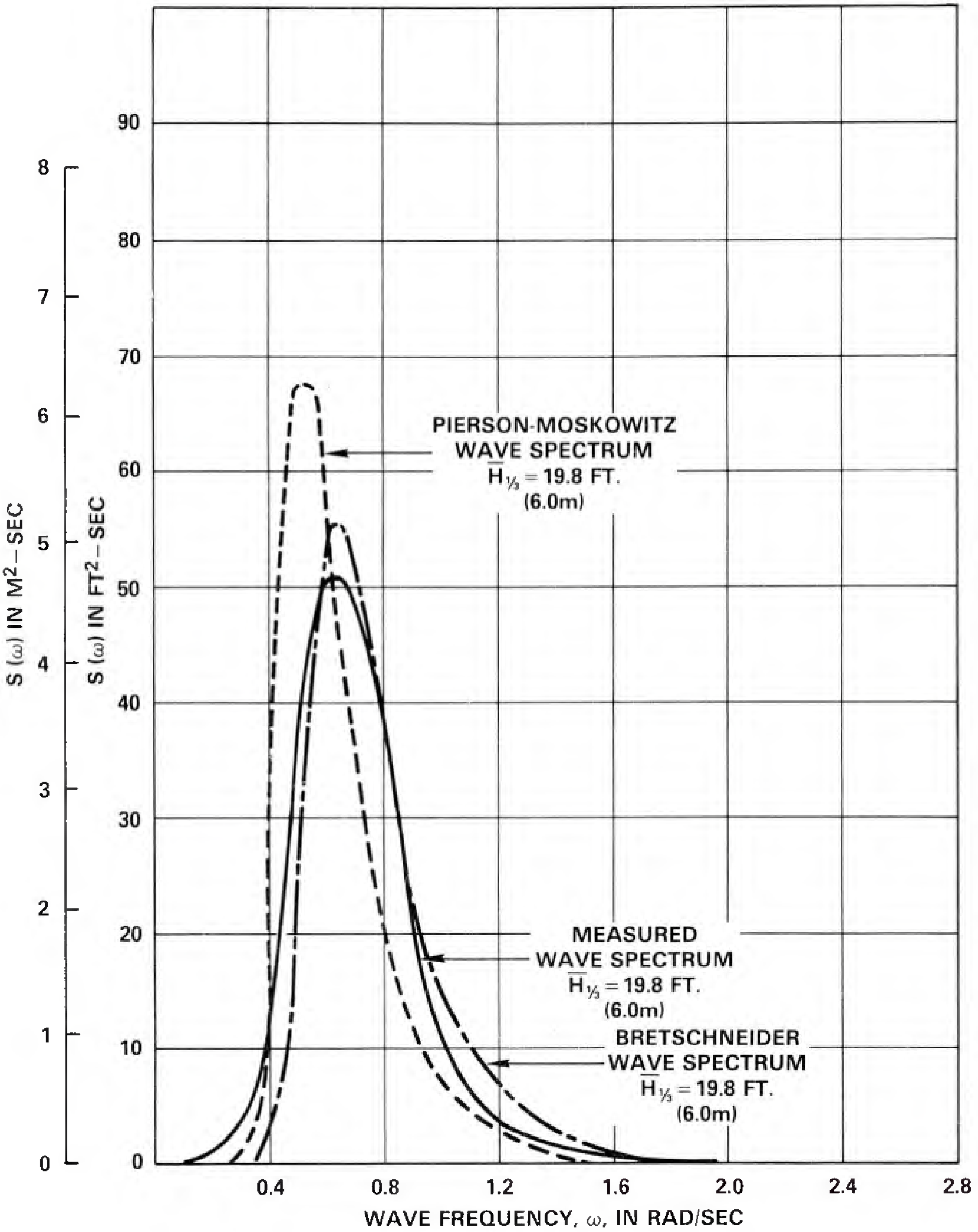

FIGURE 6i—SEA STATE 6, PROGRAM J

TABLE 4
RANDOM WAVE TEST CONDITIONS

Run Numbers	Speed, Kts	Heading, Deg	Wave Program	$\overline{H}_{1/3}$		Canards	Struts	Aft Stabilizer Flap	Comments
				Feet	Meters				
623	0	90	A	9.6	2.9	Small@ 0°	Design	5° TE*Up	
128		180	A	9.1	2.8				
136		180	A	9.4	2.9				
384		180	B	20.1	6.1				
624		90	C	26.8	8.2				
483		0	D	7.2	2.2				
204		135	D	10.0	3.0				
108		180	D	10.0	3.0				
285		90	F	9.3	2.8				
366		90	H	19.7	6.0				
512		180	J	20.6	6.3				
568-572	3.0	135	B	23.6	7.2	Small@ 0°	Design	5° TE Up	
374,375		180	B	20.1	6.1				
371,372		180	B	20.0	6.1				
385-387		180	B	21.3	6.5				
487-494		180	C	25.3	7.7				
524-527		180	C	27.1	8.3	Large @ 0°			
484-486		0	D	9.4	2.9	Small @ 0°			
837-840		0	D	11.4	3.5		Thick Fwd		⅓ Aft Stab. Removed
591,592		45	D	15.9	4.8		Design		
205,206		135	D	10.2	3.1				
850,851		180	D	11.7	3.6				⅓ Aft Stab. Removed
471,472		0	E	10.7	3.3				
841-843		0	E	11.5	3.5		Thick Fwd		⅓ Aft Stab. Removed
613,614		45	E	10.1	3.1		Design		

*TE-Trailing Edge

TABLE 4 (CONTINUED)

Run Numbers	Speed, Kts	Heading, Deg	Wave Program	$\bar{H}_{1/3}$		Canards	Struts	Aft Stabilizer Flap	Comments
				Feet	Meters				
848,849	3.0	180	E	11.2	3.4	Small @ 0°	Design	5°TE Up	⅓ Aft Stab. Removed
286,287	↓	90	F	10.0	3.0	↓	↓	↓	
578-581	↓	135,225	G	17.9	5.5	↓	↓	↓	Bi-Directional Seas
594-597	↓	135,225	G	18.1	5.5	↓	↓	↓	Bi-Directional Seas
598,599	↓	45	I	11.1	3.4	↓	↓	↓	
610-612	↓	45	J	16.5	5.0	↓	↓	↓	
562-563	↓	135	J	19.0	5.8	↓	↓	↓	
513-514	↓	180	J	19.9	6.1	↓	↓	↓	
533-535	↓	180	J	19.8	6.0	Large @ 0°	↓	↓	
702,703	↓	180	J	20.5	6.2	Small @ 0°	Thick Fwd	↓	
564-567	8.0	135	B	19.0	5.8	Small @ 0°	Design	5° TE Up	
573-577	↓	135	B	22.4	6.8	↓	↓	↓	
495-504	↓	180	C	26.3	8.0	↓	↓	↓	
528-532	↓	180	C	25.5	7.8	Large @ 0°	↓	↓	
697-701	↓	180	C	25.9	7.9	Small @ 0°	Thick Fwd	↓	
119-121	↓	180	D	9.3	2.8	↓	Design	↓	
844-847	↓	0	E	11.6	3.5	↓	↓	↓	⅓ Aft Stab. Removed
582-587	↓	135,225	G	19.2	5.9	↓	↓	↓	Bi-Directional Seas
515-518	↓	180	J	19.7	6.0	↓	↓	↓	
536-539	↓	180	J	19.0	5.8	Large @ 0°	↓	↓	
556-559	↓	180	J	20.3	6.2	Large @ 15°	↓	20°TE Up	
704-707	↓	180	J	20.6	6.3	Small @ 0°	Thick Fwd	5° TE Up	
111-114	11.0	180	A	8.6	2.6	Small @ 0°	Design	5° TE Up	
129-135	↓	180	A	8.8	2.7	↓	↓	↓	
388,389	↓	180	B	23.2	7.1	↓	↓	↓	

TABLE 4 (CONTINUED)

Run Number	Speed, Kts	Heading, Deg	Wave Program	$\overline{H}_{1/3}$, Feet	$\overline{H}_{1/3}$, Meters	Canards	Struts	Stabilizer Flap	Comments
207-210	11.0	135	D	10.1	3.1	Small @ 0°	Design	5° TE Up	
473-482	↓	0	E	11.7	3.6	↓	↓	↓	
615-622	↓	45	E	10.9	3.3	↓	↓	↓	
288-293	↓	90	F	9.5	2.9	↓	↓	↓	
600-609	↓	4	I	9.7	3.0	↓	↓	↓	
137-145	15.5	80	A	8.8	2.7	Small @ 0°	Design	5° TE Up	
211-215	↓	135	D	10.1	3.1	↓	↓	↓	
115-118	↓	180	D	8.6	2.6	↓	↓	↓	
831-835	↓	180	D	10.4	3.2	↓	↓	↓	
294-301	↓	90	F	9.8	3.0	↓	↓	↓	

previously, the following configurations were examined: two forward canard sizes; continuous stabilizers aft or large canards aft (with flap usually set at 5 deg trailing edge up); and two forward strut thicknesses (the thinner or design struts were used for most runs).

Speeds investigated in regular waves were limited to 0, 3 and 8 kts full scale. Table 5 summarizes the test conditions. Most runs were made in waves approximately 8 ft (2.4m) in full scale height, that is, from crest to trough. Some runs were carried out in mild slope conditions (wave height/wave length $\cong$ 1/100), and for another small group the wave height was increased over a wide range with wave length constant to check linearity of ship responses. The "design" configuration is represented by small canards forward set at 0 deg initial angle of attack, basic struts (no added thickness forward), and aft stabilizer flap set 5 deg trailing edge up.

Calm water runs were made for the conditions listed in Table 6. To obtain natural periods and damping for pitch, roll and heave, the model was displaced statically in the desired degree-of-freedom, then released and allowed to oscillate.

For all forward speed runs, the model was towed up to speed with the safety lines. The lines were slackened as the propulsion and steering systems were adjusted to the proper operating condition. In calm water and regular waves only one pass down the tank was usually needed to collect data for each condition. In fact, in regular waves several data collections of approximately ten wave encounters each could be accomplished in one pass. For random wave conditions several passes were made to lengthen the sample size and thus, have a statistical error in spectral ordinates no greater than 15 percent.*

PRESENTATION AND DISCUSSION OF EXPERIMENTAL RESULTS

SHIP RESPONSES IN RANDOM WAVES

Numerous statistical values of motions and accelerations were obtained by computer analysis of the time-histories recorded in random waves. From the

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*Statistical Error = $\varepsilon = [5.0096/(\tau \text{ x DW})]^{2/5}$ where: τ = run length (sec), DW = half power bandwidth (rad/sec).

TABLE 5

REGULAR WAVE TEST CONDITIONS

HEADING	SPEEDS	CONFIGURATION
180 DEG	0, 3, 8 KTS	DESIGN
135	0, 3	DESIGN
90	0, 3	DESIGN
0	0, 3	DESIGN
180	3, 8	LARGE CANARDS FORWARD
180	3, 8	THICK FORWARD STRUTS

TABLE 6

CALM WATER TEST CONDITIONS

SPEEDS	CONFIGURATION
0, 3, 11, 15.5 KTS	DESIGN
0, 3, 8	LARGE CANARDS FORWARD
0, 3, 8	THICK FORWARD STRUTS

computer printouts containing full scale results, the significant (average of the highest one-third) double amplitudes of response were extracted, and used in preparing Figures 7 through 11 of this report. Significant responses for the design configuration were plotted in Figures 7 and 8 as a function of ship heading relative to the waves: Figure 7 covers five headings ranging from head seas to following seas, while Figure 8 is limited to headings from head seas to beam seas. Furthermore, Figure 7 contains data for Sea State 5, and Figure 8 for Sea States 6 and 7. Both sets of graphs cover several speeds and several wave programs. The latter have roughly the same significant wave height for a given sea state, but different spectral shapes and modal periods depending on the wave program (see Figure 6 and Table 3).

Figure 7a shows that, at a speed of 11 kts, pitch is clearly greatest in stern quartering and following seas. At lower speeds such as 3 and 8 kts, pitch is comparable in head and following seas. As would be expected, the mildest pitch motion was experienced in beam seas. The maximum significant double amplitude measured in Sea State 5 was approximately 7 deg. For head seas operation in Sea State 6 (see Figure 8a) pitch varied greatly with speed and wave program.* The range in significant double amplitudes was from 7.3 deg to 16.1 deg, with the largest value occurring at zero speed in Sea State 6 (Wave Program J).

Examining heave in Figures 7b and 8b, it is clear that the effect of heading is not as pronounced as it was for pitch. However, there is a trend for minimum heave to occur in following seas. The maximum values of heave were found to be 10.7 ft (3.3m) in Sea State 5 (beam seas), 21.8 ft (6.6m) in Sea State 6 (bow seas), and 25.6 ft (7.8m) in Sea State 7 (head seas).**

Relative motion between a point just forward of the bow and the water surface can be an important indicator of when wave impact will occur on the bridging structure. Figures 7c and 8c indicate that RBM was small in beam seas, and was generally largest in head and following seas. Bow and stern quartering seas can also cause appreciable RBM. The largest value measured in

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*The Sea State 6 head sea data are numerous, and exhibit the greatest variability throughout Figure 8.

**Note: Only head, bow and beam sea data are available for Sea States 6 and 7.

FIGURE 7 — SIGNIFICANT DOUBLE AMPLITUDE OF MOTIONS AND ACCELERATIONS IN A SEA STATE 5; DESIGN CONDITION

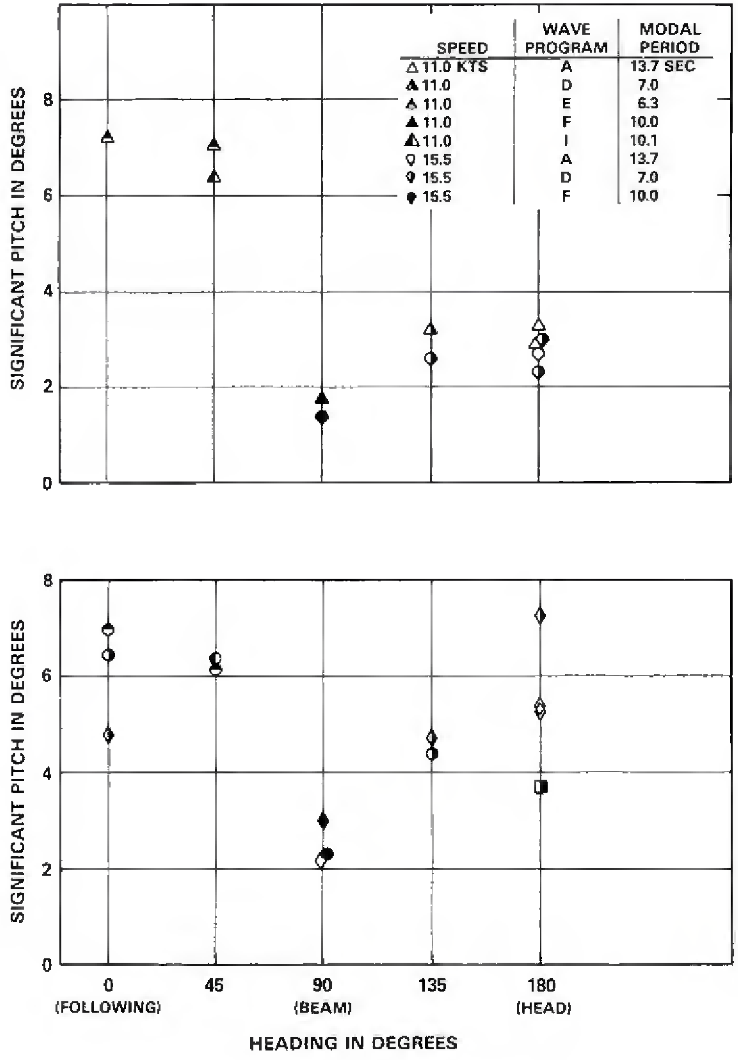


FIGURE 7a — PITCH

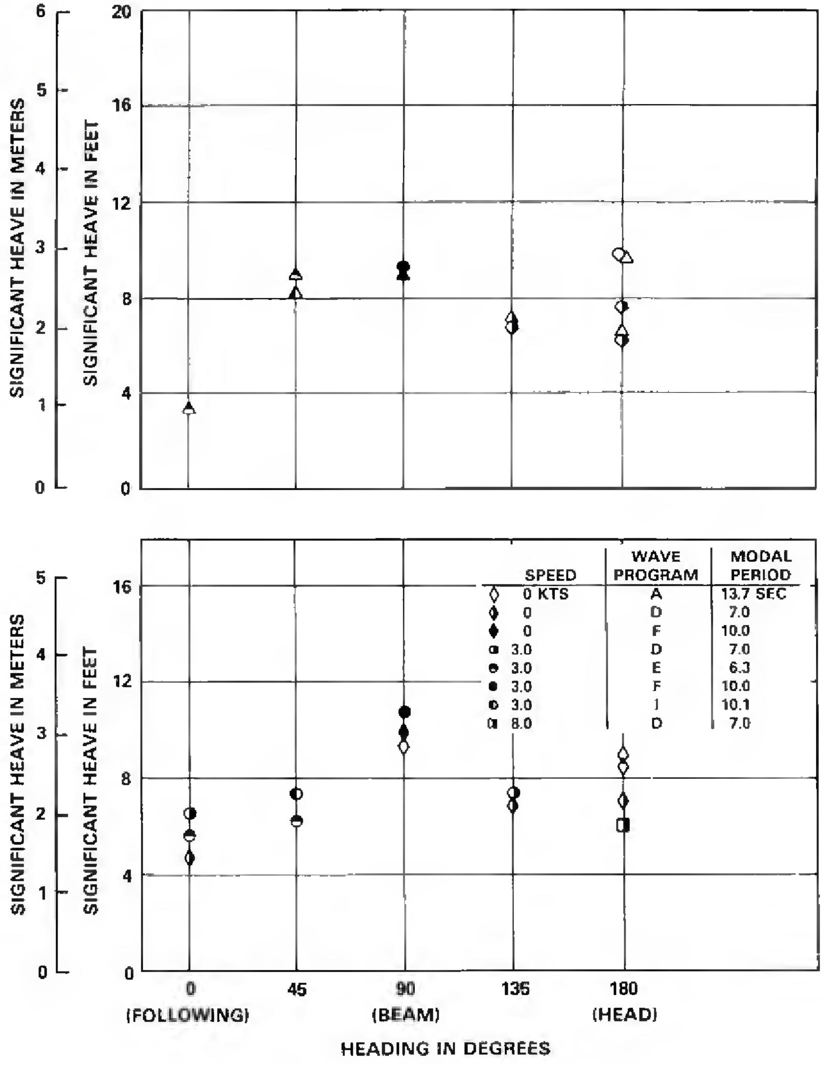


FIGURE 7b — HEAVE

FIGURE 7 (CONTINUED)

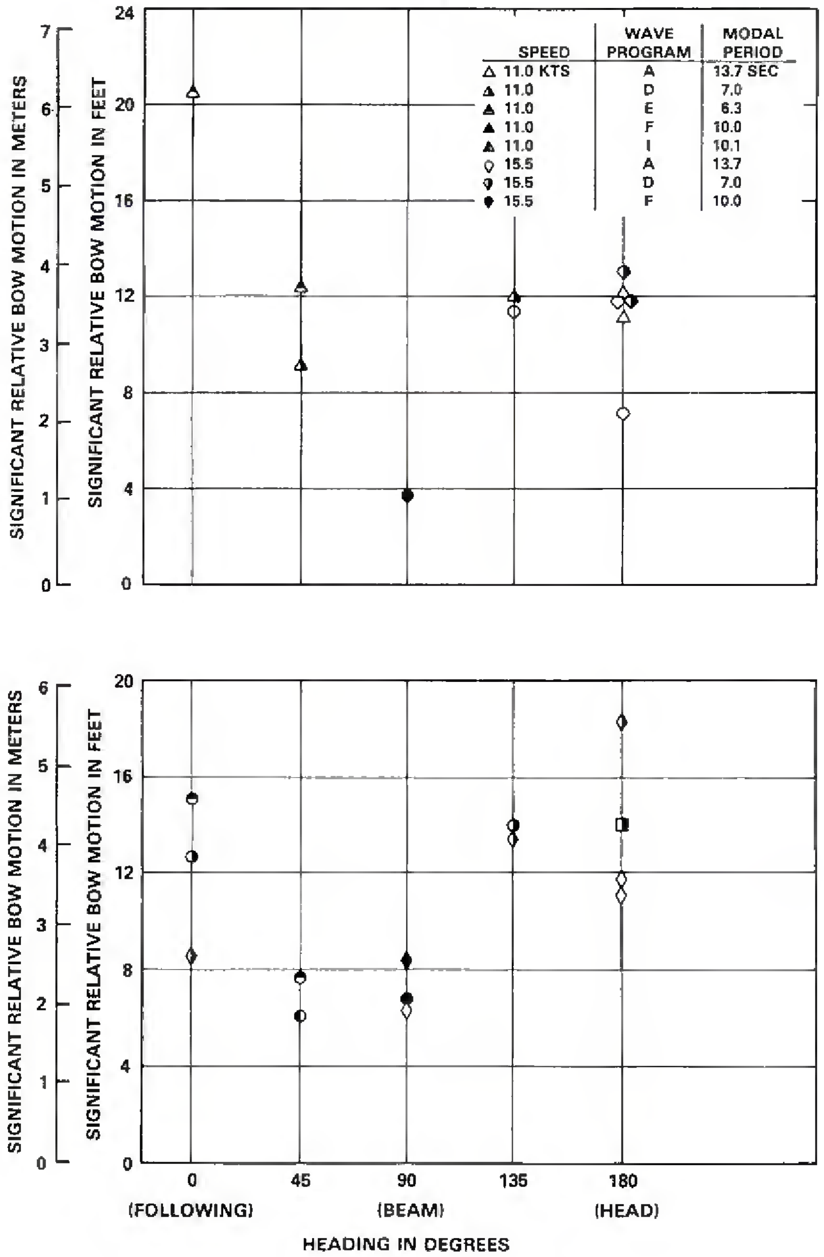


FIGURE 7c—RELATIVE BOW MOTION

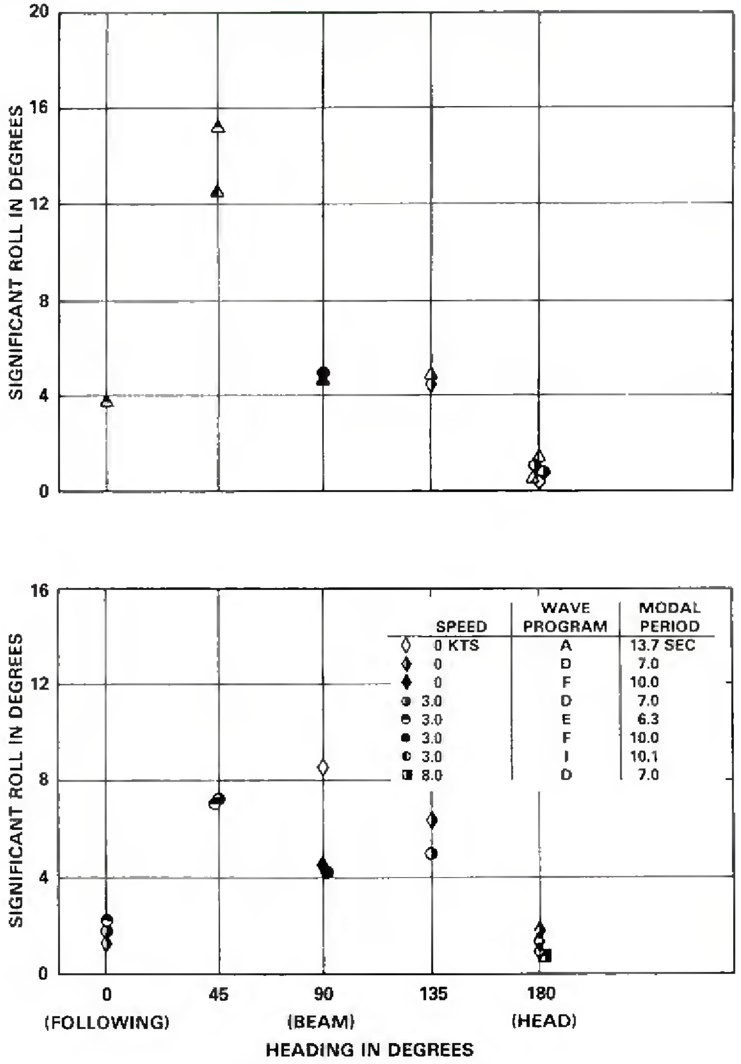


FIGURE 7d—ROLL

FIGURE 7 (CONTINUED)

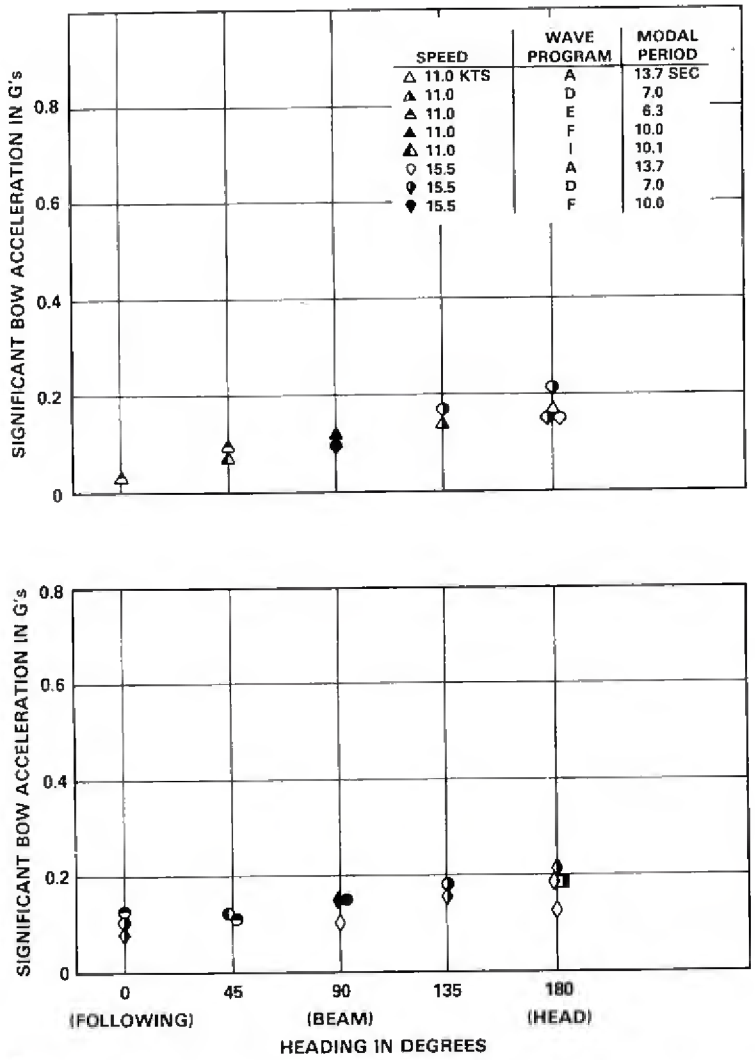


FIGURE 7e—BOW ACCELERATION

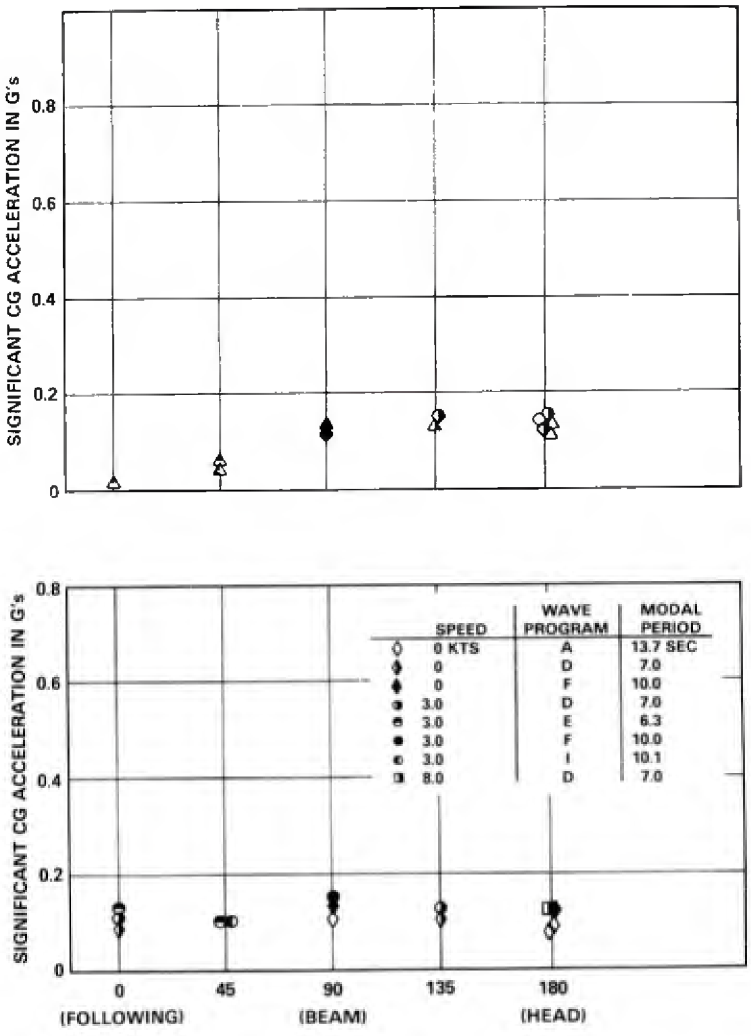


FIGURE 7f—CG ACCELERATION

FIGURE 7 (CONTINUED)

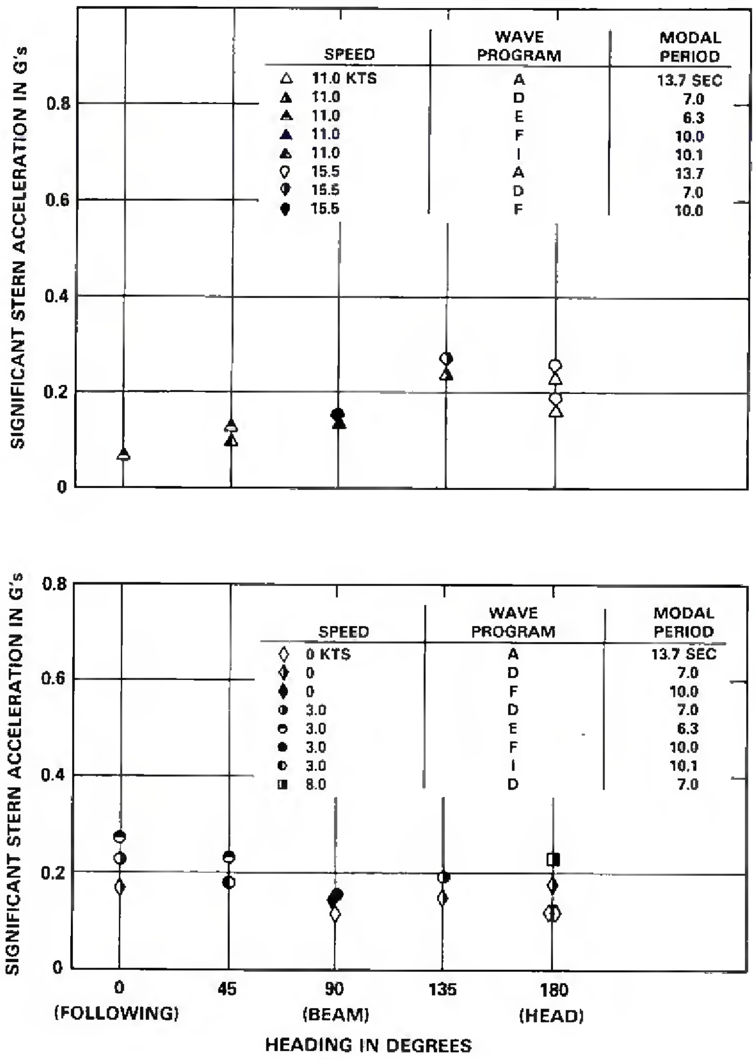


FIGURE 7g—STERN ACCELERATION

FIGURE 8 — SIGNIFICANT DOUBLE AMPLITUDE OF MOTIONS AND ACCELERATIONS IN SEA STATES 6 AND 7; DESIGN CONDITION

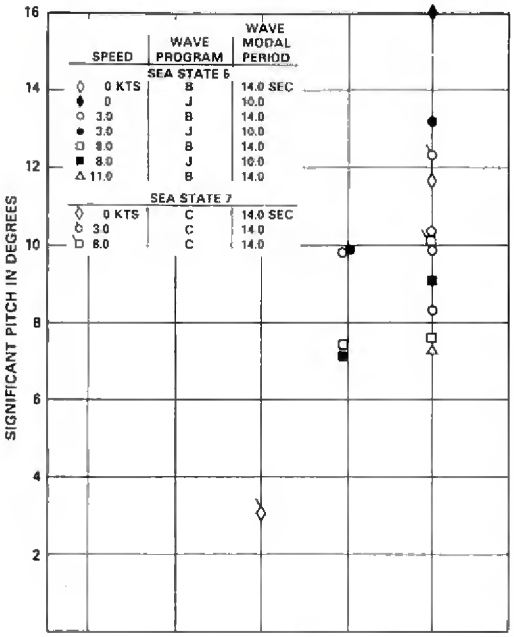


FIGURE 8a—PITCH

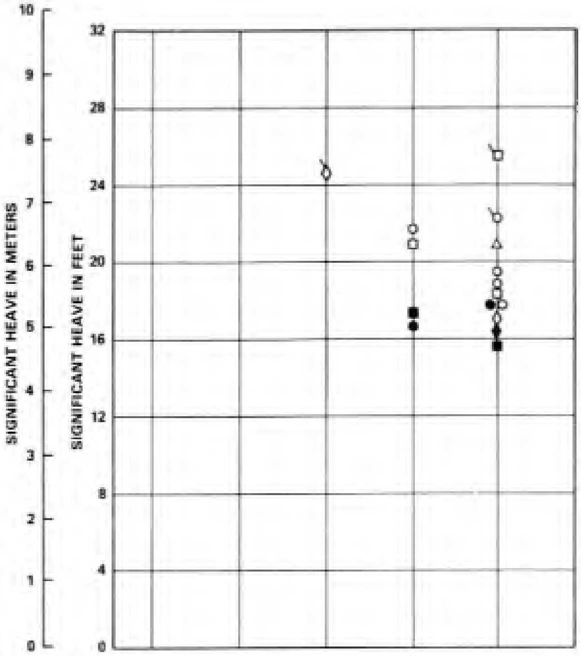


FIGURE 8b—HEAVE

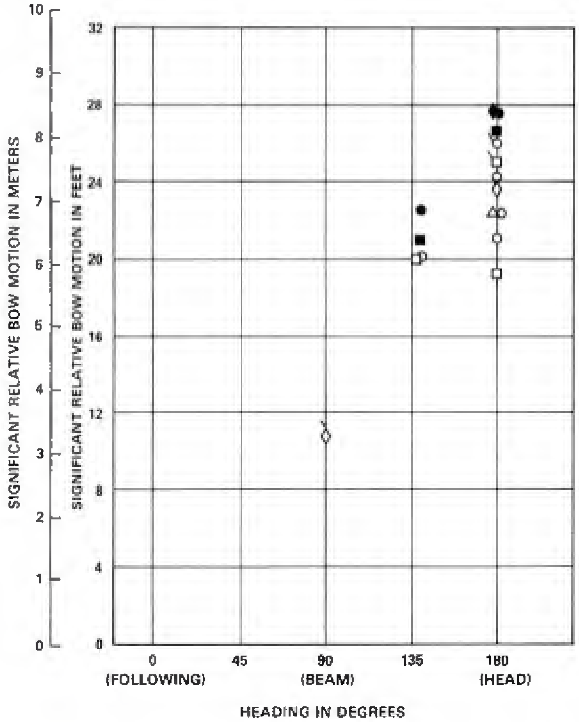


FIGURE 8c—RELATIVE BOW MOTION

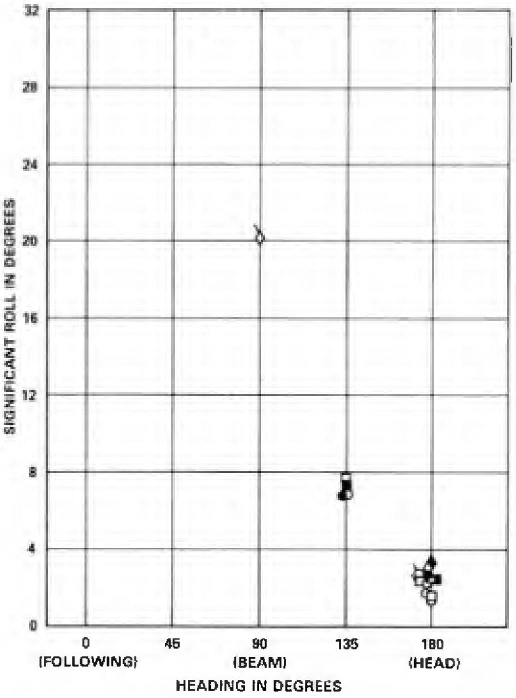


FIGURE 8d—ROLL

FIGURE 8 (CONTINUED)

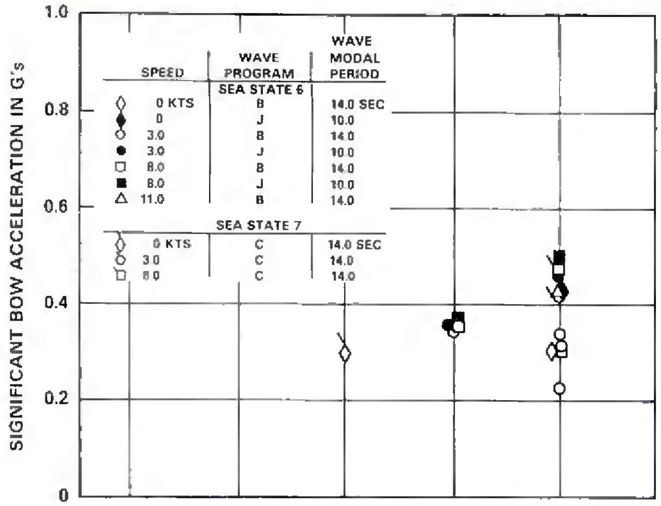


FIGURE 8e—BOW ACCELERATION

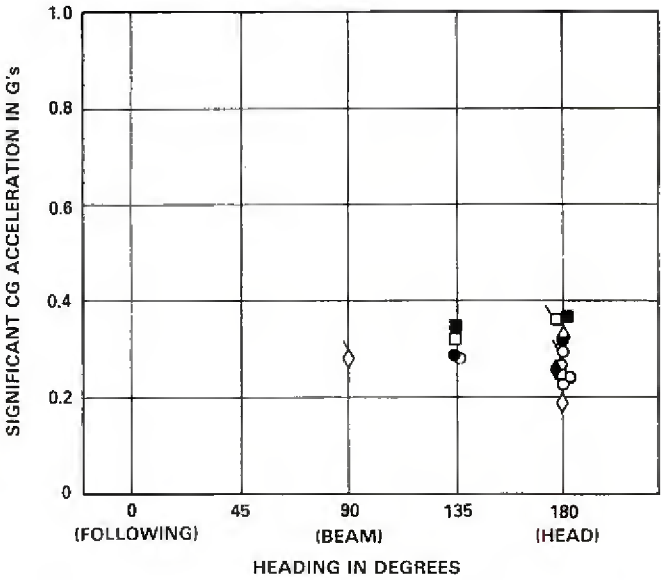


FIGURE 8f—CG ACCELERATION

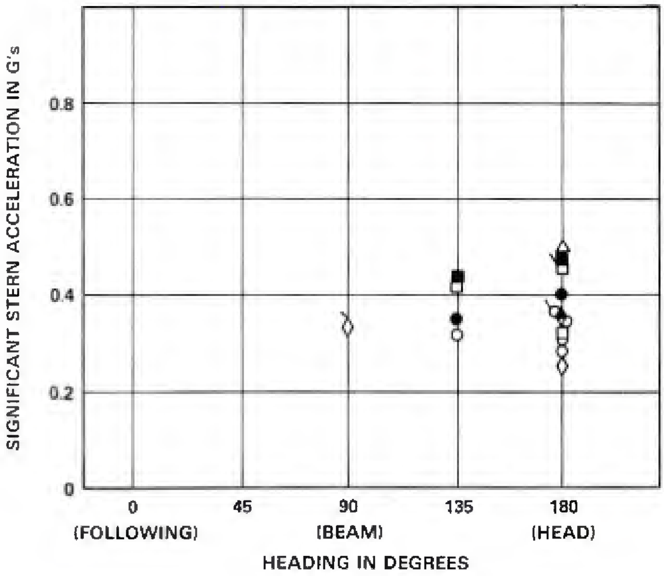


FIGURE 8g—STERN ACCELERATION

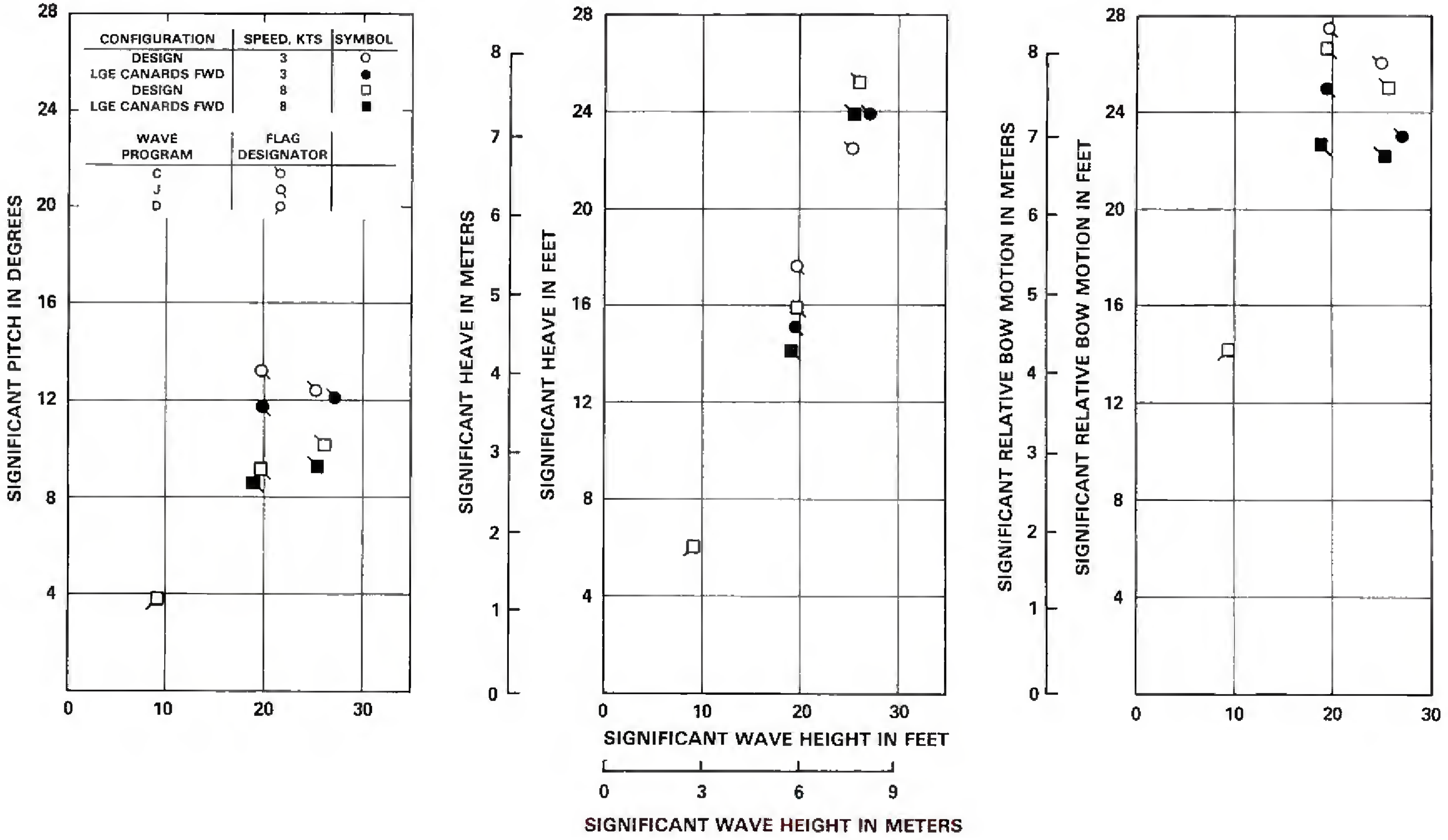
Sea State 5 occurred in following seas at 11 kts, and was 20.5 ft (6.2m). In Sea State 6, head seas RBM reached a maximum of 27.7 ft (8.4m) at zero speed.

Like a conventional surface ship when underway, the STRETCHED SSP experienced its largest Sea State 5 rolling in stern quartering seas at 11 kts (see Figure 7d). At 3 kts quartering seas was still the worst heading for roll. At zero speed in Sea State 7 beam seas, the measured significant double amplitude of roll was 20 deg (see Figure 8d). As expected, Figures 7d and 8d show that roll in head and following seas was small.

Bow acceleration plots are given in Figures 7e and 8e, and they reveal that acceleration decreased almost linearly with heading in going from head to following seas. The effect of speed and wave program (modal period) on acceleration was small in Sea States 5 and 7, but was appreciable in Sea State 6 head seas. Maximum significant double amplitude values of about 0.2 G's in head Sea State 5 and 0.5 G's in head Sea States 6 and 7 were recorded. CG (heave) acceleration in Figures 7f and 8f was a maximum of 0.15 G's in Sea State 5 and approximately 0.37 G's in Sea States 6 and 7. Again, there was not an appreciable speed or wave program effect on CG acceleration in Sea States 5 and 7. Maximum stern acceleration in head seas (Figures 7g and 8g) was about the same magnitude as bow acceleration: 0.25 G's in Sea State 5 and 0.46 to 0.5 G's in Sea States 6 and 7. In following seas maximum stern acceleration was higher than maximum bow acceleration (0.27 G's compared to 0.12 G's).

Figures 9, 10 and 11 contain significant double amplitudes of motions and accelerations plotted versus significant wave height. This was done to evaluate the relative merits of the various configurations investigated. In Figure 9 we see a comparison of motions and accelerations in head Sea States 6 and 7 for the design configuration and large canards forward configuration. Some data points are given for Sea State 5 [$\overline{H}_{1/3}$ = 9 ft (2.7m)] operation with the design configuration to provide a frame of reference at lower wave height. Tick marks or "flags" shown in the legend on the design configuration symbol, were incorporated on all symbols to designate the various wave programs used. At both speeds for which comparative data are available, namely 3 and 8 kts, pitch and RBM were reduced significantly by increasing forward canard size. Heave was also reduced, except at a speed of 3 kts in

FIGURE 9 — COMPARISON OF MOTIONS AND ACCELERATIONS IN HEAD SEAS FOR THE DESIGN CONFIGURATION AND LARGE CANARDS FORWARD CONFIGURATION (DOUBLE AMPLITUDE)



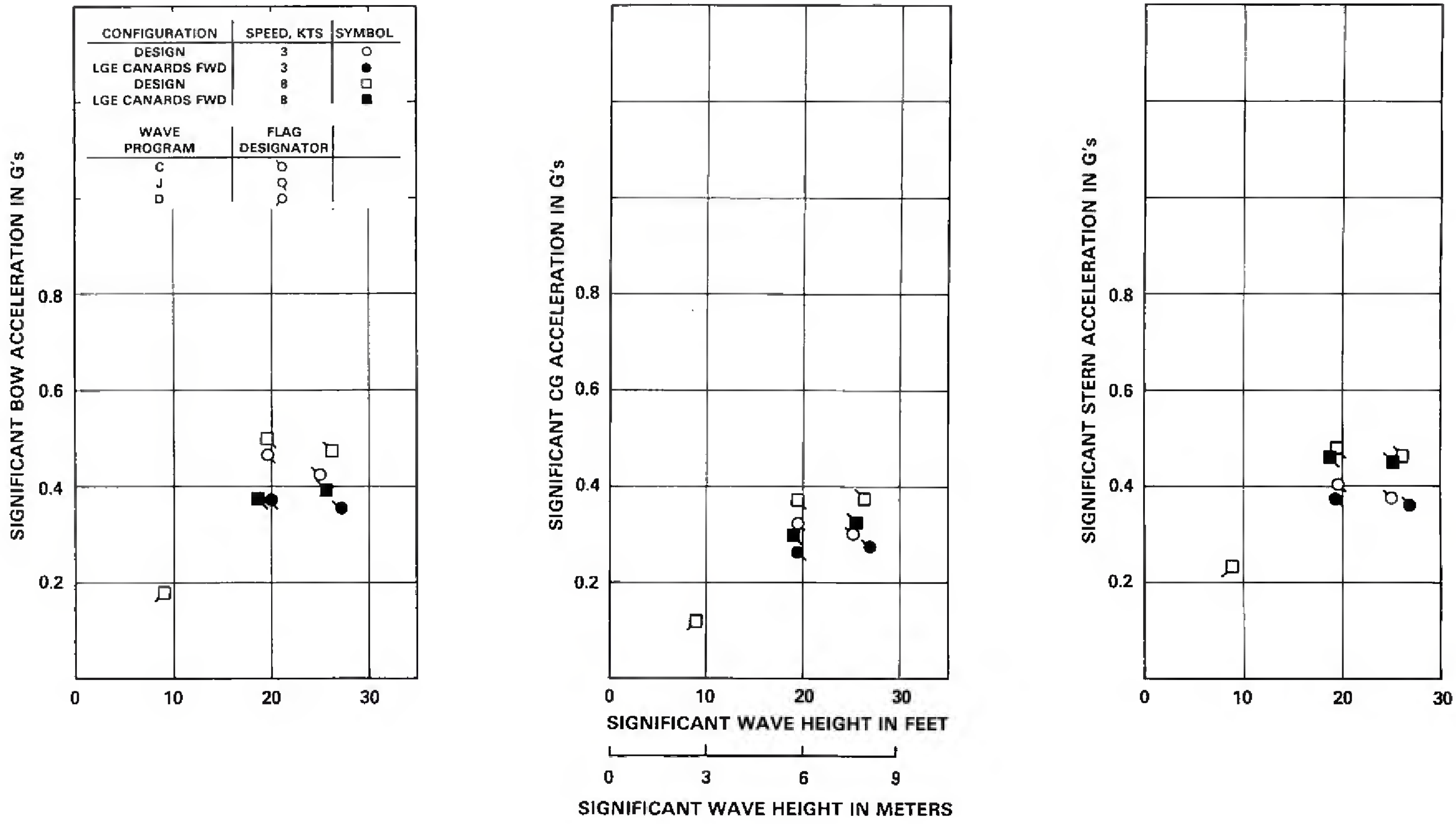
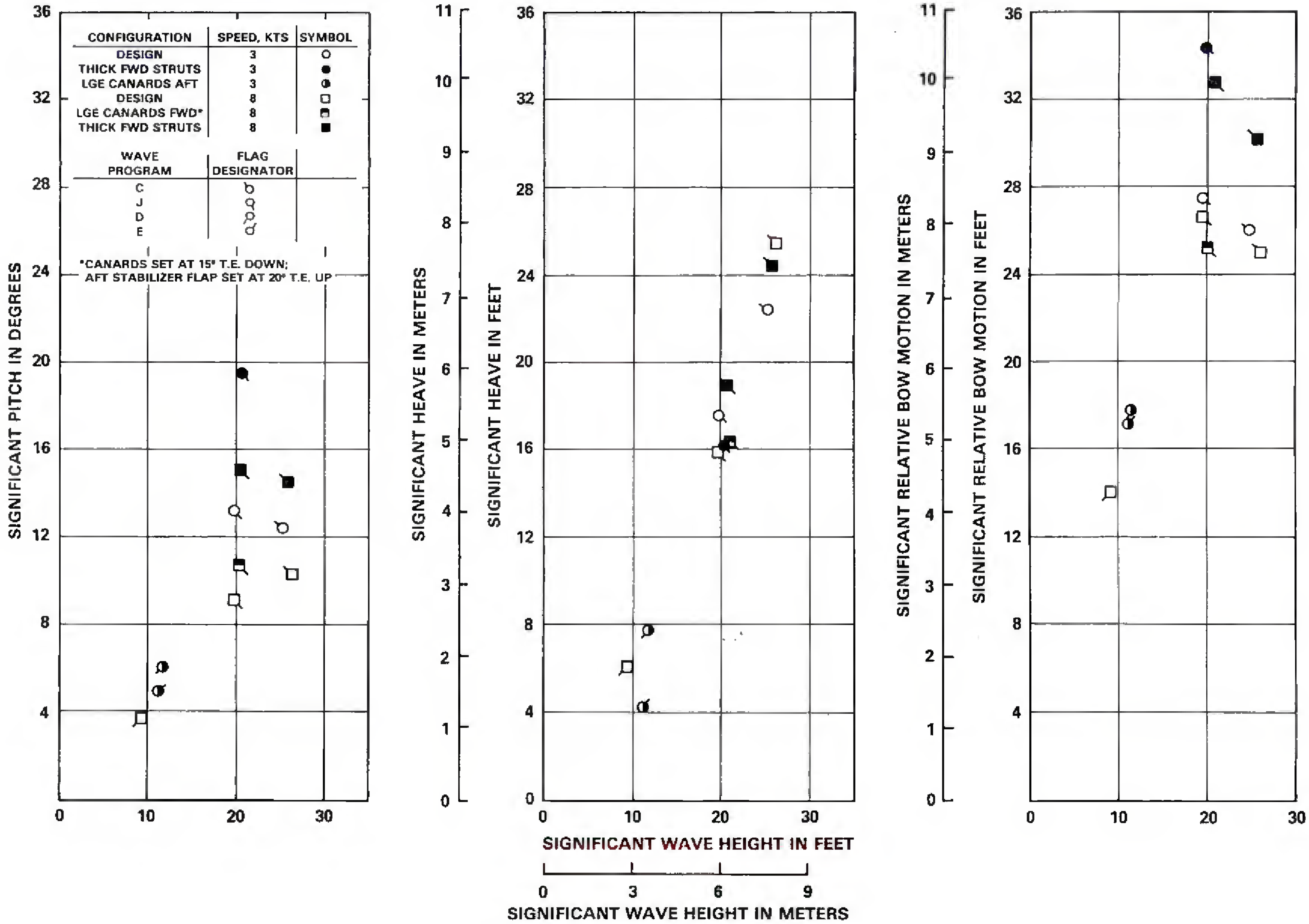


FIGURE 9 (CONTINUED)

FIGURE 10 — COMPARISON OF MOTIONS AND ACCELERATIONS IN HEAD SEAS FOR THE DESIGN CONFIGURATION AND SEVERAL ALTERNATE CONFIGURATIONS DOUBLE AMPLITUDE)



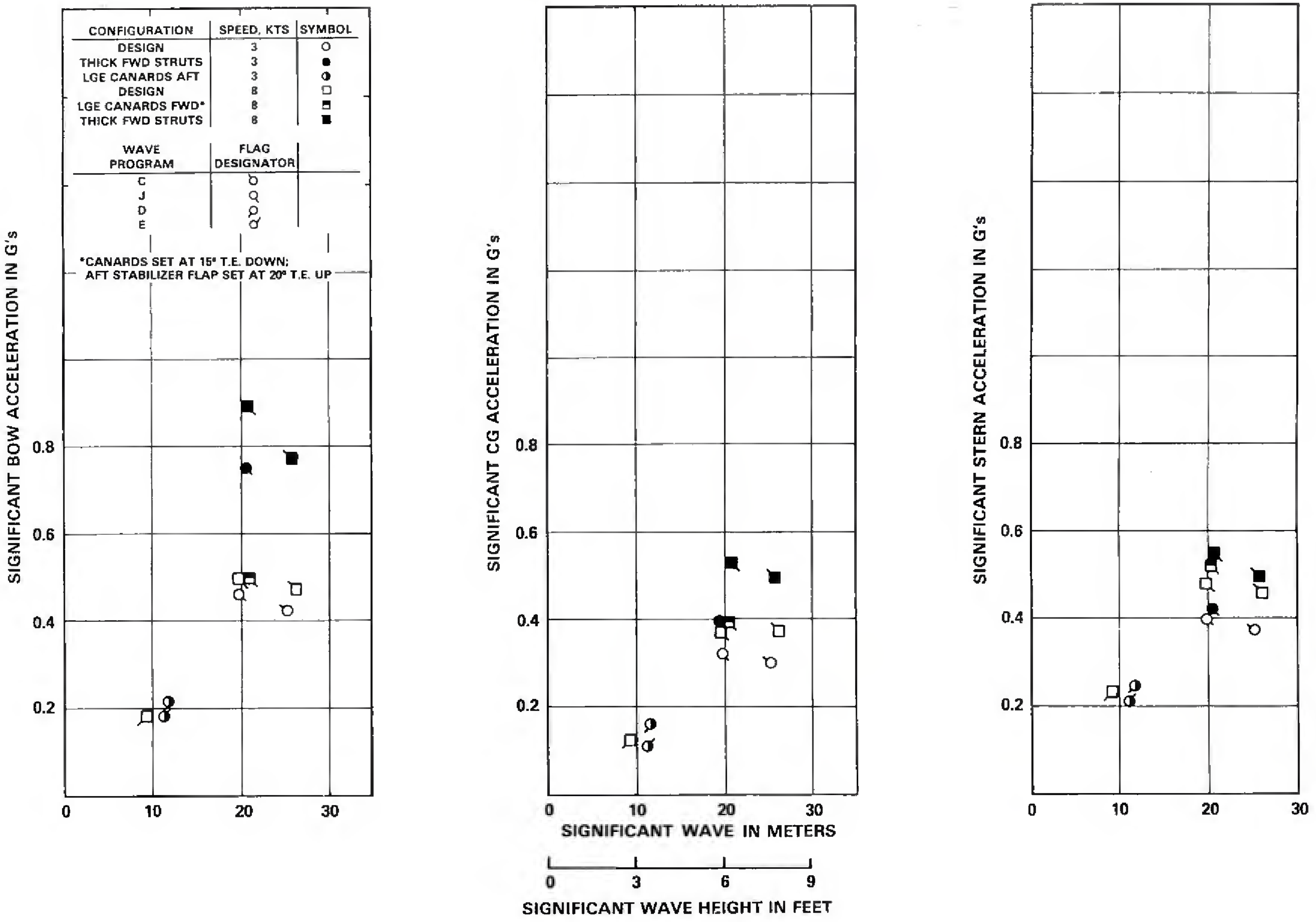
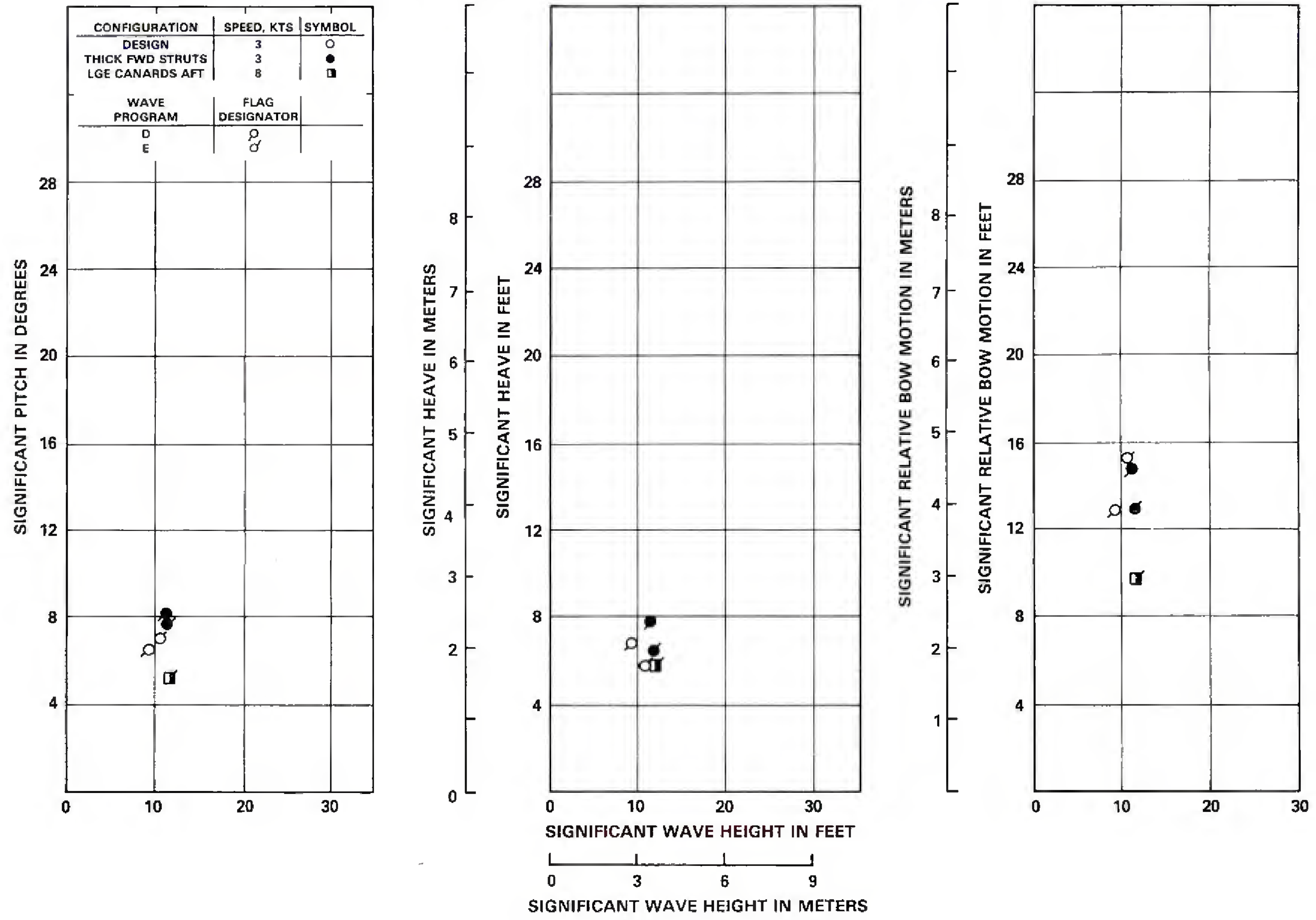


FIGURE 10 (CONTINUED)

FIGURE 11 — COMPARISON OF MOTIONS AND ACCELERATIONS IN FOLLOWING SEAS FOR THE DESIGN CONFIGURATION AND SEVERAL ALTERNATE CONFIGURATIONS (DOUBLE AMPLITUDE)



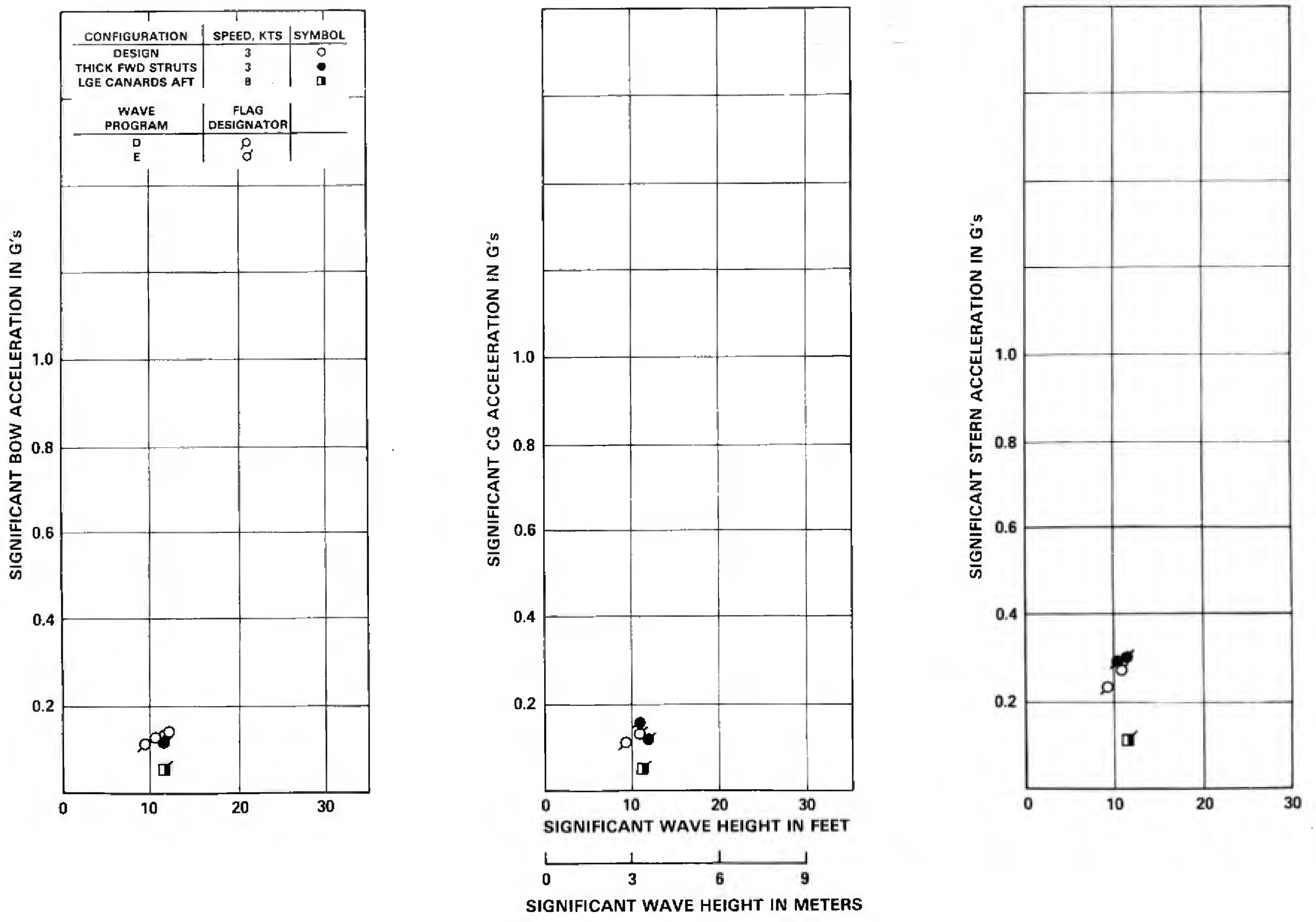


FIGURE 11 (CONTINUED)

Wave Program C. Furthermore, all accelerations were decreased by increasing the size of the forward canard.

Figure 10 contains head sea data for the following configurations in Sea States 5, 6 and 7:

- Design (Small Canards Forward and Full-Span Aft Stabilizer)
- Large Canards Forward (canards set at 15 deg trailing edge down and aft stabilizer flap set at 20 deg trailing edge up)
- Thick Forward Struts with Small Canards Forward and Full-Span Aft Stabilizer
- Small Canards Forward and Full-Span Aft Stabilizer Modified to Simulate Large Aft Canards

The worst pitch characteristic is exhibited by the thick forward struts configuration at both 3 and 8 kts. On a speed for speed comparison, the ship pitched least in the design configuration. Heave superiority is not as evident: for a significant wave height of 25 ft (7.6m) the design configuration heaved the most at 8 kts; however, for a wave height of roughly 20 ft (6.1m) the thick forward struts configuration was poorest at 8 kts and the design configuration was the worst at 3 kts. RBM was most severe with the thick forward struts installed. For the 20 ft (6.1m) wave height three configurations are compared: the large canards forward resulted in the least RBM. The largest accelerations at the bow, CG and stern were brought about by installing thick struts forward, and the smallest accelerations were experienced by the design configuration. Use of large canards forward set at a 15 deg angle of attack resulted in a small increase in CG and stern accelerations compared with the small canards, but had no effect on bow accelerations.

Using Figure 11 we can compare motions and accelerations in State 5 following seas for the design, large canards aft, and thick forward struts configurations. Removal of the middle one-third of the aft stabilizer span to, in effect, create two large canards aft, resulted in the smallest values of all motions and accelerations. The data for the large canards aft are for 8 kts, while for the design configuration and thick strut configuration the only data are for 3 kts. Normally, the measured accelerations were found to increase at higher ship speeds, so that the conclusion can be drawn that, if the design configuration had been tested at 8 kts, the accelerations would have been higher than those measured with the aft stabilizer replaced by two large canards. It would appear that the full-span stabilizer does increase the lift on the stern due to waves in following seas. Comparing data for the same conditions (i.e., speed and wave program) we find that the thick forward struts usually caused the worst motions (an exception is RBM at 3 kts in Wave Program E). The design and thick forward struts configurations compete for having the highest accelerations in following seas.

Ship responses in bi-directional seas are given in Table 7. Wave Program F was encountered off the starboard bow and Wave Program D (modified with higher significant wave height) was encountered simultaneously off the port bow; they combined to produce Wave Program G with a significant wave height of about 20 ft (6.1m). The motions and accelerations in bi-directional seas are appreciable compared to those recorded in unidirectional waves of the same height, but they are not the largest.

Impact accelerations were measured in random waves as shown in Figure 5 and discussed on page 13. The results are presented in Table 8 which should be keyed to Table 4 using run numbers so that the test conditions can be determined. The three largest impact accelerations recorded at each of three locations -- bow, CG and stern -- are tabulated. Where less than three values are given, fewer impacts occurred in the data sample; if none are given, either no impacts were sensed at that location, or the transducer was inoperative for that series of runs. A severe bow impact acceleration of 2.73 G's was recorded; it occurred when the thick forward struts were installed and the ship was operating in head seas (Wave Program J) at 3 kts. The largest stern impact (1.17 G's) was also sustained with the thick forward struts configuration; in this case for 8 kts, head seas, Wave Program C. The design configuration experienced the largest CG acceleration of 1.57 G's: the ship's forward speed was 8 kts, and it was operating in head Wave Program J.

Since the structure of the proposed prototype was not scaled in the model used for the experiments, the impact acceleration data presented must be used with caution. They should be useful for determining relative levels of acceleration for the various configurations tested. However, absolute values of acceleration may not be correct at prototype scale.

The results of analysis of the impact pressure data have been reported

TABLE 7

SIGNIFICANT DOUBLE AMPLITUDE OF MOTIONS AND ACCELERATIONS IN BI-DIRECTIONAL SEAS; DESIGN CONFIGURATION

RUN NUMBERS	SPEED, KTS	WAVE PROGRAM	PITCH, DEG	HEAVE, FT	HEAVE, M	RBM, FT	RBM, M	ROLL, DEG	BOW ACCELERATION, G's	CG ACCELERATION G's	STERN ACCELERATION G's
578-581	3	G	9.0	17.2	5.2	21.4	6.5	7.3	0.36	0.28	0.36
594-597	3	G	10.4	15.8	4.8	—	—	11.9	0.22	0.18	0.31
582-587	8	G	6.9	16.9	5.2	21.3	6.5	7.4	0.37	0.33	0.45

TABLE 8

IMPACT ACCELERATIONS IN RANDOM WAVES

RUN	BOW ACCELERATION, G's			CG ACCELERATION, G's			STERN ACCELERATION, G's		
NUMBERS	HIGHEST	2ND	3RD	HIGHEST	2ND	3RD	HIGHEST	2ND	3RD
623	–			–			0.31	0.29	0.29
128				0.05			0.03		
384	1.21	1.14	1.14	0.71	0.47	0.47	0.55	0.49	0.41
624	1.21	0.97	0.65	0.47	0.47	0.21	0.95	0.92	0.88
483	–			–			0.88	0.71	0.59
204	0.57	0.48	0.22	0.53	0.21	0.19	0.17	0.13	
108	0.75	0.57	0.40	0.23	0.23	0.21	0.27	0.20	0.05
568-572	1.27	1.27	1.17	1.44	0.96	0.96	0.83	0.80	0.77
371,372	1.21	1.14	1.14	0.48	0.48	0.45	0.57	0.56	0.55
374,375	1.21	1.14	1.14	0.47	0.45	0.44	0.84	0.81	0.55
385-387	1.30	1.30	1.24	0.71	0.69	0.65	0.84	0.83	0.81
487-494	1.40	1.27	1.27	0.75	0.71	0.68	0.88	0.83	0.83
524-527	1.33	1.33	1.30	0.84	0.75	0.72	0.92	0.91	0.88
484-486	–			0.15	0.14	0.13	0.21	0.09	0.05
837-840	–			0.22	0.18	0.16	0.21	0.19	
591,592	1.68	1.55	0.95	0.35	0.31	0.40	0.15		
205,206	0.98			0.29	0.12		0.27	0.23	0.21
850,851	–			0.23	0.23	0.23	0.76	0.75	0.63
471,472	–			0.13	0.13	0.12	0.24	0.21	0.20
841-843	0.30			0.26	0.24	0.15	0.21		
613,614	0.19	0.17	0.17	0.47	0.47	0.19	0.51	0.44	0.29
848,849	0.71	0.63	0.62	0.27	0.27	0.25	0.93	0.91	0.89
286,287	–			0.15	0.15	0.11	0.23	0.20	0.18
578-581	1.30	1.14	1.14	0.51	0.51	0.49	0.83	0.83	0.83
594-597	0.25			0.52	0.47	0.45	0.52	0.48	0.41
598,599	–			0.20	0.19	0.17	0.27	0.23	0.23
610-612	0.35	0.25	0.19	0.52	0.52	0.51	0.55	0.43	0.36
562,563	1.14	0.83	0.79	0.80	0.80	0.64	0.77	0.69	0.37
513,514	1.02	0.98	0.98	1.15	0.93	0.88	1.07	1.07	0.96
702,703	2.73	2.60	2.53	1.20	1.09	1.07	0.83	0.83	0.83

TABLE 8 (CONTINUED)

RUN	BOW ACCELERATION, G's			CG ACCELERATION, G's			STERN ACCELERATION, G's		
NUMBERS	HIGHEST	2ND	3RD	HIGHEST	2ND	3RD	HIGHEST	2ND	3RD
564-567	1.36	1.30	1.27	1.44	0.93	0.91	0.77	0.77	0.77
573-577	1.52	1.49	1.27	1.28	0.91	0.83	0.85	0.85	0.83
495-504	1.36	1.30	1.30	1.15	1.01	0.99	0.85	0.83	0.77
528-532	1.46	1.46	1.33	1.55	1.49	1.44	0.88	0.88	0.83
697-701	2.03	1.97	1.97	1.01	1.01	1.01	1.17	1.15	1.12
119-121	1.14			0.37	0.37		0.56	0.34	0.25
844-847	0.73	0.63	0.60	0.26	0.25	0.25	0.89	0.75	0.60
582-587	1.36	1.33	1.30	0.92	0.52	0.52	0.96	0.83	0.83
515-518	1.43	1.40	1.36	1.57	1.55	1.44	0.96	0.88	0.88
536-539	1.30	1.24	1.14	1.39	1.01	0.96	0.88	0.85	0.83
556-559	1.40	1.33	1.33	1.41	0.93	0.93	0.83	0.83	0.83
704-707	2.54	2.48	2.48	1.01	0.99	0.96	1.04	1.04	1.04
111-114	0.62	0.57		0.25	0.25	0.23	0.93	0.89	0.81
388,389	–			0.48	0.47	0.47	0.88	0.84	0.83
207-210	0.51	0.32	0.25	0.52	0.45	0.25	0.40	0.35	0.35
473-482	–			0.15	0.14	0.14	0.24	0.20	0.20
615-622	–			0.27	0.24	0.19	0.53	0.53	0.53
600-609	–			0.25	0.24	0.21	0.41	0.39	0.35
137-145	–			0.33	0.17		0.20		
211-215	1.87	1.55	1.46	0.56	0.53	0.23	0.95	0.92	0.41
115-118	1.21	1.14	0.98	0.43	0.41	0.17	0.59	0.39	0.39
831-835	0.98	0.98	0.98	0.49	0.47	0.45	0.99	0.99	0.96

separately by the Structures Department of DTNSRDC.* Both impact accelerations and pressures were read from strip chart records after the tests were completed.

SHIP RESPONSES IN REGULAR WAVES

Transfer functions (TF's) were obtained for the motions and accelerations of the STRETCHED SSP in regular waves. These are discussed in the text that follows. A harmonic analysis of the time-histories was carried out, and the non-dimensional transfer functions were calculated from values of the fundamental of ship response and wave height. In some of the non-dimensionalizations, the maximum wave slope given by $\pi H/\lambda$, where H is wave height and λ is wave length, was used. Also used was ω_e, the frequency of wave encounter derived from the measured signals.

Figures 12, 13 and 14 contain TF's obtained from experiments in head waves of approximately constant height [8 ft (2.4m) was desired]. They are for the design configuration, and cover speeds of 0, 3 and 8 kts, respectively. As speed increases from 0 to 8 kts, pitch damping increases so that at 8 kts the maximum value of the TF barely exceeds 1.0. The heave TF peak shifts to a longer wave length as speed increases. This is a common occurrence: a longer wave length is required to produce the resonant frequency of wave encounter as speed is increased in head seas. The magnitude of maximum heave, however, remains about the same when speed changes.

Peak RBM also shifts to longer wave lengths with speed increase and the peak value decreases -- particularly in going from 0 to 3 kts (i.e., from a magnitude of 2.6 to 1.8). A segment of the RBM curve for 0 kts is drawn broken because the recorded signal was somewhat erratic for those runs. Roll is small (as expected) in head seas. There is some increase in magnitude for wave lengths greater than 800 ft (243.8m) at 0 and 3 kts, but this may be due to difficulty in maintaining the model on course (i.e., perpendicular to the wave crests) in the longer waves.

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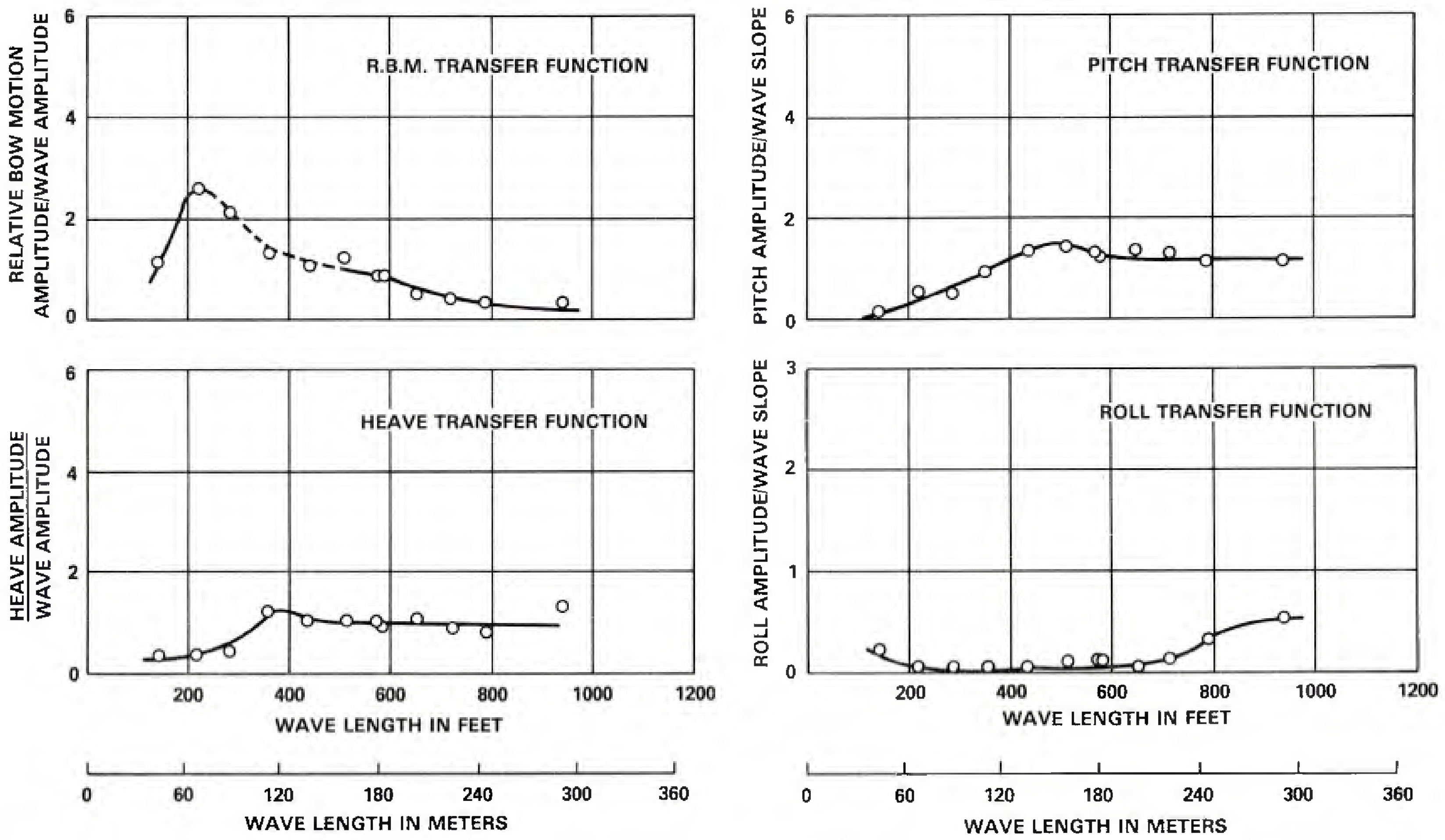
*Enclosure (4) to DTNSRDC ltr 1113:GRL, Ser 3900 of 12 Mar 1981.

FIGURE 12—MOTION TRANSFER FUNCTIONS FOR THE DESIGN CONFIGURATION AT A SPEED OF 0 KNOTS IN HEAD SEAS (180 DEGREE HEADING)



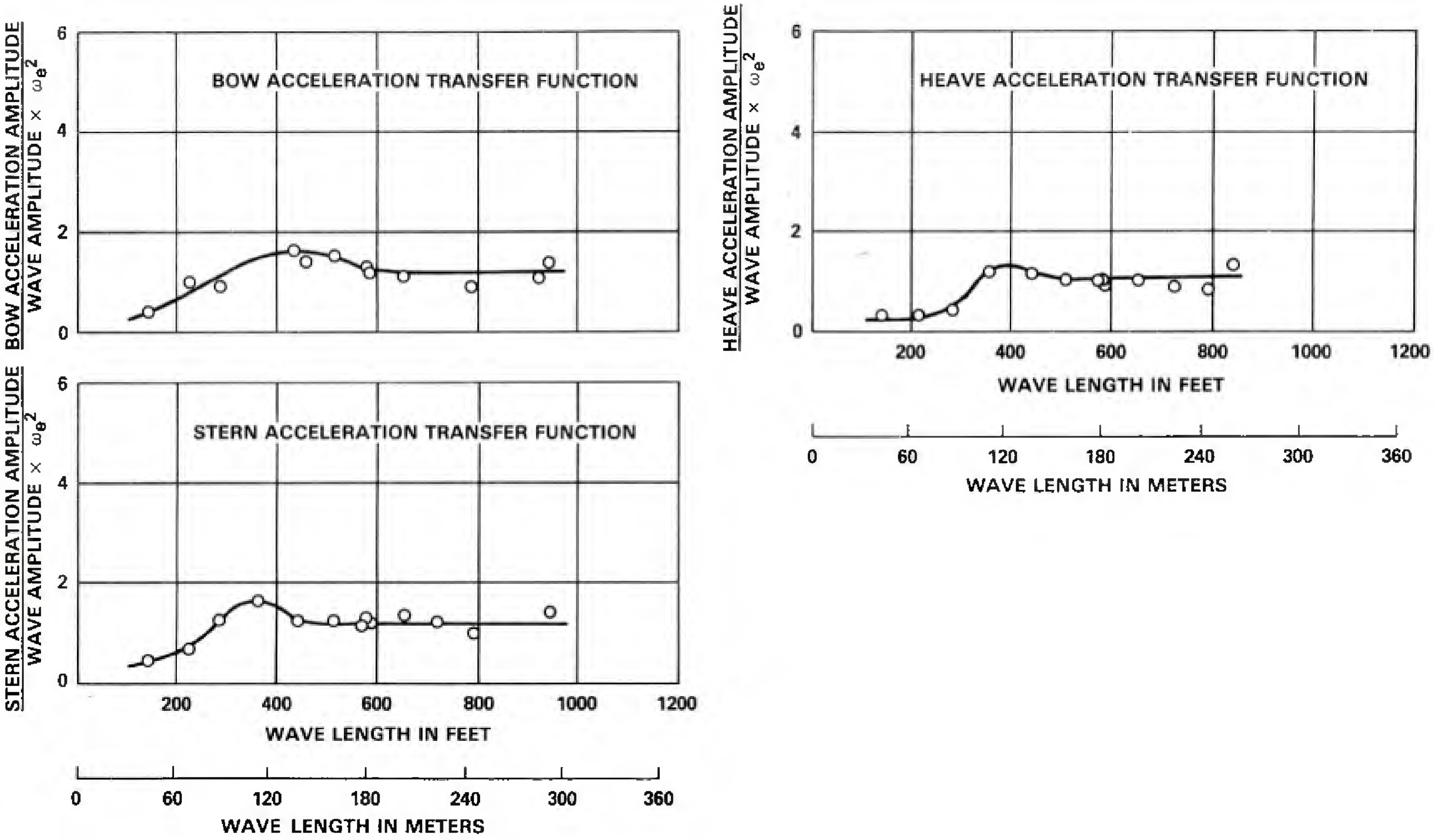
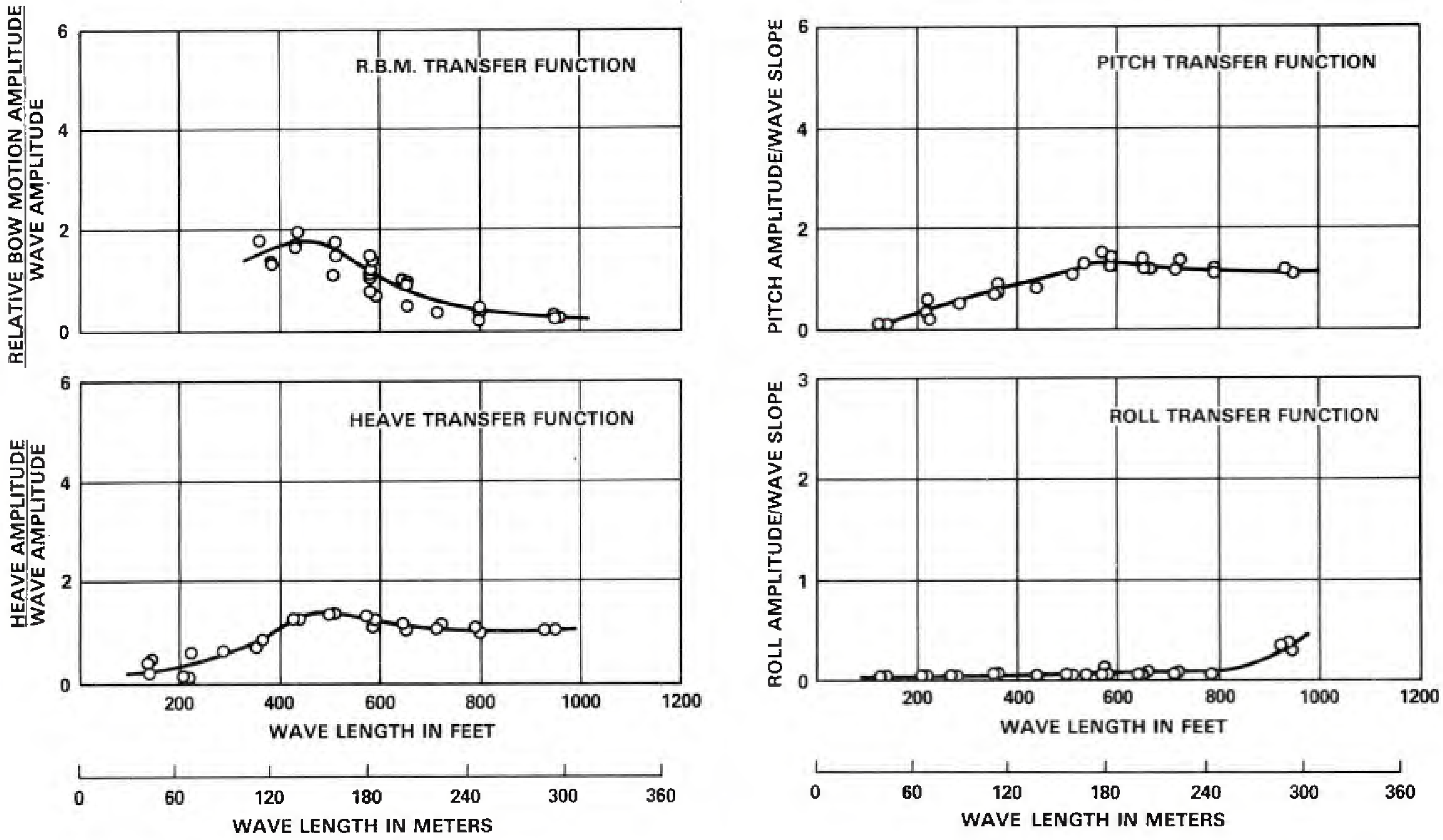


FIGURE 12 (CONTINUED)

FIGURE 13—MOTION TRANSFER FUNCTIONS FOR THE DESIGN CONFIGURATION AT A SPEED OF 3 KNOTS IN HEAD SEAS (180 DEGREE HEADING)



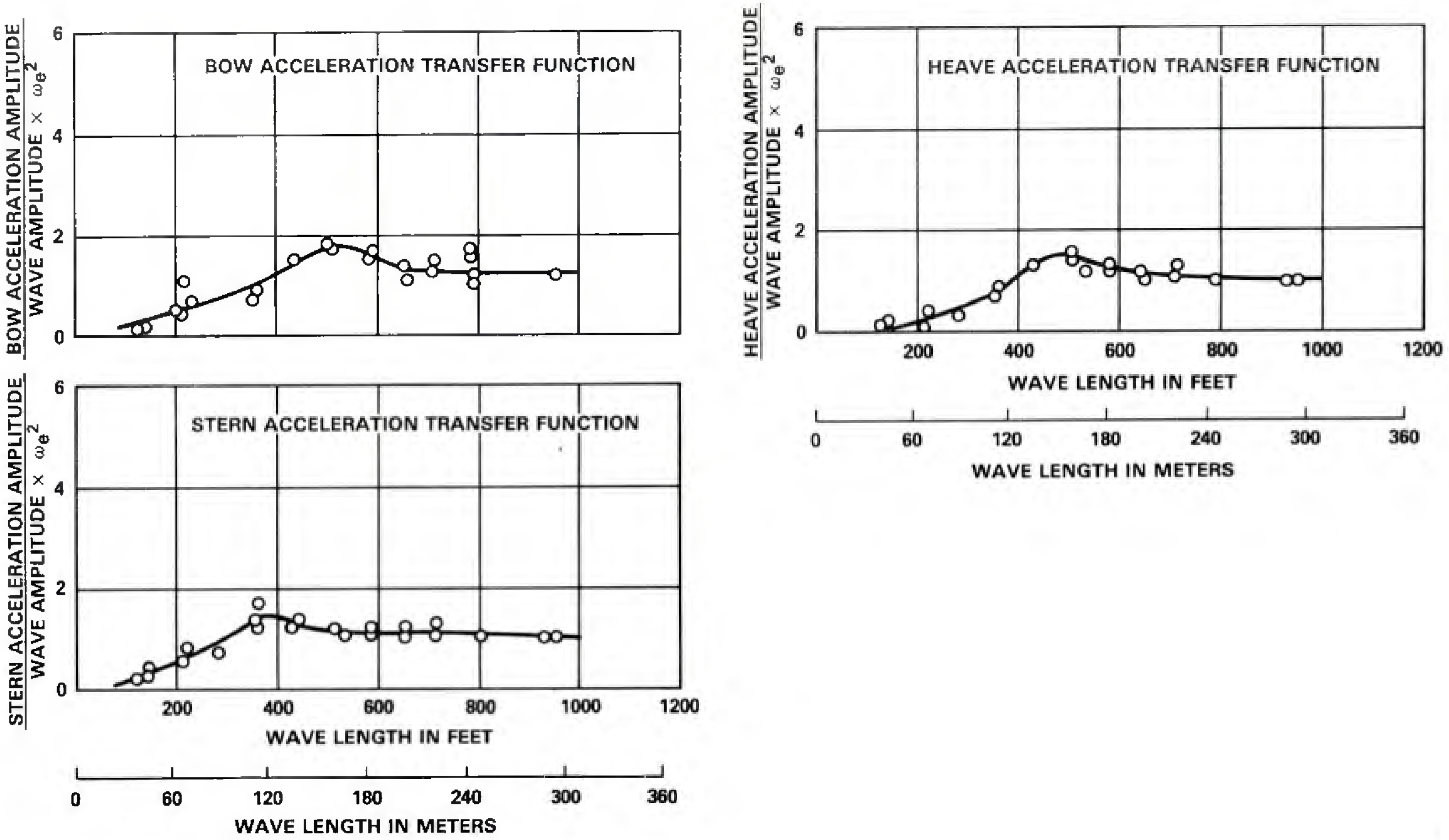
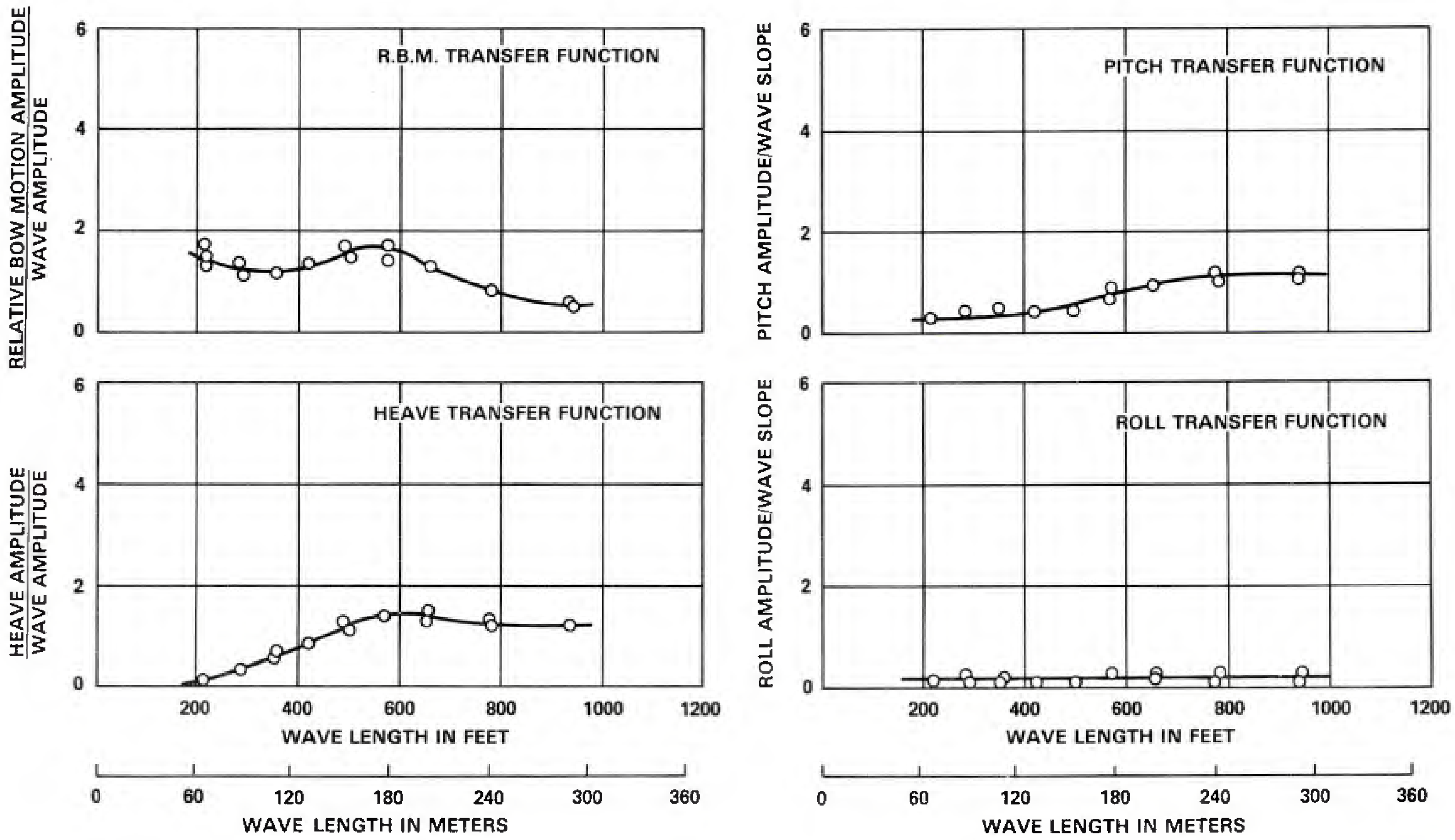


FIGURE 13 (CONTINUED)

FIGURE 14—MOTION TRANSFER FUNCTIONS FOR THE DESIGN CONFIGURATION AT A SPEED OF 8 KNOTS IN HEAD SEAS (180 DEGREE HEADING)



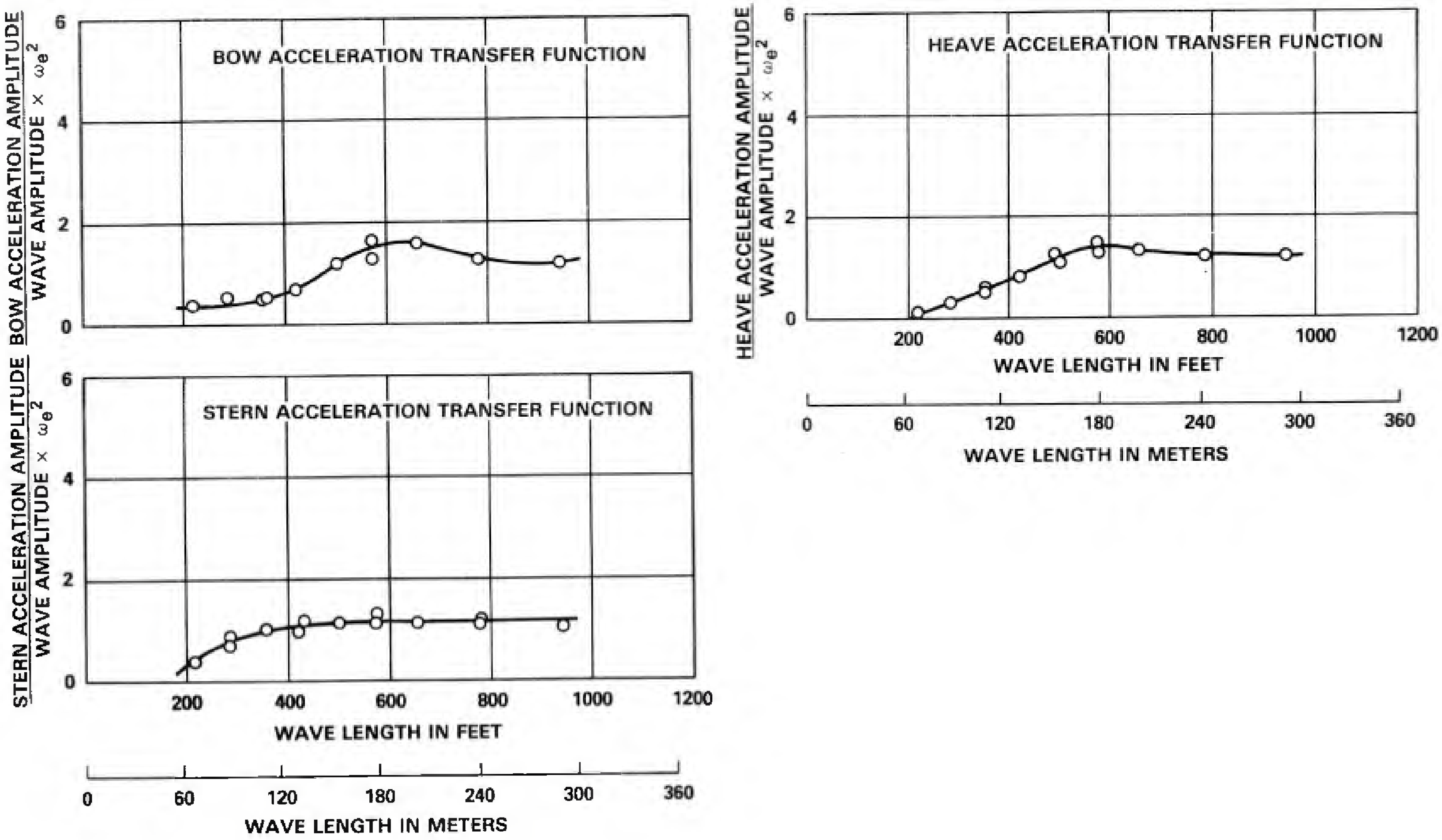


FIGURE 14 (CONTINUED)

All of the acceleration transfer functions have peaks which shift to longer wave lengths with speed increase. The magnitude of peak bow acceleration is fairly constant ranging from 1.6 to 1.8, and the heave acceleration peak ranges from 1.3 to 1.5. Maximum stern acceleration decreases significantly with speed increase, so that at 8 kts the TF isrepresentative of a critically damped spring-mass-dashpot system; specifically, the TF peak decreases from 1.6 to 1.2 as speed increases from 0 to 8 kts.

Operation with the design configuration in bow seas is characterized by the transfer functions presented in Figures 15 and 16; these are for speeds of 0 and 3 kts. The RBM, pitch and heave TF's don't change much as speed is increased; however, some details of their shape -- such as broadness or location of a peak -- are altered. Part of the RBM curve for 3 kts is drawn broken, again because the recorded trace was erratic for a few runs. The maximum RBM value for zero speed is much lower in bow seas than in head seas (approximately 1.8 compared to 2.6). The difference between bow seas and head seas RBM TF's is not as great at 3 kts.

Accelerations in long waves greater than 500 ft (152.4m) are less severe in bow waves than in head waves. Furthermore, for large wave lengths 45 deg off the bow, accelerations are lower at 0 kts than at 3 kts.

Some roll response is evident in bow seas, and it tends to increase with wave length, reaching a roll per unit wave slope value of roughly 1.6 at 0 speed in waves 1,000 ft (304.8m) long.

Figures 17 and 18 show regular wave responses in beam seas for the design configuration. It is not surprising that roll increases a lot compared to the magnitude in head and bow waves since there is much roll excitation in beam seas. Scatter in the data points indicates that roll is sensitive to heading relative to the waves, and that the heading is not being maintained precisely. Maximum values of the TF reach about 4.2 at 0 kt and 3.3 at 3 kts. This degree of magnification* indicates that roll motion is lightly damped at low speeds. The maxima occur in wave lengths of 900 to 950 ft

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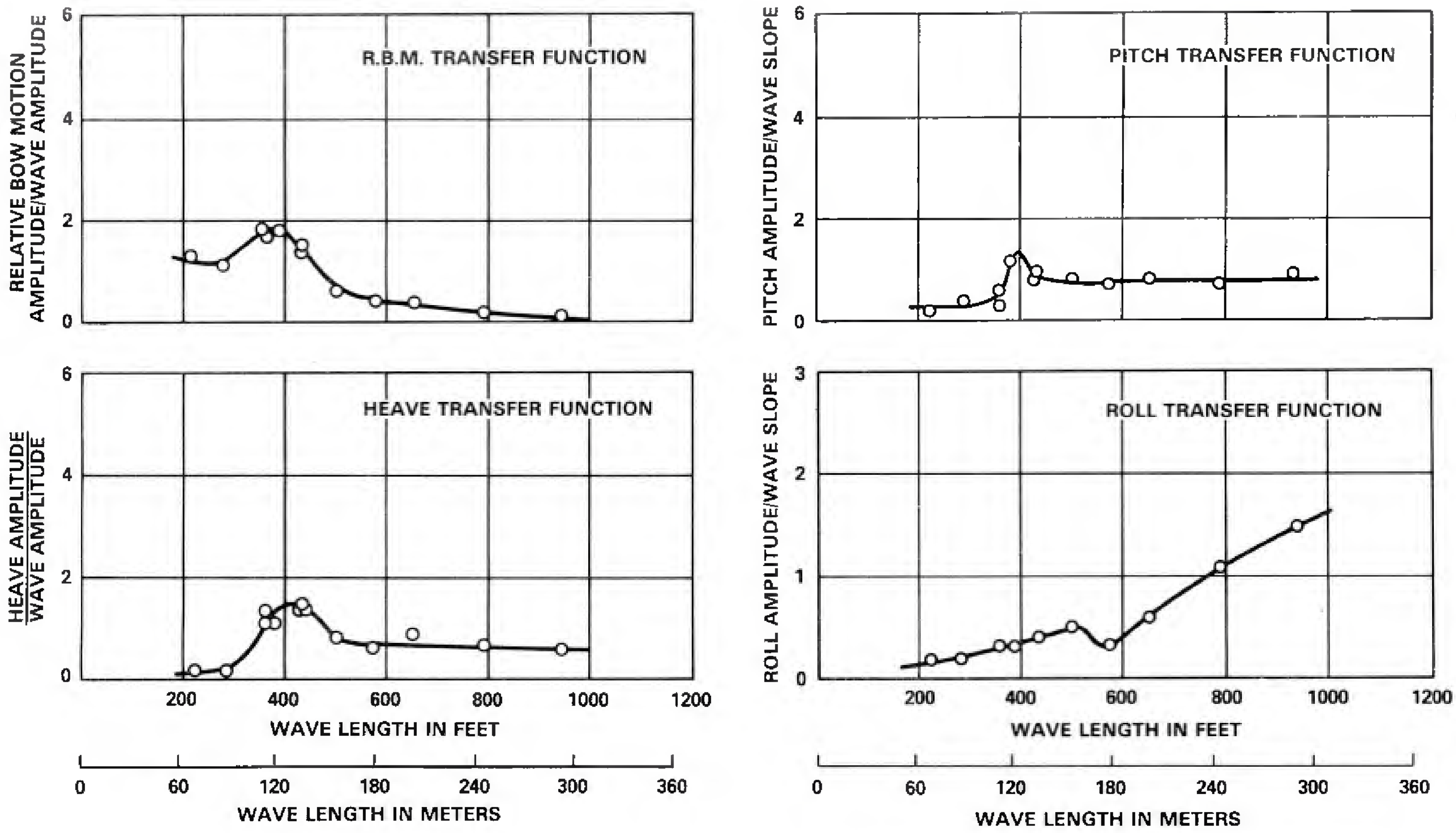
*Magnification represents the factor by which the zero frequency (static) response must be multiplied to determine the dynamic response, assuming the same peak force or moment is applied.

FIGURE 15 — MOTION TRANSFER FUNCTIONS FOR THE DESIGN CONFIGURATION AT A SPEED OF 0 KNOTS IN BOW SEAS (135 DEGREES HEADING)



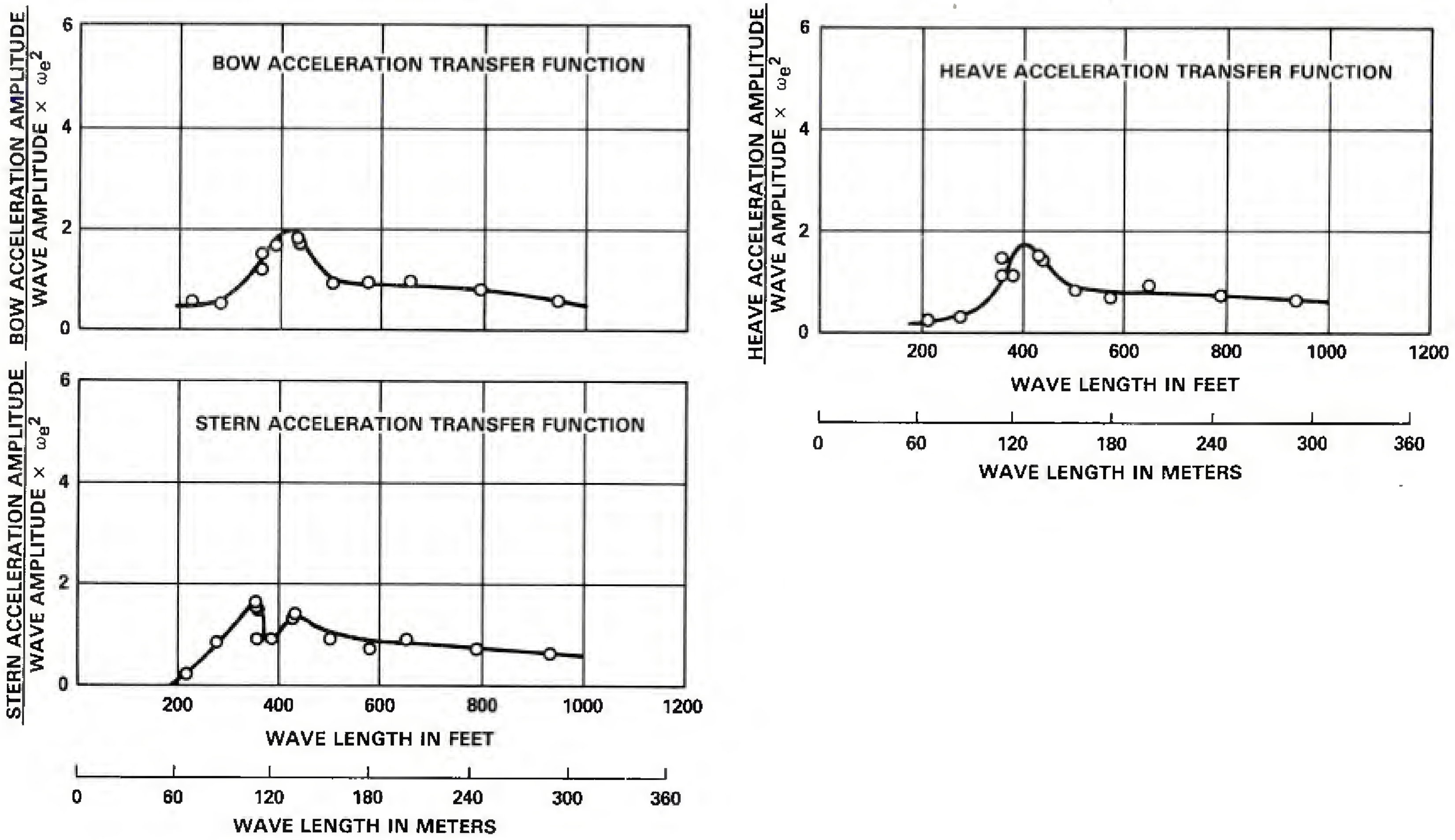
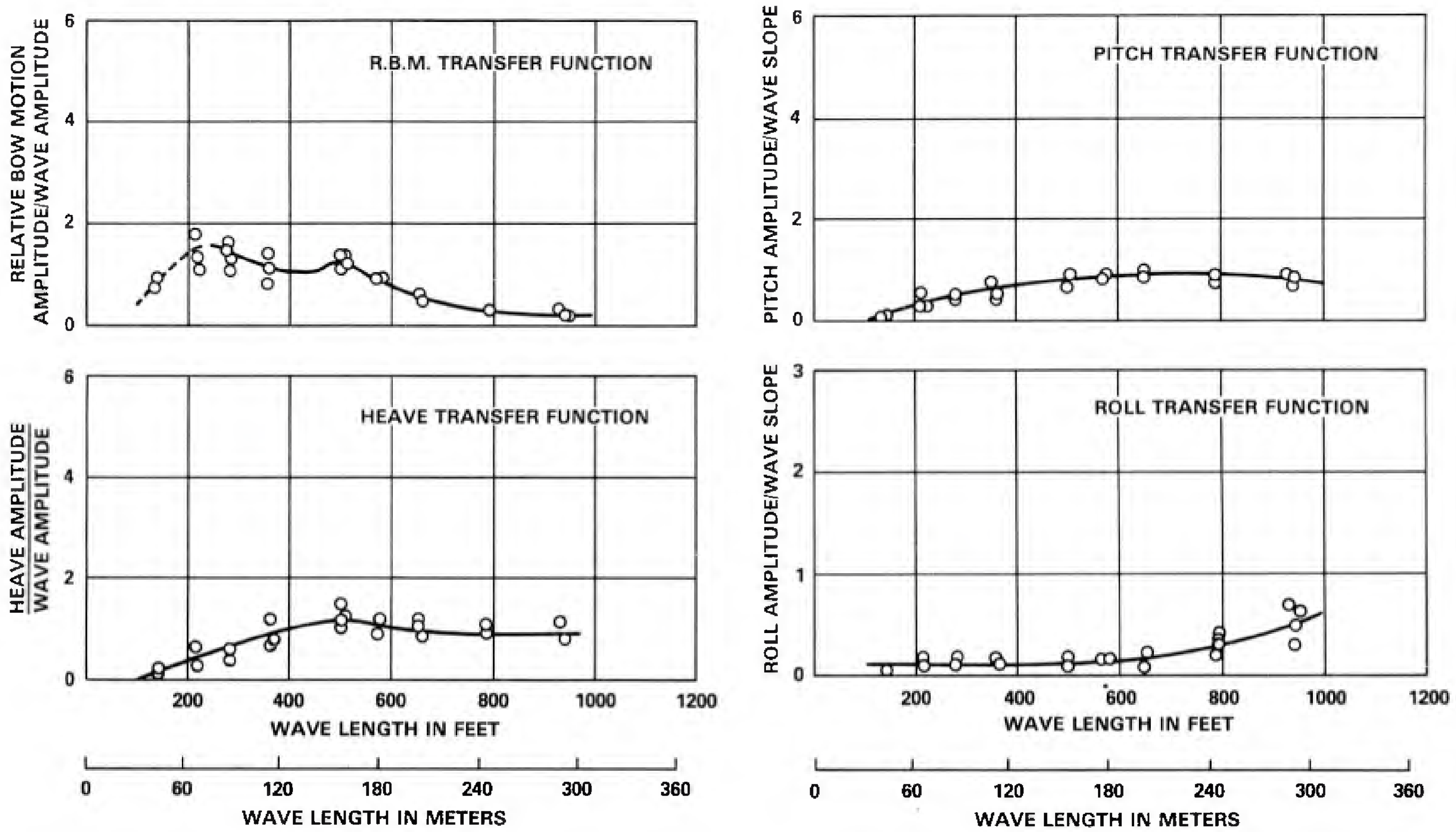


FIGURE 15 (CONTINUED)

FIGURE 16—MOTION TRANSFER FUNCTIONS FOR THE DESIGN CONFIGURATION AT A SPEED OF 3 KNOTS IN BOW SEAS (135 DEGREE HEADING)



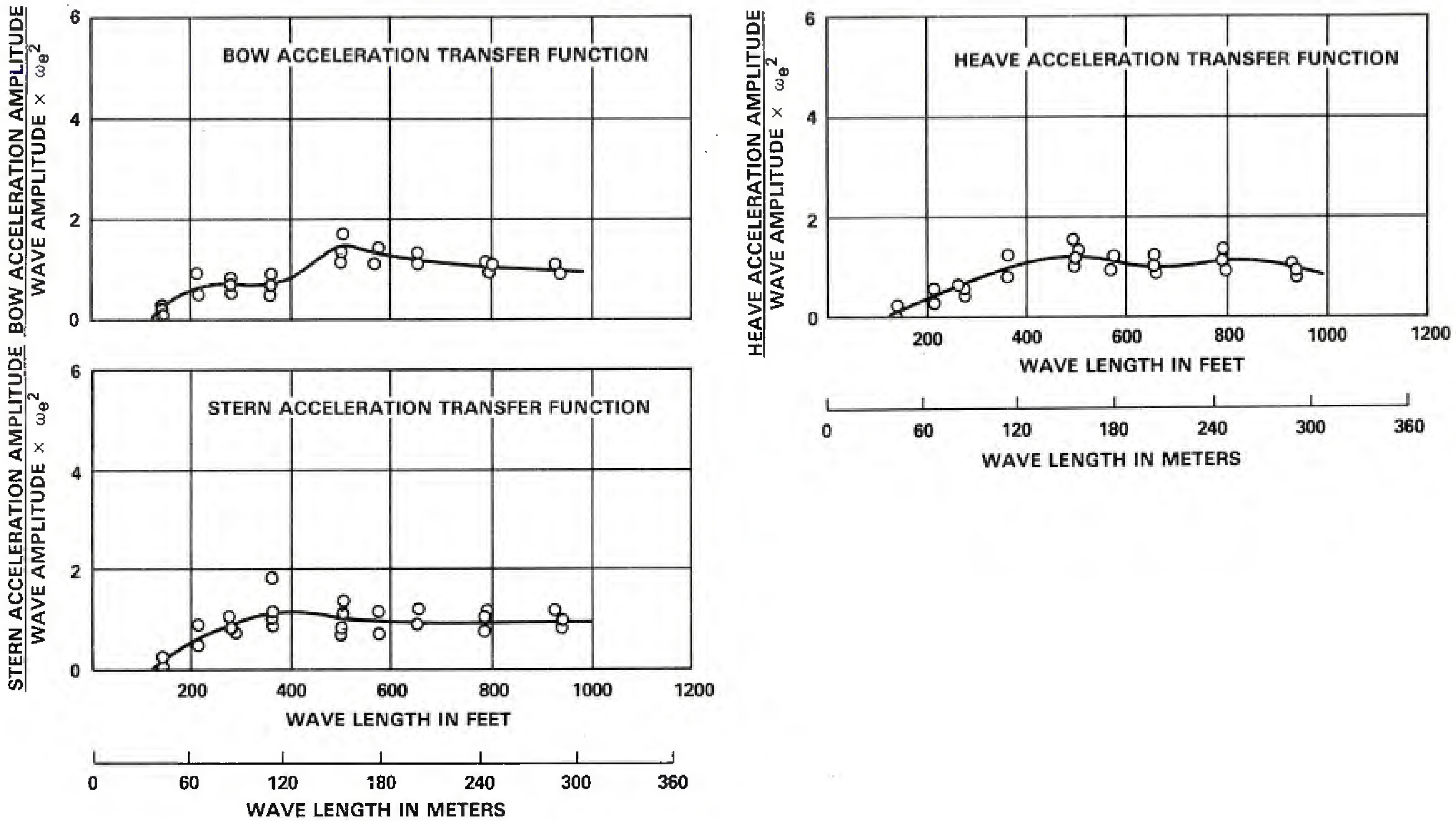
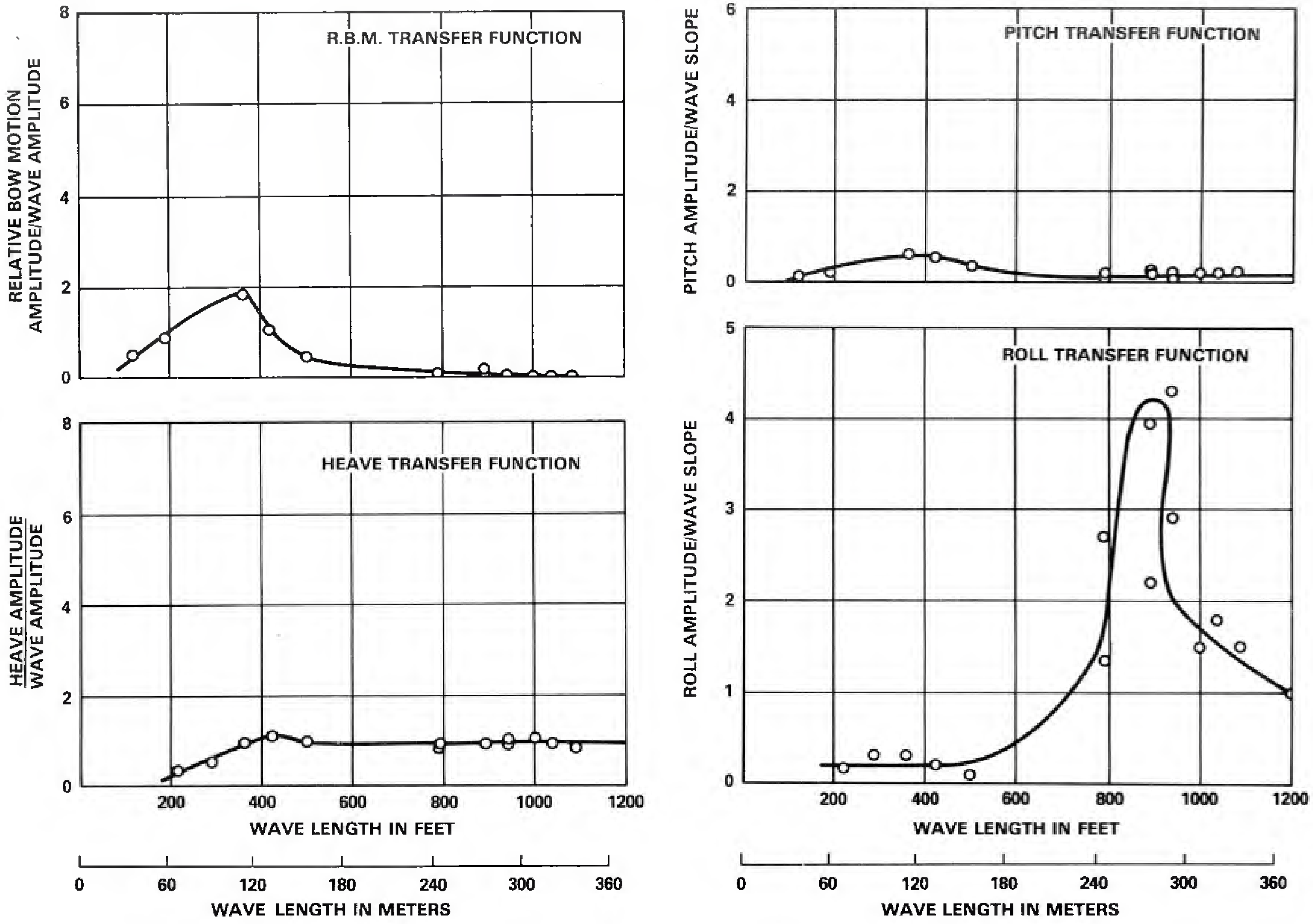


FIGURE 16 (CONTINUED)

FIGURE 17—MOTION TRANSFER FUNCTIONS FOR THE DESIGN CONFIGURATION AT A SPEED OF 0 KNOTS IN BEAM SEAS (90 DEGREE HEADING)



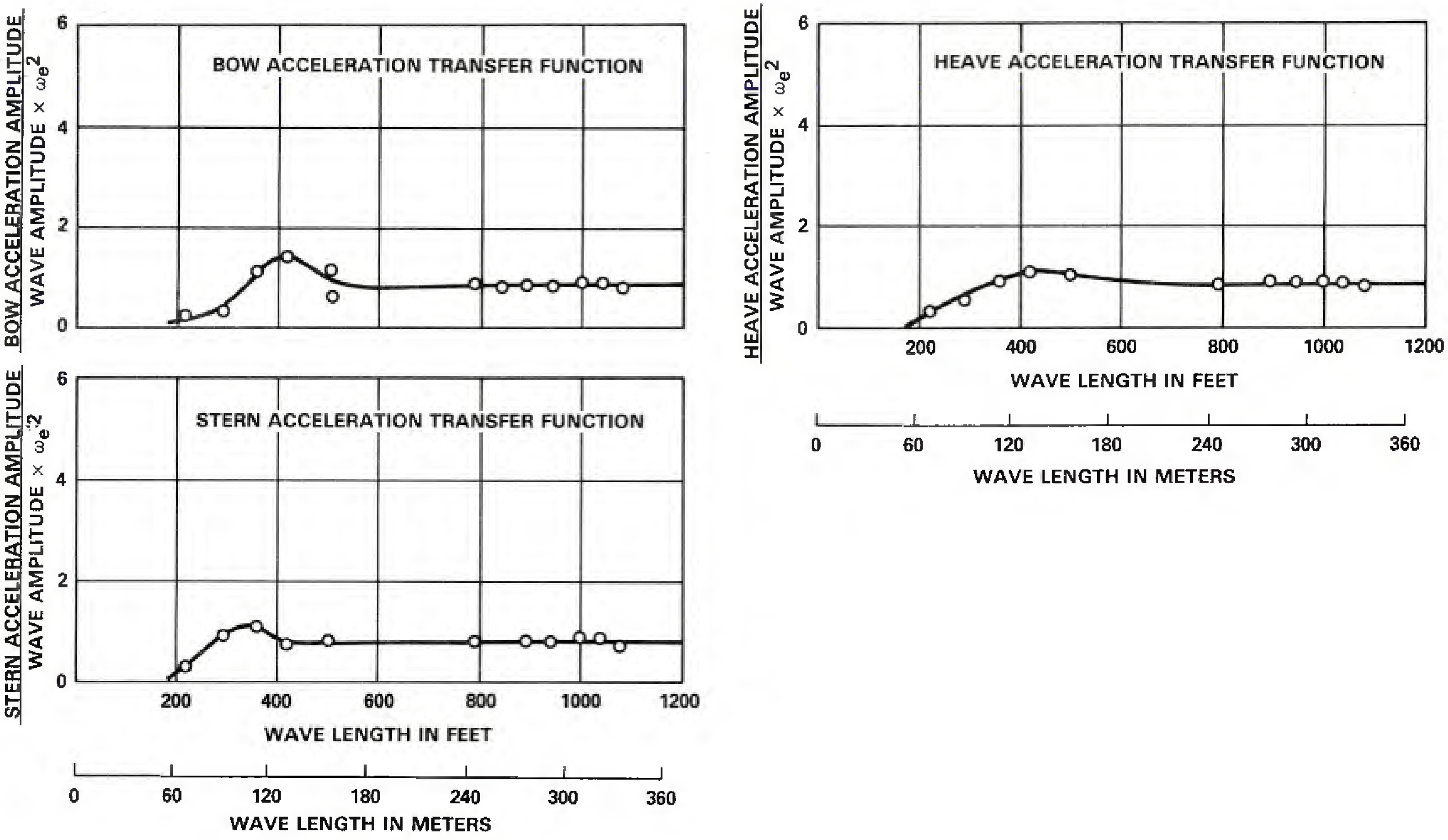
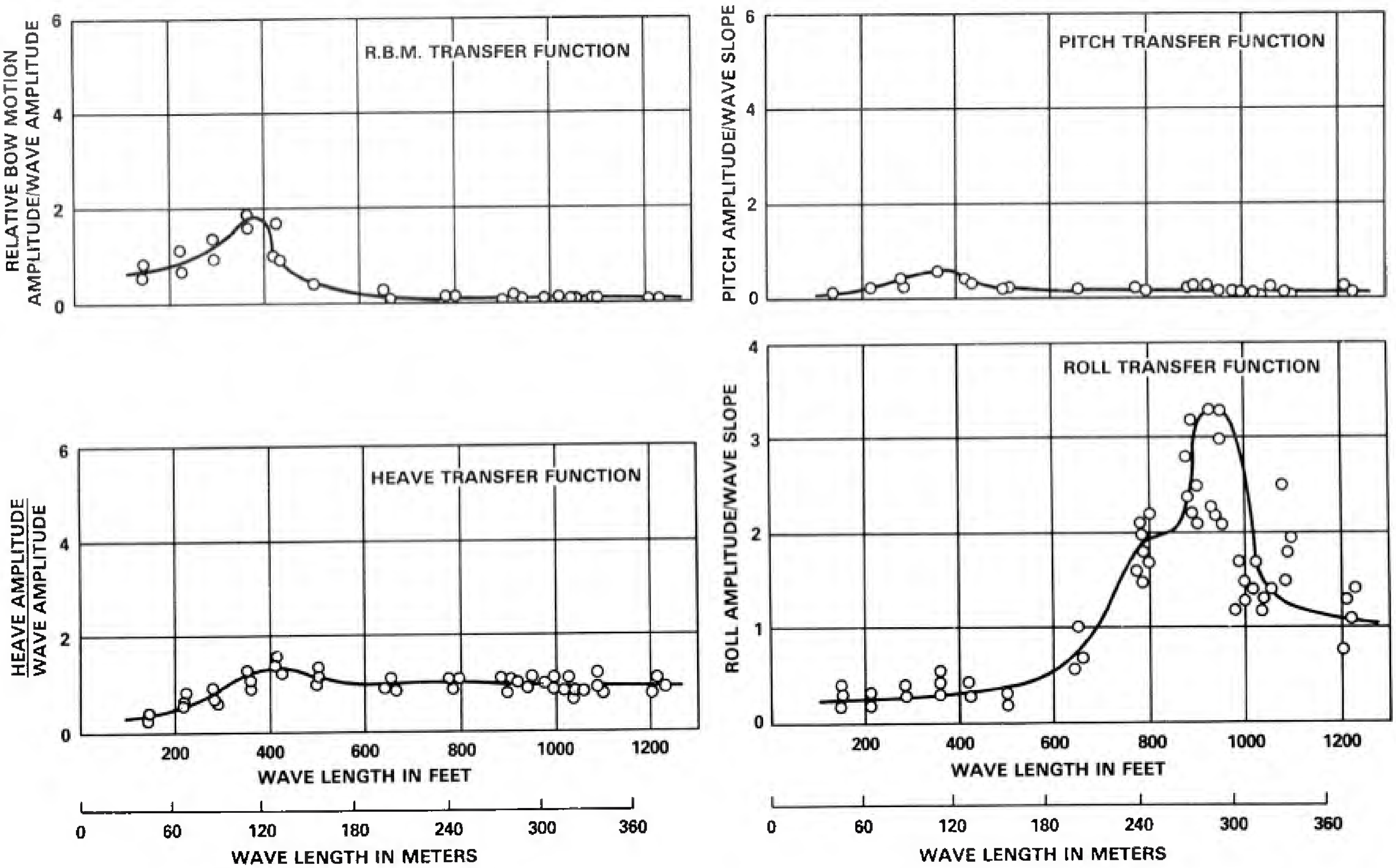


FIGURE 17 (CONTINUED)

FIGURE 18—MOTION TRANSFER FUNCTIONS FOR THE DESIGN CONFIGUTATION AT A SPEED OF 3 KNOTS IN BEAM SEAS (90 DEGREE HEADING)



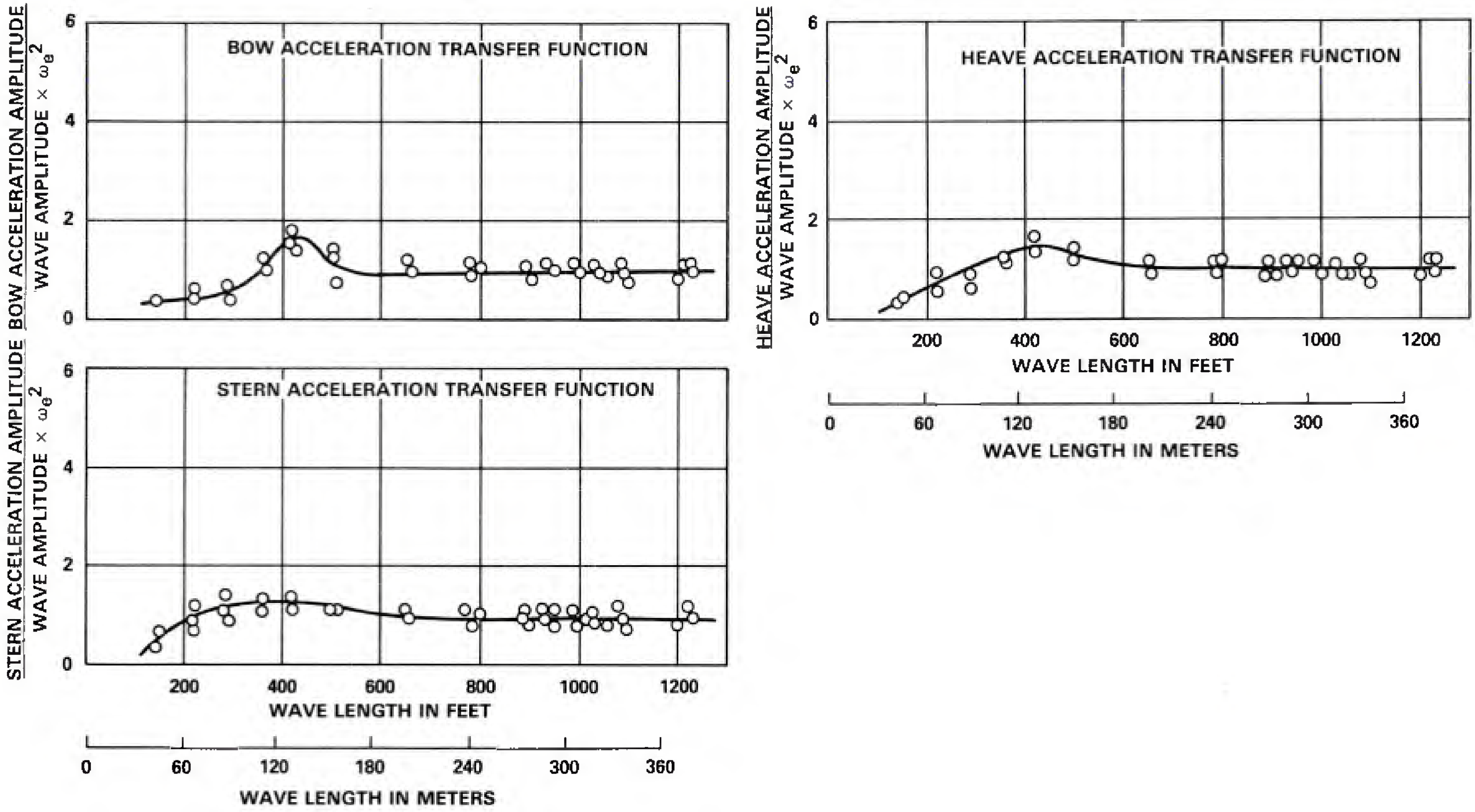


FIGURE 18 (CONTINUED)

(274.3 to 289.6m). Such long waves would be encountered frequently in high seas such as State 7.

When large canards are installed forward (see Figures 19 and 20), motions and accelerations in head regular waves are much the same as experienced with the small canards. Figures 21 and 22 show a comparison of RBM, pitch and heave TF's for the large and small canard configurations. We can see that at 3kts (Figure 21) RBM for longer wave lengths is somewhat greater with the large canards, and that at 8 kts (Figure 22) RBM is generally a little less with the large canards. We should recall that in random waves -- the more realistic environment -- there was a consistent, albeit undramatic, decrease in motions and accelerations achieved by changing from small to large canards (cf. Figure 9).

Conversely, installation of thick forward struts increased RBM a great deal. Other motions and accelerations were also made worse. The RBM TF given in Figure 23 for 3 kts in head seas reaches a maximum of 5.9 compared to a peak of no more than 2.0 with the design struts. At 8 kts (Figure 24) the RBM TF maximum is 3.3, whereas with design struts it was only 1.6. Subsequent analytical investigations* have shown that the increase in RBM with the thick struts was due to three factors: increased waterplane area, higher longitudinal GM, and reduced separation between the longitudinal centers of buoyancy and flotation. There was also some increase in nondimensional pitch response when thick struts were used; however, the peak shifts to a shorter wave length usually more prevalent in a milder seaway. Bow acceleration at resonance became substantially worse when the forward struts were made thicker, particularly at 8 kts; there was also an increase in heave at this speed.

A few runs were made in following regular waves with the design configuration. The average transfer functions for 3 kts are presented in Table 9. Maximum relative bow motion was a little greater in following waves than in head waves (cf. Figure 13). Also, in contrast to head waves, the stern acceleration TF is significantly larger than the bow acceleration TF for all wave lengths examined.

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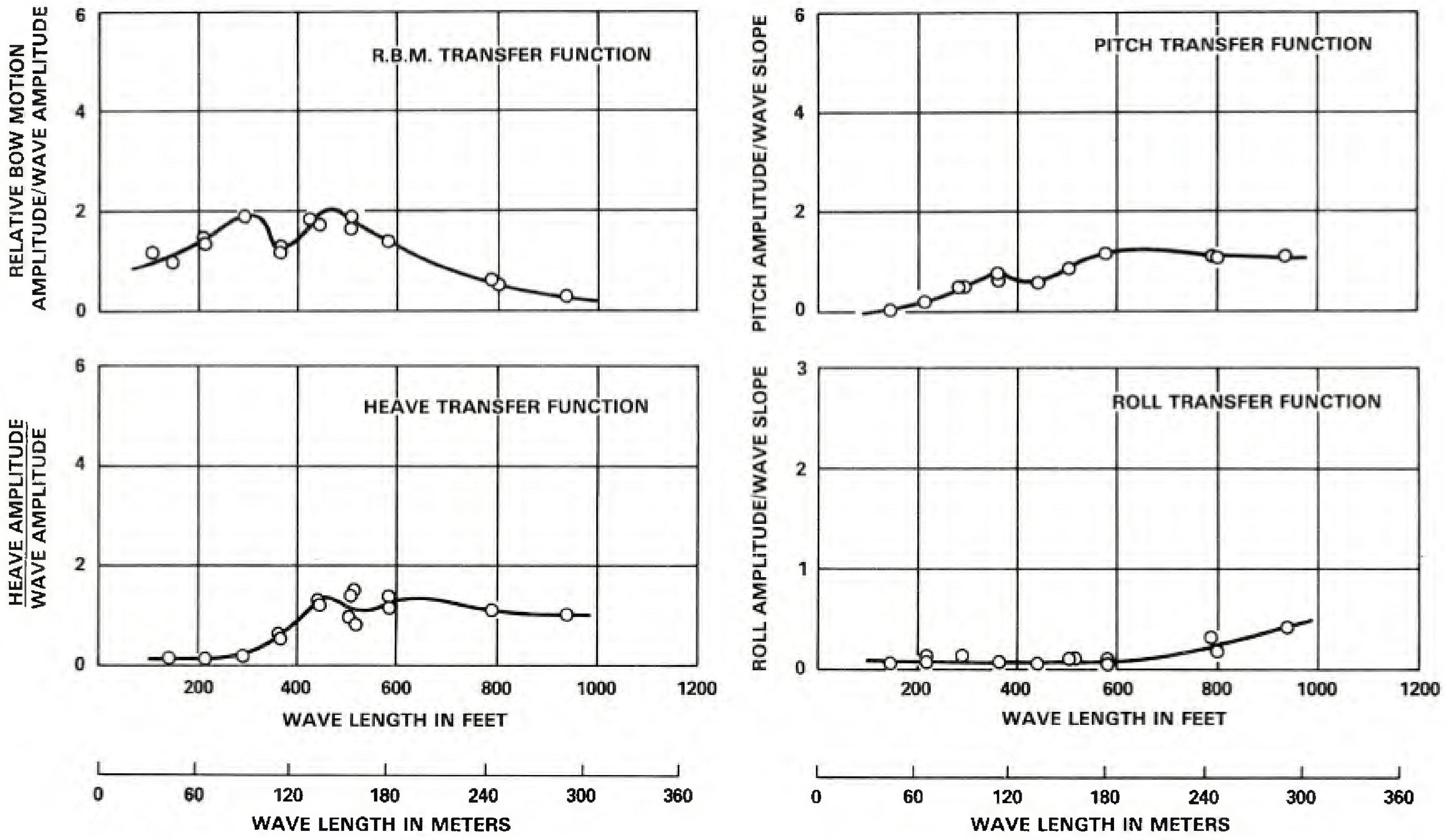
*McCreight, K.K., and Stahl, R., "Seakeeping Assessment of Candidate Designs for Modification of the SSP KAIMALINO," David Taylor Naval Ship R and D Center Report DTNSRDC/SPD-0986-01 (June 1981).

FIGURE 19—MOTION TRANSFER FUNCTIONS FOR THE LARGE CANARDS FORWARD CONFIGURATION AT A SPEED OF 3 KNOTS IN HEAD SEAS (180 DEGREE HEADING)



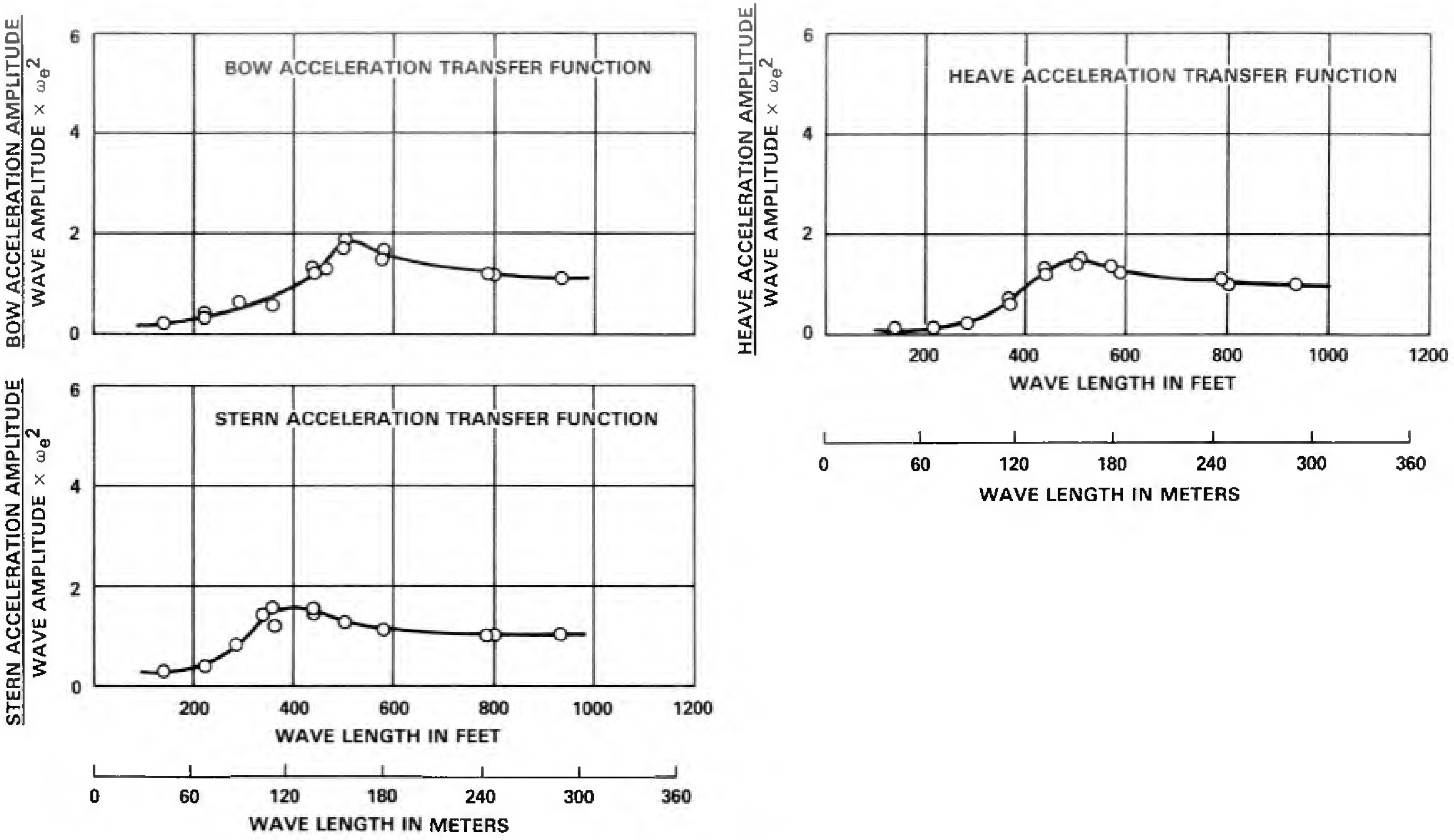
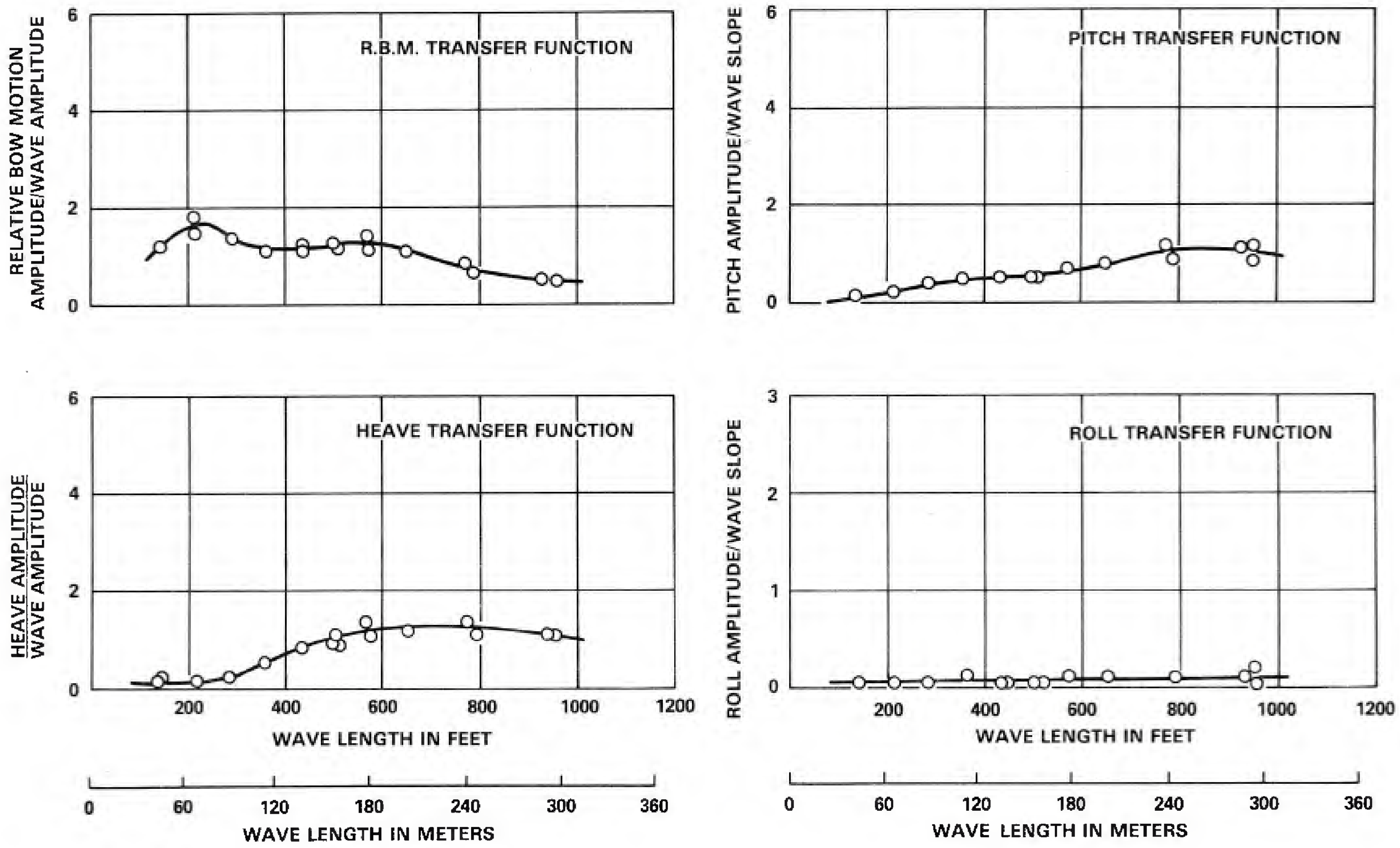


FIGURE 19 (CONTINUED)

FIGURE 20—MOTION TRANSFER FUNCTIONS FOR THE LARGE CANARDS FORWARD CONFIGURATION AT A SPEED OF 8 KNOTS IN HEAD SEAS (180 DEGREE HEADING)



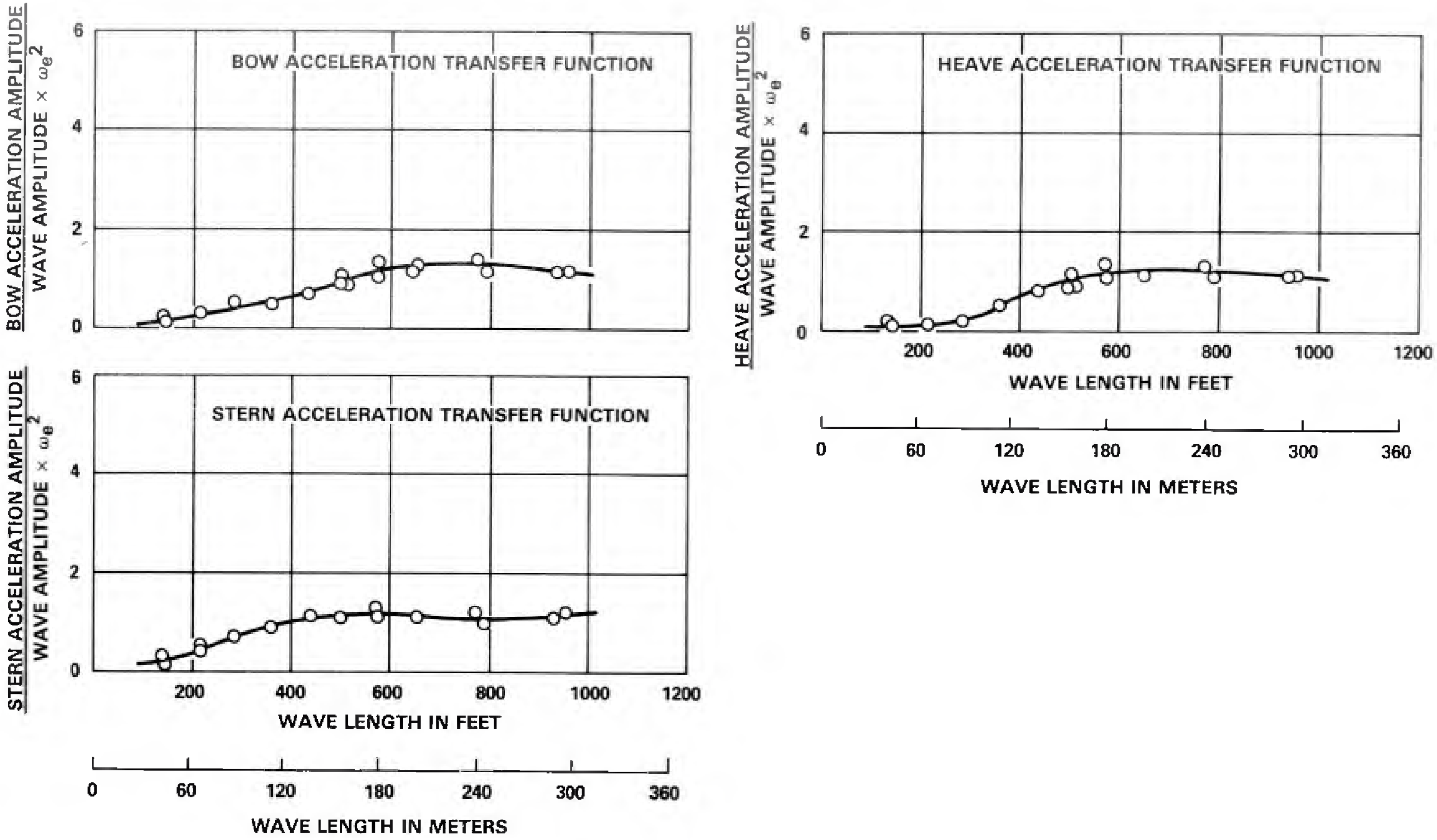


FIGURE 20 (CONTINUED)

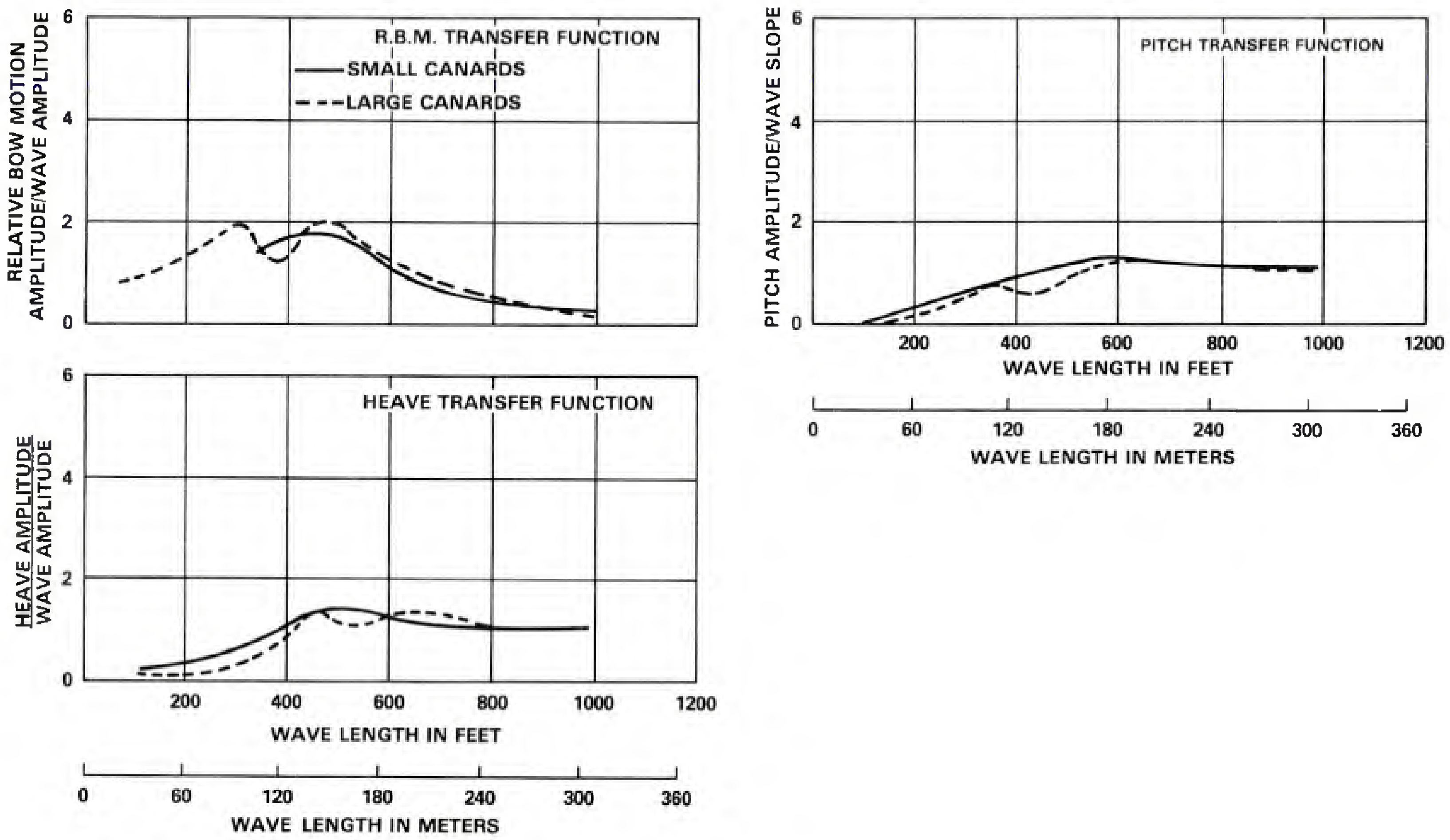


FIGURE 21— COMPARISON OF MOTION TRANSFER FUNCTIONS FOR THE SMALL CANARDS (DESIGN) AND LARGE CANARDS FORWARD CONFIGURATIONS AT A SPEED OF 3 KNOTS IN HEAD SEAS

FIGURE 22 — COMPARISON OF MOTION TRANSFER FUNCTIONS FOR THE SMALL CANARDS (DESIGN) AND LARGE CANARDS FORWARD CONFIGURATIONS AT A SPEED OF 8 KNOTS IN HEAD SEAS

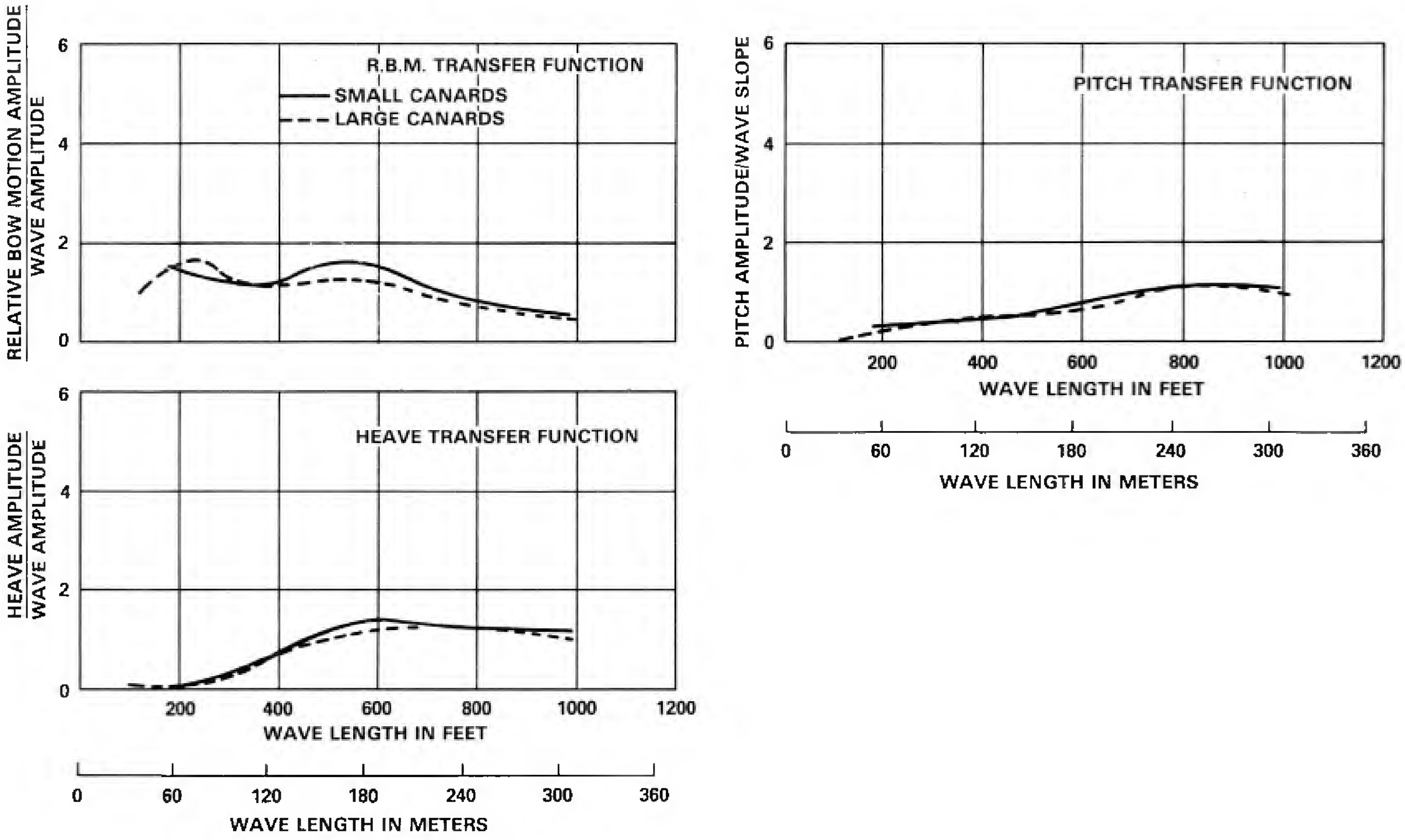
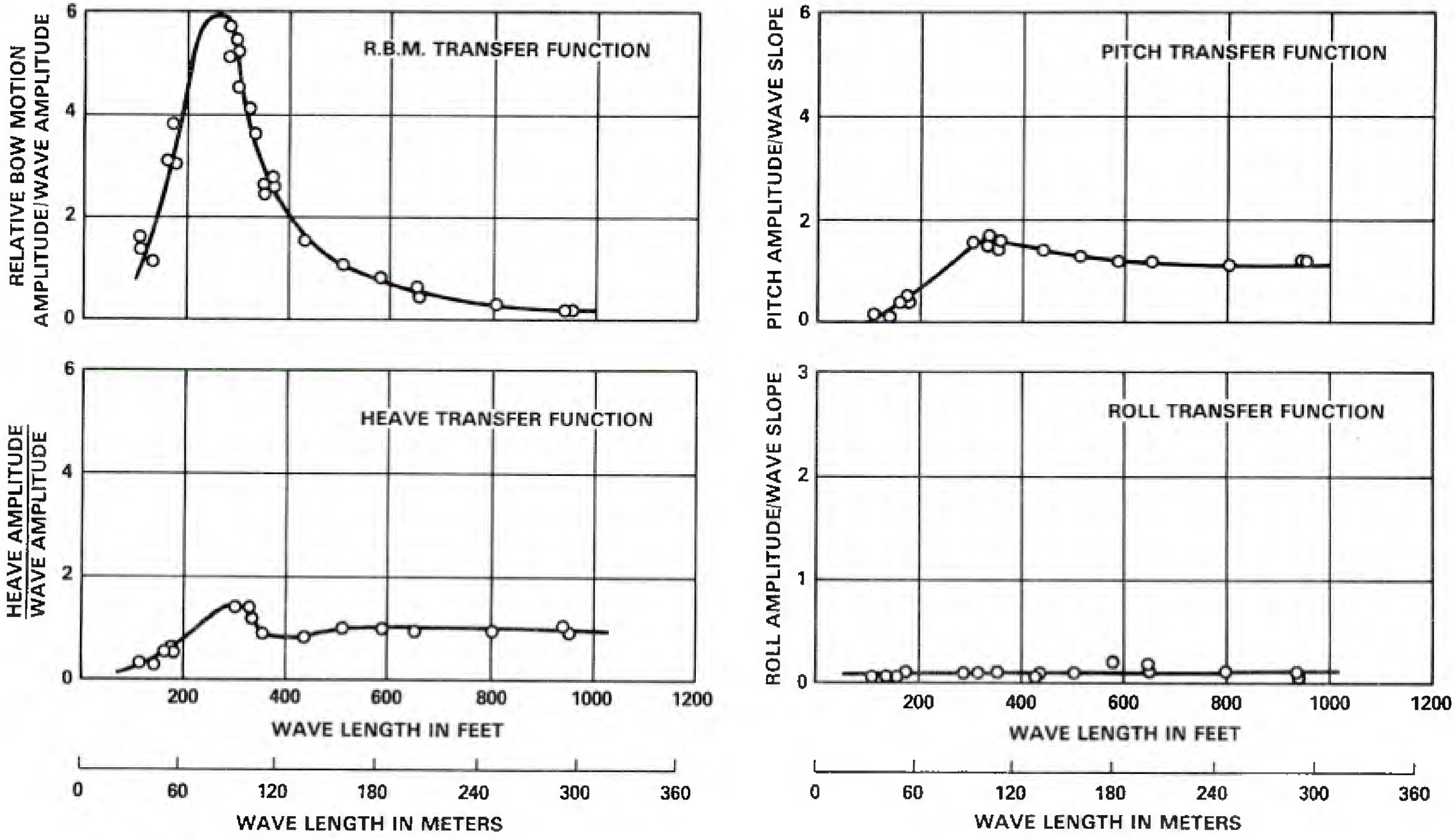


FIGURE 23—MOTION TRANSFER FUNCTIONS FOR THE THICK FORWARD STRUTS CONFIGURATION AT A SPEED OF 3 KNOTS IN HEAD SEAS (180 DEGREE HEADING)



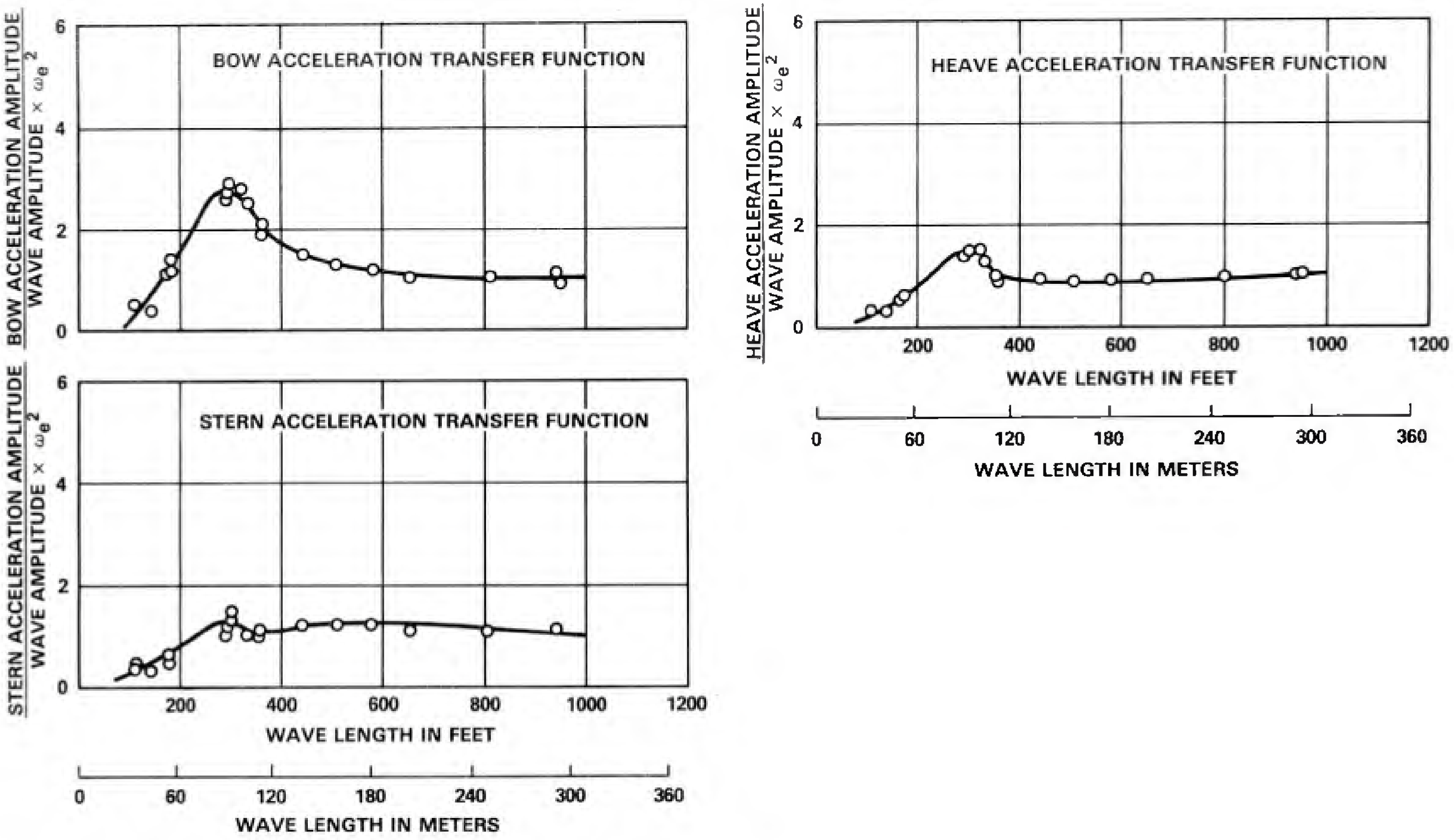
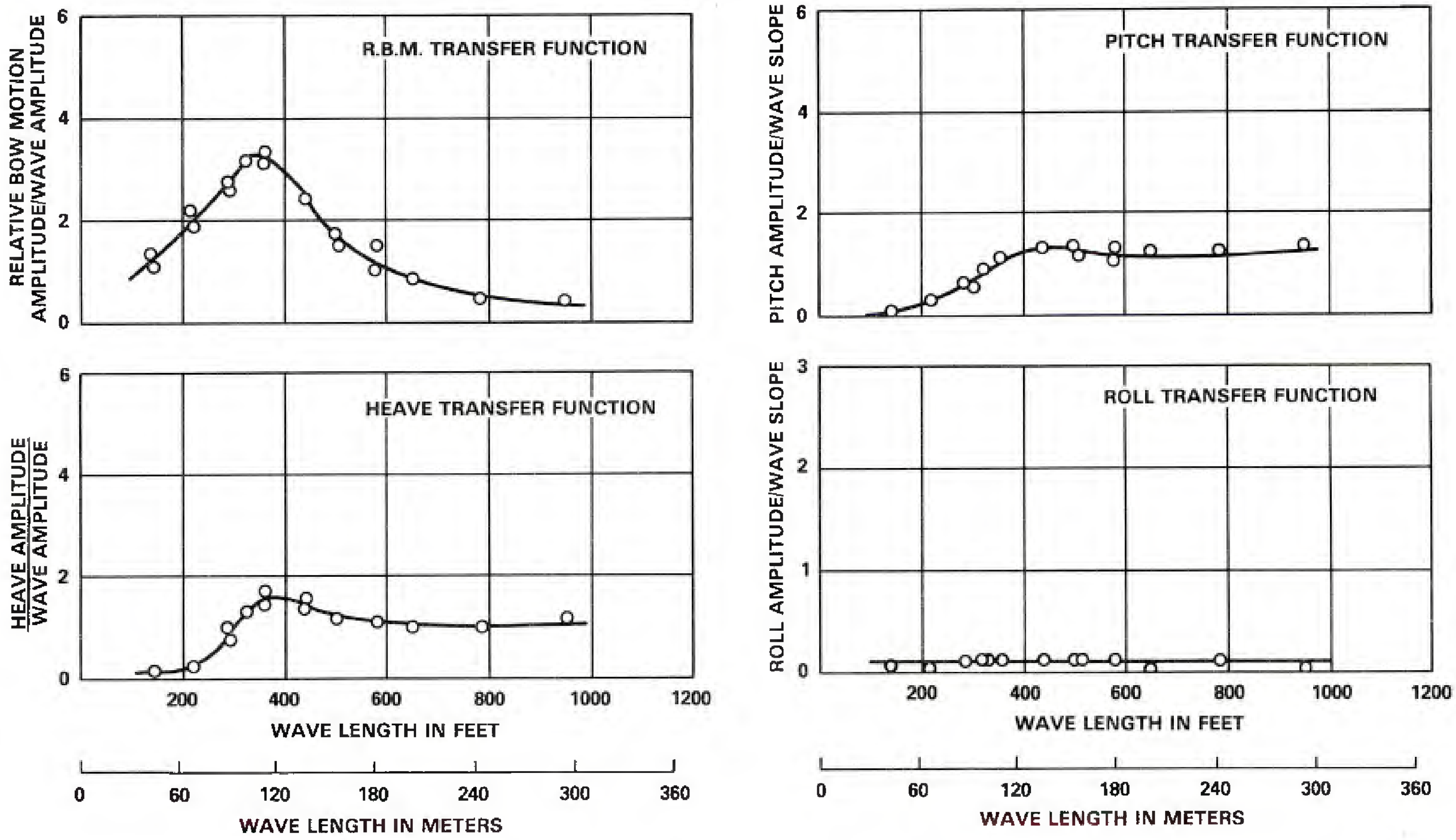


FIGURE 23 (CONTINUED)

FIGURE 24—MOTION TRANSFER FUNCTIONS FOR THE THICK FORWARD STRUTS CONFIGURATION AT A SPEED OF 8 KNOTS IN HEAD SEAS (180 DEGREE HEADING)



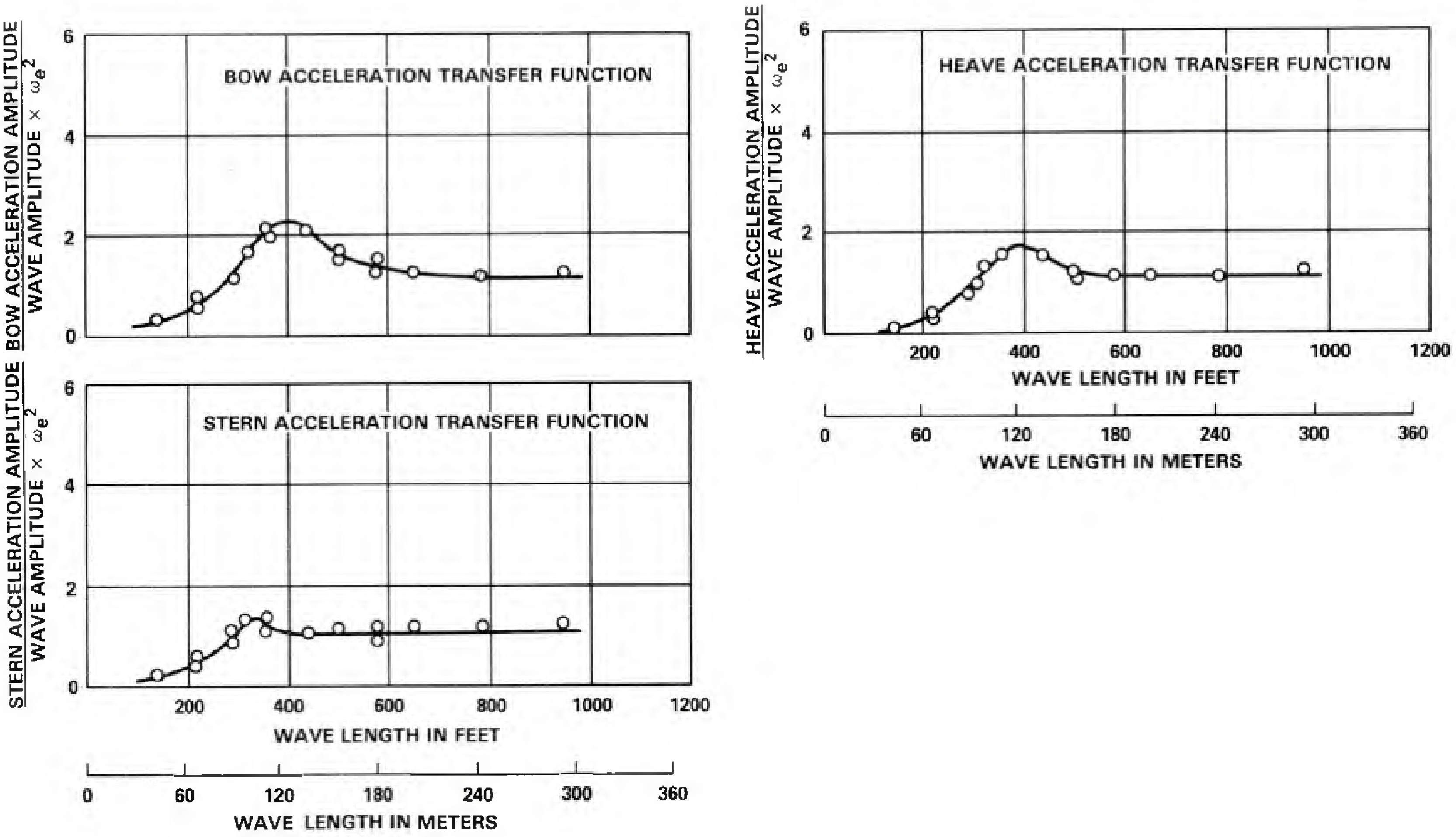


FIGURE 24 (CONTINUED)

TABLE 9

MOTION TRANSFER FUNCTION DATA FOR THE DESIGN CONFIGURATION AT A SPEED OF 3 KNOTS IN FOLLOWING SEAS*

WAVE LENGTH					BOW	HEAVE	STERN
FT	M	RBM	PITCH	HEAVE	ACCELERATION	ACCELERATION	ACCELERATION
140.5	42.8	2.13	0.28	0.63	0.68	0.64	1.25
143.5	43.7	2.41	0.31	0.69	0.71	0.69	1.37
216.0	65.8	0.97	0.41	0.66	0.50	0.65	1.33
287.8	87.7	0.32	0.46	0.29	0.36	0.29	0.89

*See Figure 12 for nondimensionalizing factors.

During the regular wave experiments linearity of response was checked by increasing wave height while maintaining wave length at a value which brought about appreciable pitch in head seas and roll in beam seas. Figure 25 contains the head seas results for speeds of 0 and 8 kts. For these conditions the motions and accelerations are found to be fairly linear. Figure 26 allows us to examine linearity in beam waves for 0 and 3 kts. In this case, heave is the most linear response. Roll exhibits some degree of linearity, but the data points are scattered. Bow, heave (CG) and stern accelerations also appear to be at least quasi-linear, but these data are scattered too. RBM, which is heavily pitch dependent -- pitch receiving little excitation in beam seas -- varies erratically with wave height at 3 kts.

NATURAL PERIODS AND DAMPING

Natural periods and damping for pitch, roll and heave were determined by free oscillation of the model in calm water. In some cases this was done for several speeds. Figure 27 is a sample of the amplitude decay curves obtained. Where the decay was linear, damping proportional to the first power of velocity can be assumed in the equation of motion. This is true for pitch for all cycles in the plot shown, and for heave for the first three cycles. A log decrement is defined by:

$$\delta = \frac{1}{q} \ell n \frac{x_n}{x_{n+q}}$$

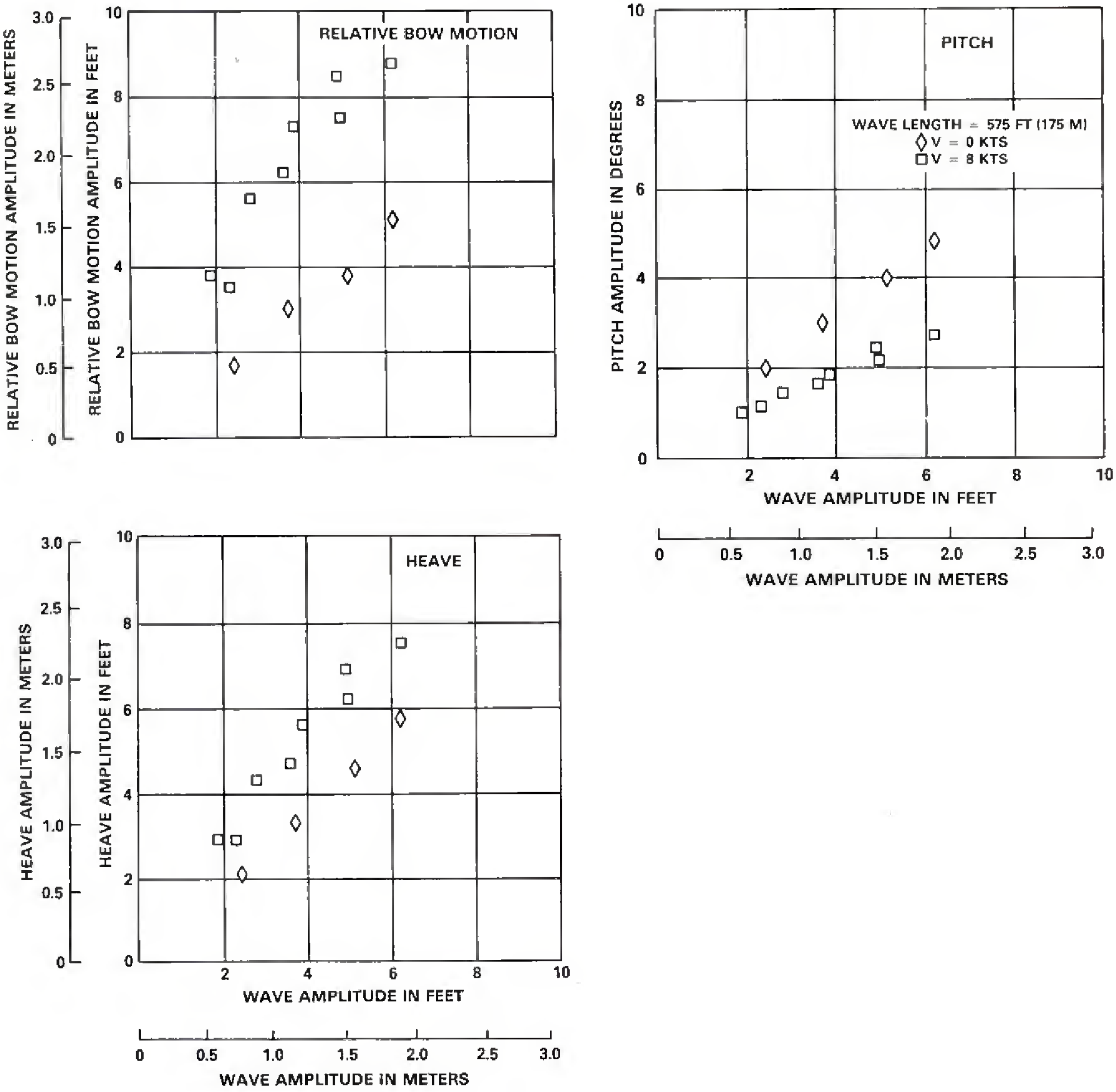
where x_n is the amplitude of oscillation after cycle number n and x_{n+q} is the amplitude q cycles later. For small damping, which we have here, the damping factor, ζ, is given by

$$\zeta = \frac{\delta}{2\pi} = \frac{C}{C_c}$$

where C is the damping coefficient and C_c is the critical damping coefficient.

A summary of damping factors and natural periods obtained is given in Table 10. The damping factors generally increase with speed: for example, ζ for roll increases from 0.028 to 0.260 as speed is increased from 0 to 15.5

FIGURE 25 — RESULTS OF LINEARITY EXPERIMENTS IN REGULAR HEAD SEAS FOR DESIGN CONFIGURATION



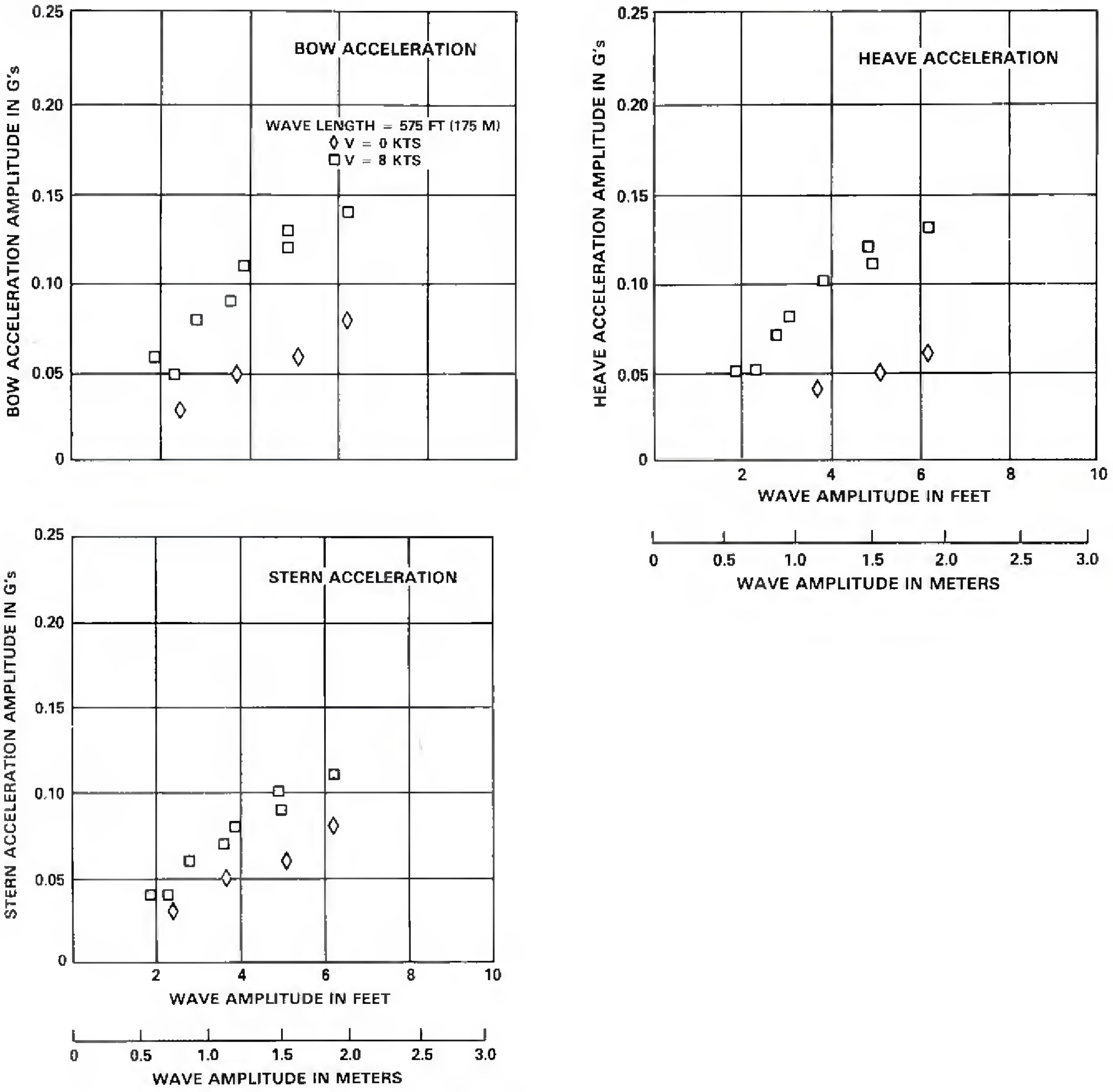
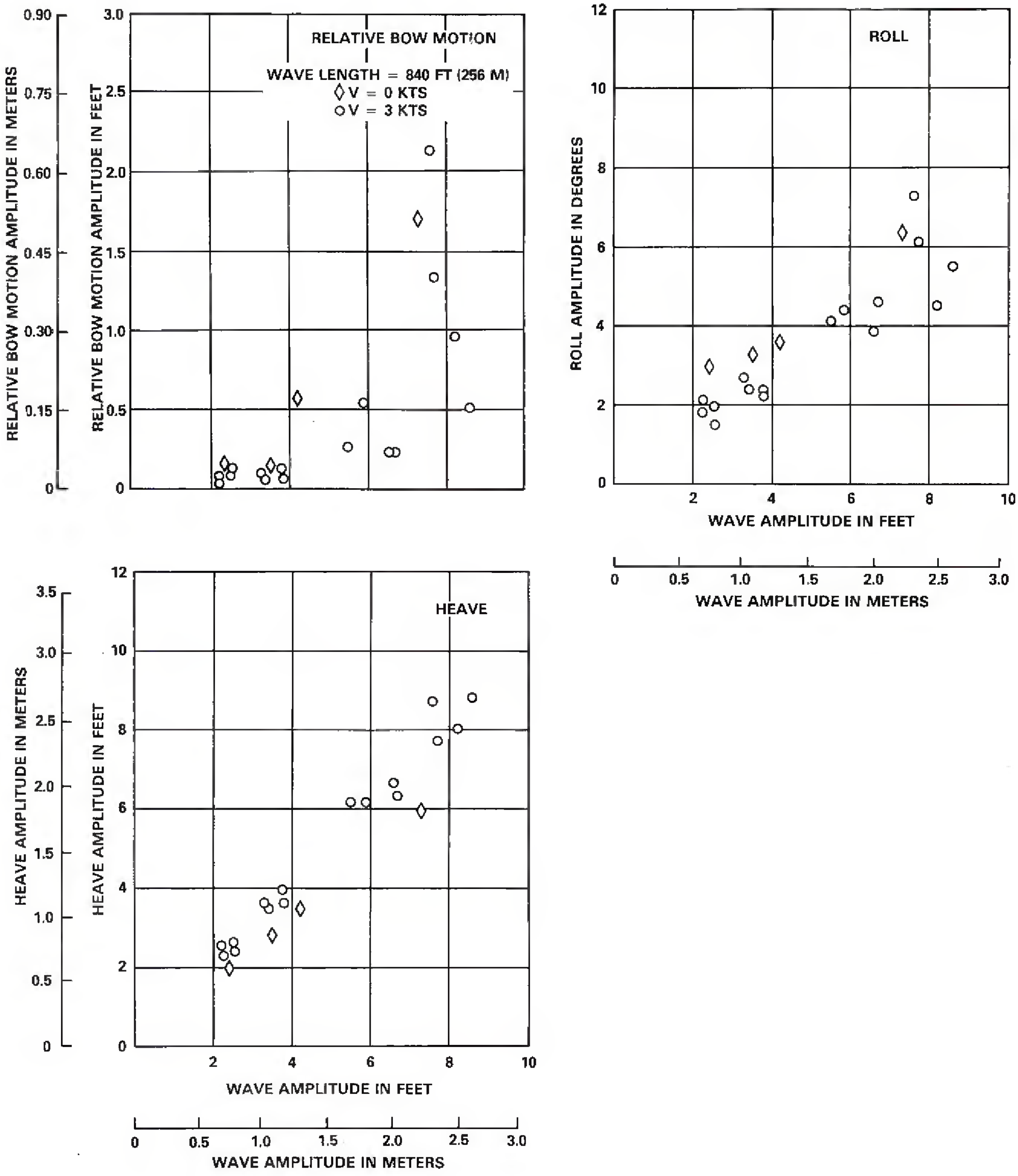


FIGURE 25 (CONTINUED)

FIGURE 26 — RESULTS OF LINEARITY EXPERIMENTS IN REGULAR BEAM SEAS FOR DESIGN CONFIGURATION



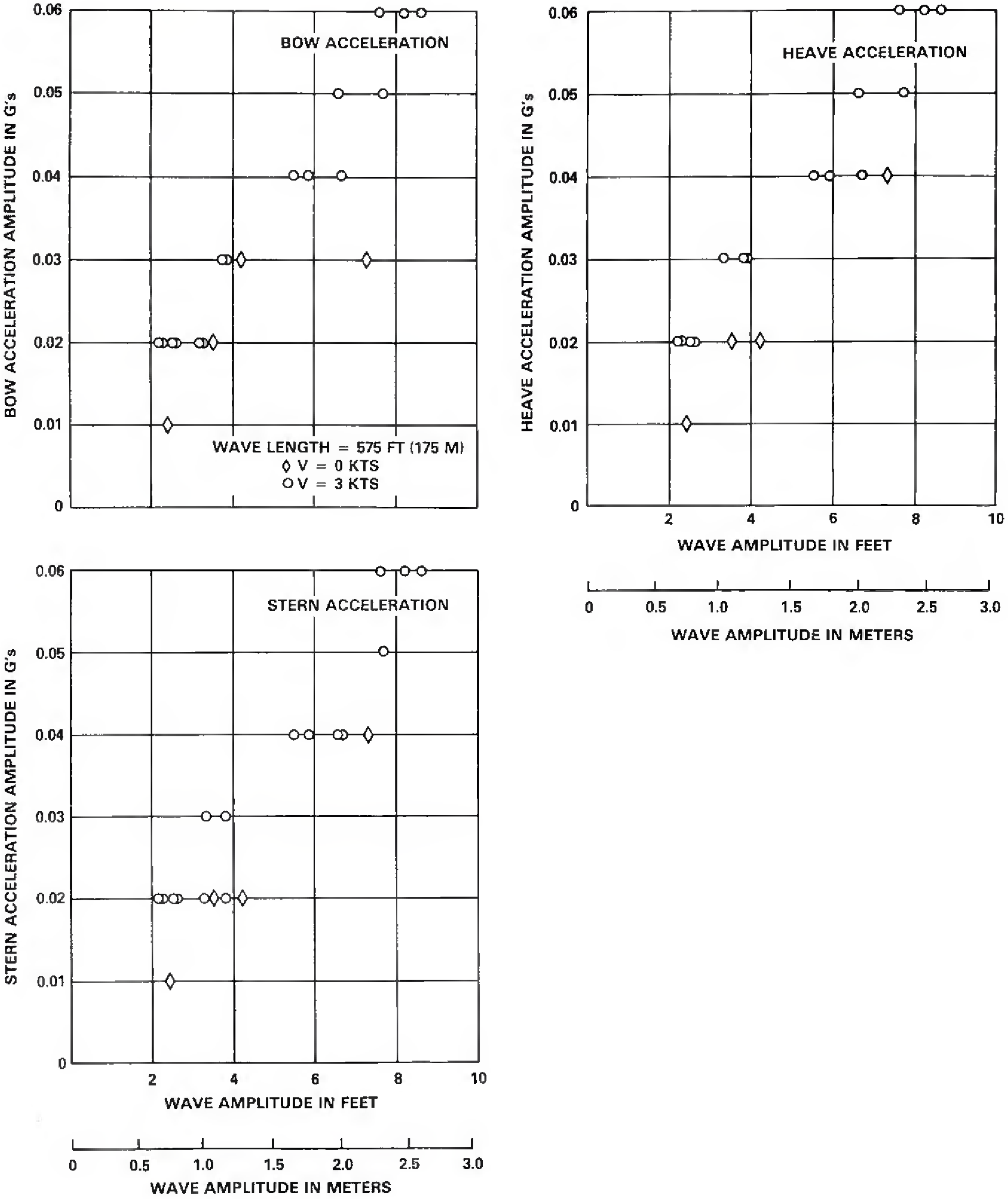


FIGURE 26 (CONTINUED)

FIGURE 27 — AMPLITUDE DECAY FOR THE DESIGN CONDITION AT ZERO SPEED

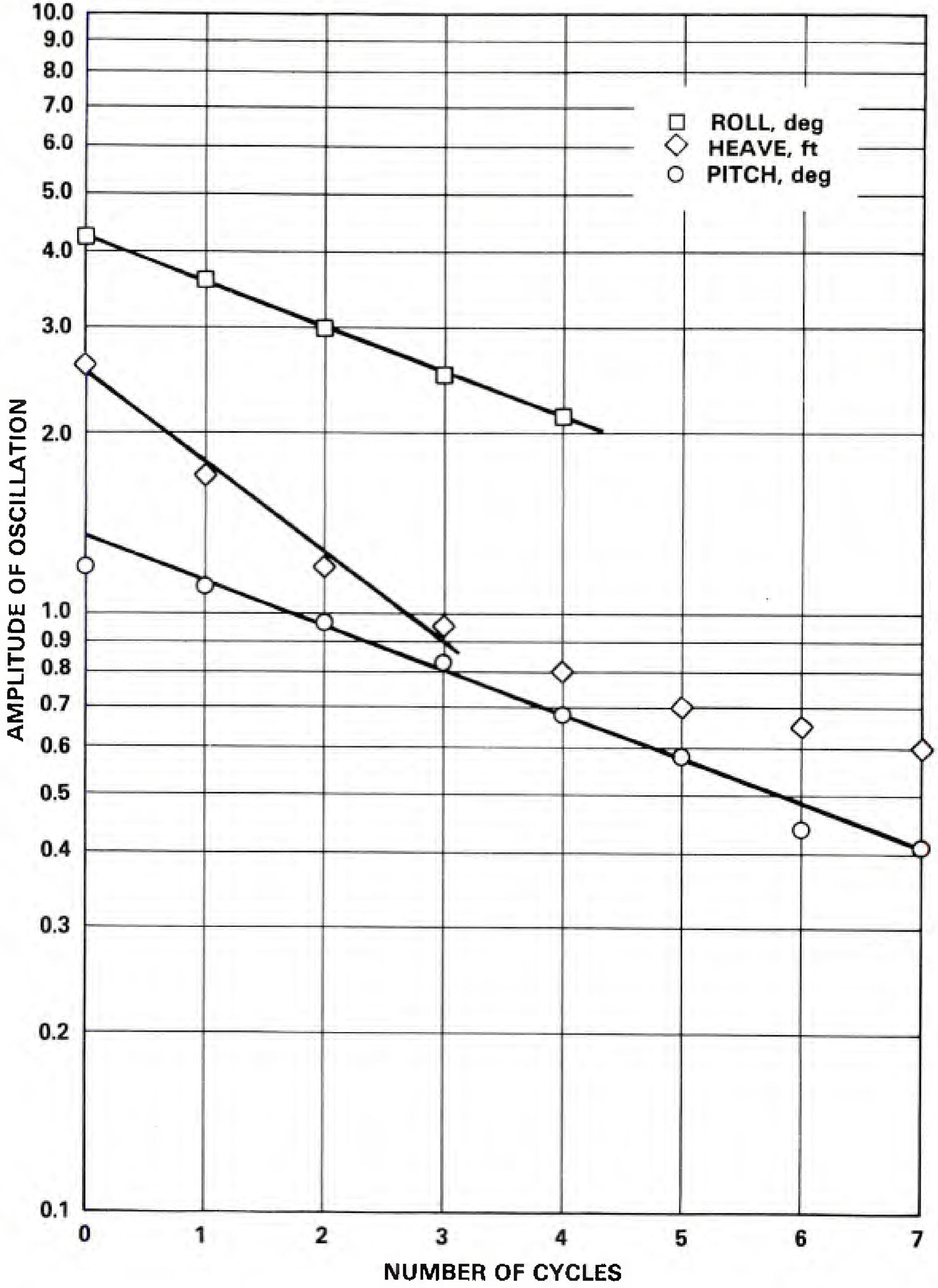


TABLE 10
DAMPING FACTORS AND NATURAL PERIODS FOR SEVERAL CONFIGURATIONS

	DAMPING FACTOR (ζ)*															NATURAL PERIOD, SEC														
	PITCH					ROLL					HEAVE**					PITCH					ROLL					HEAVE				
SPEED, KTS →	0	3	8	11	15.5	0	3	8	11	15.5	0	3	8	11	15.5	0	3	8	11	15.5	0	3	8	11	15.5	0	3	8	11	15.5
DESIGN CONFIGURATION	0.027	0.060	–	–	–	0.028	0.076	–	0.165	0.260	0.055	0.054	–	0.150	0.180	8.62	8.72	–	8.42	8.33	12.8	13.1	–	–	13.6	8.62	8.72	–	8.62	8.91
LARGE CANARDS FORWARD	0.049	0.067	0.140	–	–	0.029	0.072	0.250	–	–	0.100	0.080	0.178	–	–	8.96	8.77	–	–	–	12.9	12.7	–	–	–	8.91	8.67	8.82	–	–
THICK FORWARD STRUTS	0.027	0.050	0.097	–	–	–	–	–	–	–	0.060	0.053	0.110	–	–	7.05	6.86	6.66	–	–	–	–	–	–	–	6.86	7.10	6.76	–	–

*$\zeta = C/C_c$ where C is the damping coefficient, and C_c is the critical damping coefficient.

** For heave, damping was "linear" generally during first few cycles of oscillation only.

kts. Changes in configuration do not affect ζ a great deal. Natural periods are long, and are not significantly altered by increasing forward speed.

CONCLUSIONS

This investigation has been concerned with the conduct of seaworthiness experiments on the STRETCHED SSP design. The model tests were conducted at the David W. Taylor Naval Ship Research and Development Center and included the effect of altering appendage configuration.

The following general conclusions can be drawn from the results of this program:

1. The STRETCHED SSP sustained some severe contacts between its bridging structure and oncoming waves in heavy seas (up to mid-State 7), and occasionally had waves break over the forward cabin and wash across the main deck (see Figure 3). When this occurred, the vessel always maintained its stability even when a large bow down attitude was assumed for part of a motion cycle.

2. In short regular waves, at low and intermediate speeds, maximum RBM for the design configuration of STRETCHED SSP was found to be much less than that of the USNS HAYES (see Appendix A for details). In long waves at low speeds, RBM TF values for SSP are slightly greater than those of HAYES. However, use of large canards forward on the SSP when operating in a random seaway appears to significantly improve its RBM response relative to the HAYES.

3. Increasing forward canard size resulted in a reduction in motions and accelerations when the model operated in random waves simulating the ocean environment. In sinusoidal waves, however, the improvement was not as evident, possibly because mild motions in the relatively low amplitude regular waves kept the angle of the attack on the canards small, thus preventing the generation of substantial forces.

4. Use of thick forward struts was detrimental to ship performance. Most responses -- particularly pitch and RBM -- were amplified.

5. Employment of large canards aft rather than a stabilizer spanning the distance between hulls was advantageous in following seas, and produced a decrease in motions and accelerations. Reduced control surface area near the

stern apparently reduces the amount of lift on the stern as waves are encountered in following seas.

The following, more specific, conclusions were also derived from the experimental data*:

1. For the design configuration (small canards forward, standard struts, and aft stabilizer flap set at 5 deg trailing edge up) maximum pitch in Sea State 5 occurred in stern quartering seas. The significant double amplitude was approximately 7 deg. In head Sea State 6 the range in significant pitch was from 7.3 to 16.1 deg, with the largest value occurring at zero speed.

2. Minimum heave for the design configuration was measured in following seas.

3. At low speed, RBM was generally greatest in head seas, and at high speed it was greatest in following seas. In head Sea State 6, at 0 kts and 3 kts, a significant double amplitude of almost 28 ft (8.5m) was reached. In following Sea State 5 the maximum value of 20.5 ft (6.2m) was measured at 11 kts.

4. In State 5 seas, roll for the design configuration was most severe at a stern-quartering heading. At zero speed in State 7 beam seas, a significant double amplitude roll of 20 deg was measured.

The roll TF for the STRETCHED SSP, based on tests at 3 kts in regular beam waves, revealed a peak roll response of over three times the wave slope in 940 ft (286.6m) long waves. This wave length is common in State 7 seas, which suggests that rolling will be a problem when beam-on to the waves in severe seas.

5. In following seas, maximum stern acceleration was greater than maximum bow acceleration.

6. Motions and accelerations in bi-directional seas were found to be appreciable, but not as large as experienced in unidirectional waves of the same average height.

7. In head, regular waves, motions and accelerations were reasonably linear (i.e., increased in proportion to wave height).

---

*Although "design configuration" is specified in some cases, the conclusions probably apply to other configurations; however, insufficient data are available to ascertain this.

8. Damping factors for STRETCHED SSP generally increase with speed. Natural periods are long compared with a conventional surface ship of 624 metric tons displacement, and not significantly speed dependent.

RECOMMENDATIONS

After observing the experiments discussed in this report, and examining the data, the SWATH Ship Development Office of DTNSRDC made the following recommendations:

1. The bridging structure of the STRETCHED SSP should be made stronger than that of the original SSP KAIMALINO to survive the higher slamming loads which were measured during the model tests in mid-Sea State 7.
2. The pilothouse windows and forward facing pilothouse structure should be strengthened to withstand the impact of solid water at ship speeds up to 8 kts.
3. The engine intakes should be moved topside facing inboard, and should be protected by an enclosure. The engine exhausts should be directed upward.
4. The large forward canards should be adopted for the STRETCHED SSP to reduce wave impact pressures at the bow by reducing the RBM amplitudes.
5. The adequacy of the plating along the sides of the bridging structure to resist wave slap loads in severe beam seas should be determined.
6. It is desirable that rotating arm experiments be carried out on the STRETCHED SSP model to evaluate its course-keeping characteristics at low speed for its intended towing operations.

ACKNOWLEDGMENTS

The author wishes to thank G. R. Lamb of the SWATH Ship Development Office for his many useful contributions to the formulation and execution of the test plan. Thanks are also due J. Kallio, C. Hart, Y. Hong and M. Kinlow of DTNSRDC for their assistance during the model experiments. D. Huminik did his usual outstanding job of preparing the instrumentation and keeping it operating during the experiments. Operation of the digital data collection system, and computer reduction of the data were very capably performed by M. Dipper. S. L. Bales provided the wave data contained in Appendix C. D. McLean of ORI, Inc. was invaluable in performing additional data reduction and arranging for preparation of the final report.

APPENDIX A

COMPARISON OF TRANSFER FUNCTIONS FOR STRETCHED SSP AND USNS HAYES

The USNS HAYES is the first oceangoing "conventional" catamaran of the U.S. Navy. This vessel has basically standard displacement ship hulls; the structure connecting the two hulls is a considerable distance above the calm-water surface as in SWATH ships. HAYES has an LBP of 220 ft (67.1m) and a displacement of 3,140 long tons (3,190 metric tonnes); thus, it is considerably larger than the STRETCHED SSP.

In this appendix we will compare the motion transfer functions of the STRETCHED SSP and HAYES. Figure A.1 contains curves for RBM, pitch and heave in head seas, and roll in beam seas -- all at 3 kts.

During the experiments, RBM for the STRETCHED SSP was measured forward of station 1.5. These data were corrected to station 1.5 by employing a motion prediction computer program to calculate RBM at two locations -- the one used during the tests, and station 1.5 -- and then determining the difference, Δ. The measured RBM was then modified by subtracting Δ.

Although the 3 kt RBM curve for the STRETCHED SSP does not extend to wave lengths below 300 ft (91.4m), the results indicate that the maximum TF value of 3.1 for HAYES at a wave length of 250 ft (76.2m) is much greater than the STRETCHED SSP peak. In regular waves longer than roughly 400 ft (121.9m) RBM response for the design configuration of STRETCHED SSP is slightly greater than that of HAYES. However, as discussed in the main body of this report, when large canards are installed forward on the STRETCHED SSP its RBM in random waves is reduced. For this more realistic condition, RBM for STRETCHED SSP with large canards should be significantly less than that of HAYES in short waves, and comparable to or less than HAYES in long waves.

Pitch and heave TF's for the two vessels are similar: those for the STRETCHED SSP have a somewhat more pronounced and higher peak, with greater response than HAYES in long wave lengths, and less response in short wave lengths.

On the other hand, the roll TF's in beam waves for the two ships are much different. The peak response for the STRETCHED SSP occurs in much longer

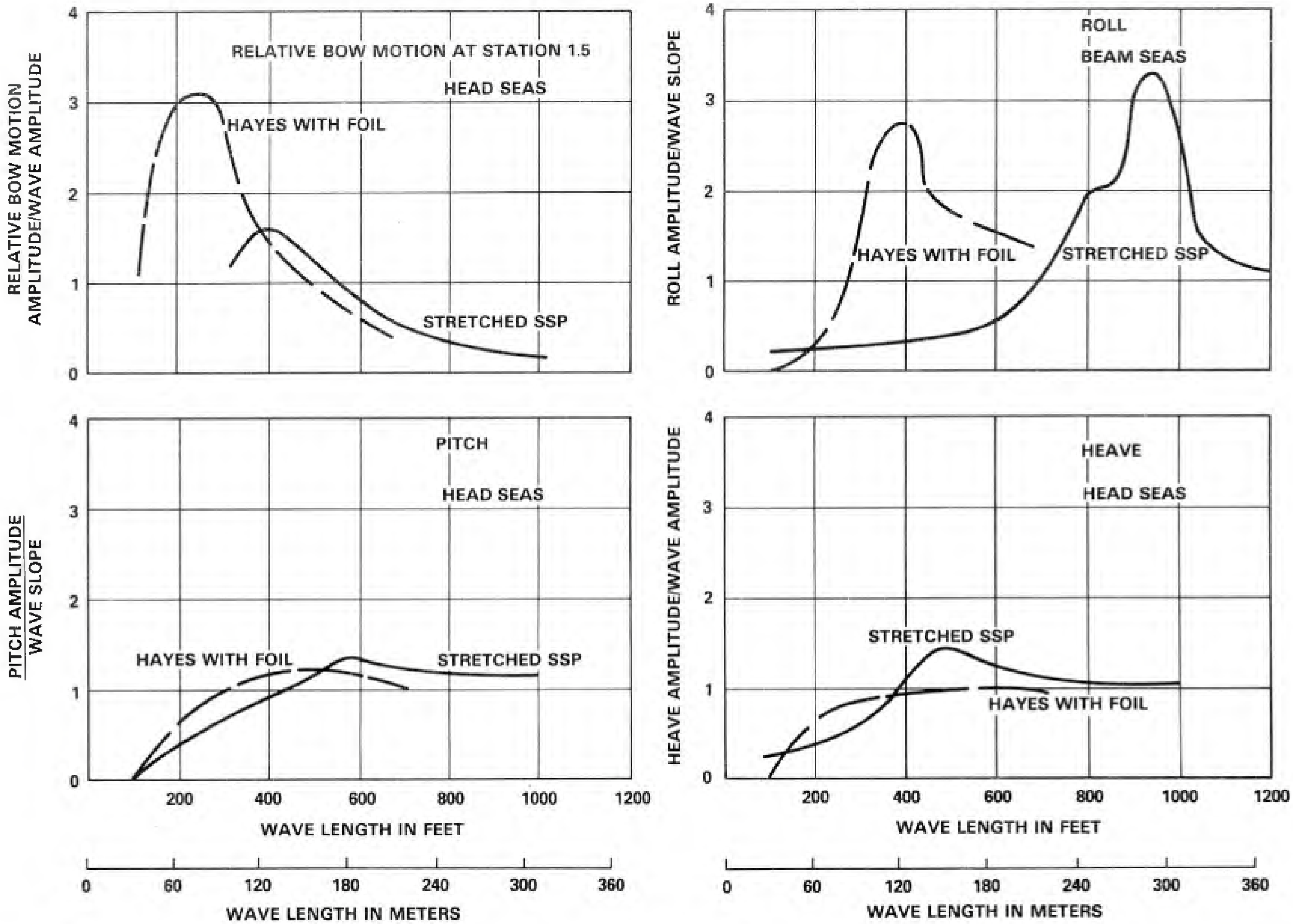


FIGURE A.1—COMPARISON OF TRANSFER FUNCTIONS FOR STRETCHED SSP (DESIGN CONFIGURATION) AND USNS HAYES (T-AGOR-16) AT 3 KNOTS waves [approximately 940 ft (286.5m) compared to 390 ft (118.9m)] and is slightly higher (3.30 compared to 2.75). It should be noted that for a given wave height the maximum slope is inversely proportional to wave length. However, wave lengths close to 940 ft (286.5m) are frequently found in severe seas such as State 7, which indicates that the STRETCHED SSP has a potential roll problem in severe seas, particularly at low speeds when beam-on to the waves.

When the HAYES is operating at 10 kts and the STRETCHED SSP at 8 kts, their transfer functions compare as in Figure A.2. Here again, maximum RBM for the STRETCHED SSP is much less than the peak value for HAYES. In addition, for all wave lengths where data are available for both ships [i.e., 270 ft (82.3m) to 670 ft (204.2m)], the STRETCHED SSP RBM is lower. Pitch and heave TF's compare much the same as at 3 kts: response of the STRETCHED SSP is more favorable in short waves, and about the same or perhaps slightly worse than HAYES in longer waves. Roll data at similar intermediate speeds are not available for comparison.

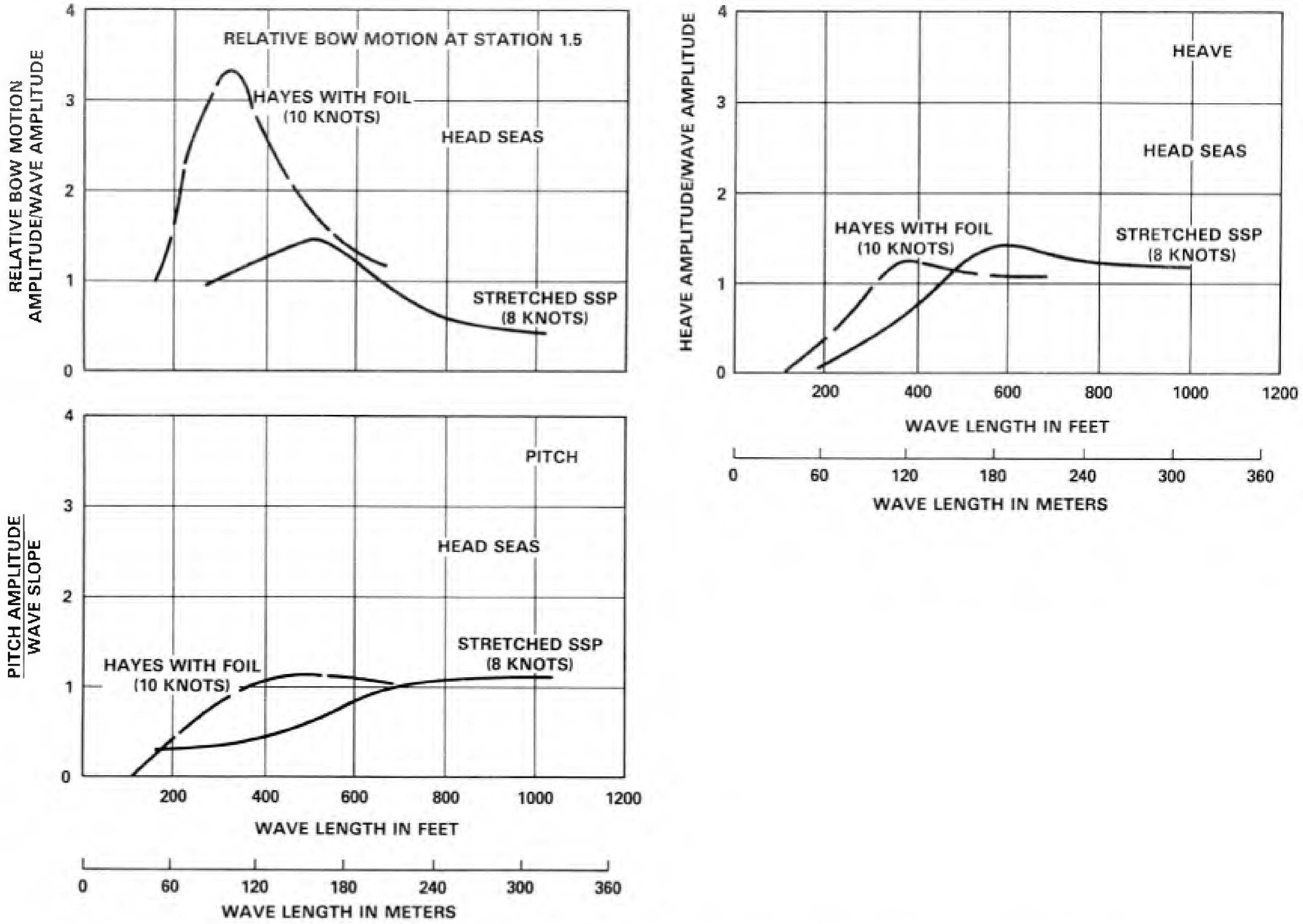


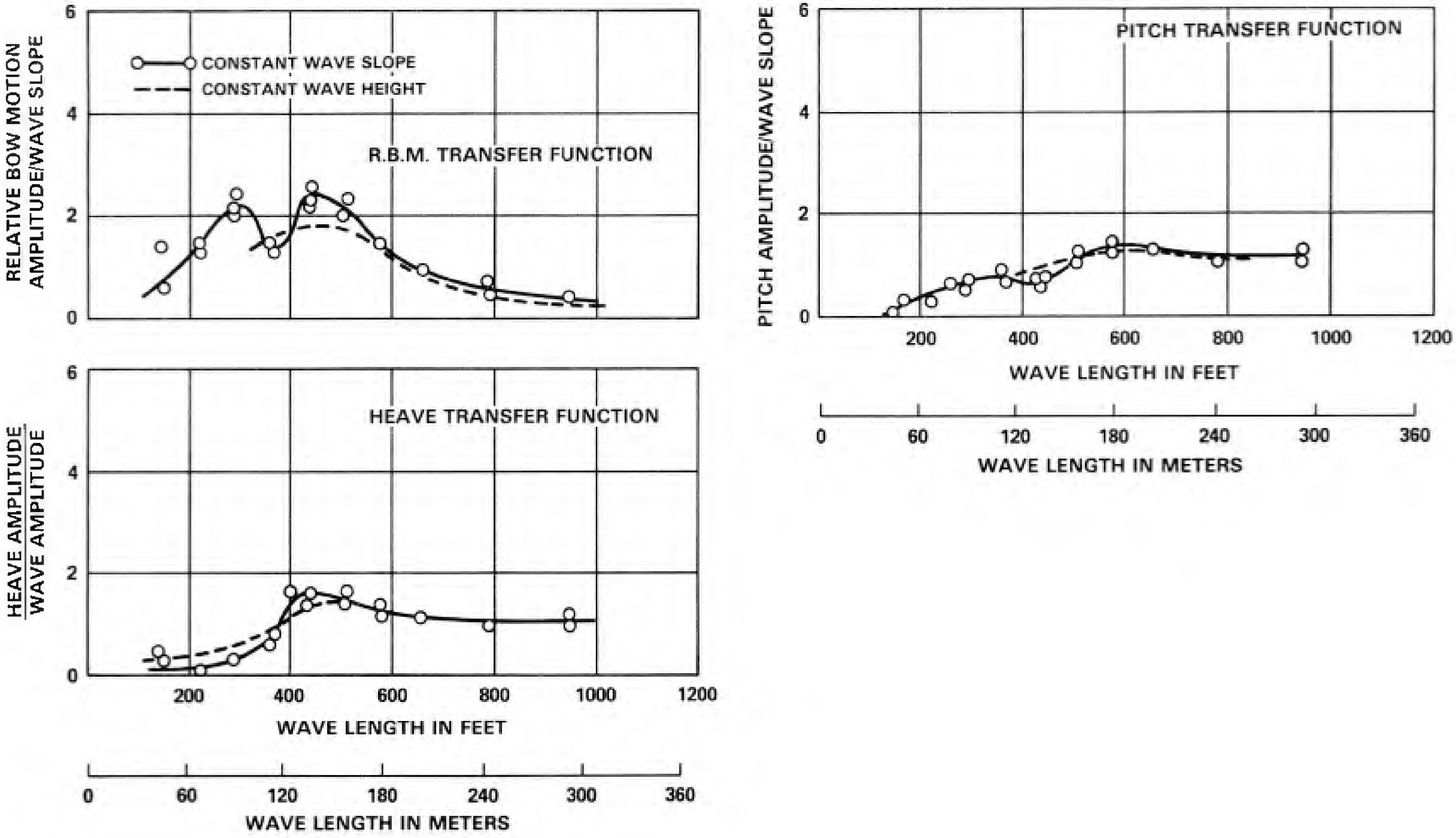
FIGURE A.2—COMPARISON OF TRANSFER FUNCTIONS FOR STRETCHED SSP (DESIGN CONFIGURATION) AND USNS HAYES (T-AGOR-16) AT INTERMEDIATE SPEEDS

APPENDIX B

COMPARISON OF TRANSFER FUNCTIONS OBTAINED IN WAVES OF CONSTANT HEIGHT AND CONSTANT SLOPE

It sould be recalled that although most regular wave runs were conducted in waves of essentially constant height -- roughly 8 ft (2.4m) -- some were carried out in milder constant slope conditions, i.e., wave height/wave length of approximately 1/100. In Figure B.1, we see a comparison of transfer functions for the design configuration operating at 3 kts in these two types of wave systems. The TF's are generally not much different; however, the peak value for constant wave slope is usually a little higher than its constant wave height counterpart. This is particularly true for relative bow motion, and is probably due to mild nonlinearity of response.

FIGURE B.1—COMPARISON OF TRANSFER FUNCTIONS FOR STRETCHED SSP OBTAINED IN WAVES OF CONSTANT HEIGHT AND CONSTANT SLOPE AT 3 KNOTS



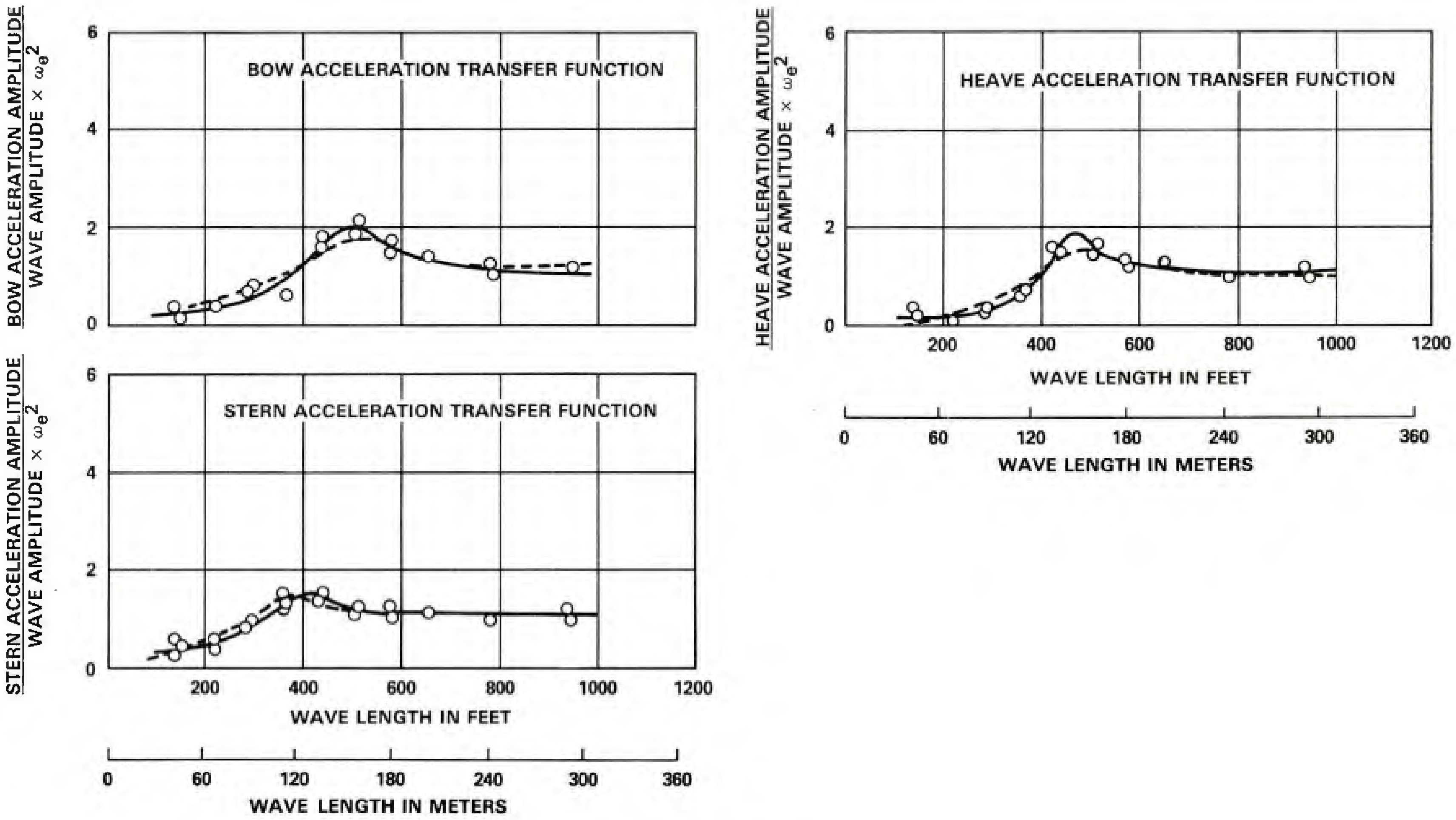


FIGURE B.1 (CONTINUED)

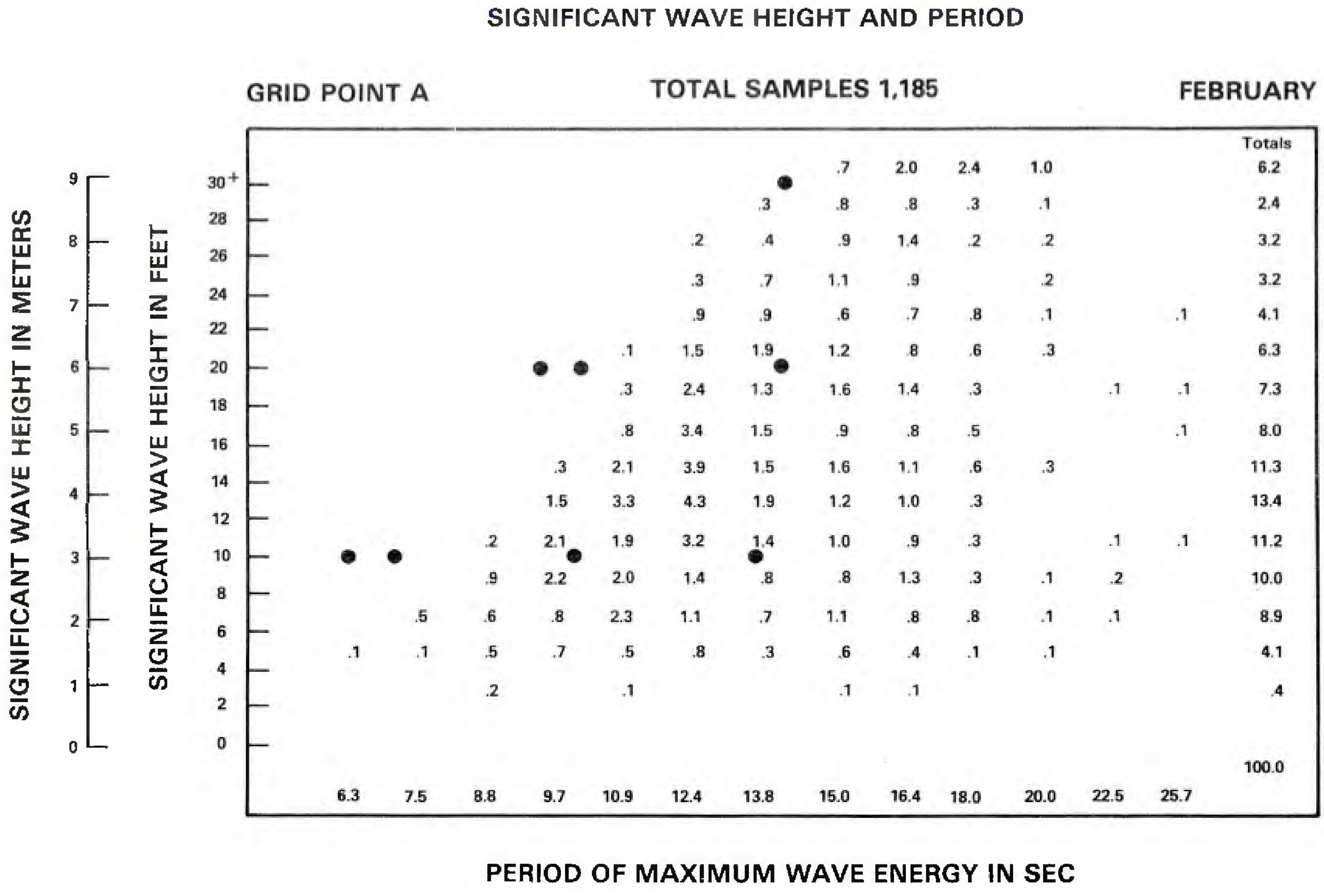
APPENDIX C

WAVE CHARACTERISTICS FOR STRETCHED SSP OPERATION

Figure C.1 contains statistics of wave conditions (joint occurrence of significant wave height, $\overline{H}_{1/3}$, and period of maximum energy, T_{max}) for two regions in which the STRETCHED SSP may operate. The numbers tabulated in the body of the figure are the percent occurrence of the wave heights and periods given on the ordinate and abscissa, respectively. All values were obtained by means of hindcasts. Scaled-up characteristics of the waves generated in the towing tank are represented by blackened circles scattered on the figure. We see that some of the tank test conditions occur relatively frequently: for example $\overline{H}_{1/3}$ = 10 ft (3.0m) and T_{max} = 10 sec, which is found in about 3 percent of the cases at Grid Point 56 during February and July to September. Other conditions, such as $\overline{H}_{1/3}$ = 10 ft (3.0m) and T_{max} = 6.3 and 7.0 sec occur infrequently. In fact, these exact conditions were not hindcast for the sampling period. They were, however, investigated during the experiments because the wave systems have much energy at periods close to the natural pitch and heave periods of STRETCHED SSP.

Another way of presenting wave statistics for the areas of interest is given in Table C.1. Of the three samples considered, the two for winter have the highest wave heights. Furthermore, predominant wave periods in winter are longer and closer to the ship's roll natural period, whereas in late summer the wave periods tend to excite pitch and heave.

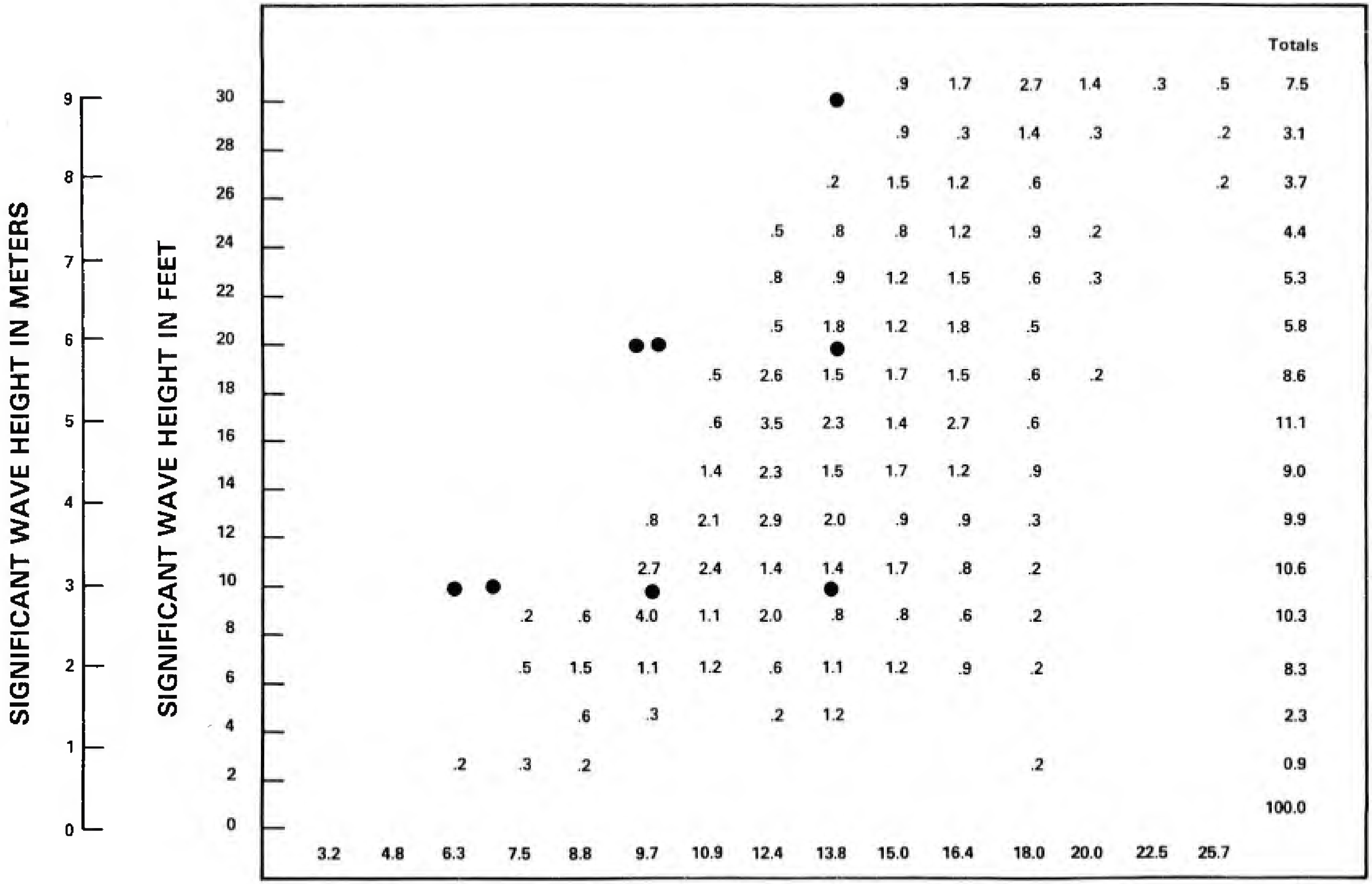
FIGURE C.1—FREQUENCY OF OCCURRENCE (PERCENT) OF SIGNIFICANT WAVE HEIGHT AND MODAL PERIOD COMBINATIONS HINDCAST FOR STRETCHED SSP REGIONS OF OPERATION



													Totals
						.7	2.0	2.4	1.0				6.2
					.3	.8	.8	.3	.1				2.4
				.2	.4	.9	1.4	.2	.2				3.2
				.3	.7	1.1	.9		.2				3.2
				.9	.9	.6	.7	.8	.1		.1		4.1
			.1	1.5	1.9	1.2	.8	.6	.3				6.3
			.3	2.4	1.3	1.6	1.4	.3		.1	.1		7.3
			.8	3.4	1.5	.9	.8	.5			.1		8.0
		.3	2.1	3.9	1.5	1.6	1.1	.6	.3				11.3
		1.5	3.3	4.3	1.9	1.2	1.0	.3					13.4
	.2	2.1	1.9	3.2	1.4	1.0	.9	.3		.1	.1		11.2
	.9	2.2	2.0	1.4	.8	.8	1.3	.3	.1	.2			10.0
.5	.6	.8	2.3	1.1	.7	1.1	.8	.8	.1	.1			8.9
.1	.5	.7	.5	.8	.3	.6	.4	.1	.1				4.1
	.2		.1			.1	.1						.4
													100.0
7.5	8.8	9.7	10.9	12.4	13.8	15.0	16.4	18.0	20.0	22.5	25.7		

SIGNIFICANT WAVE HEIGHT AND PERIOD

GRID POINT B **TOTAL SAMPLES 657** **FEBRUARY**



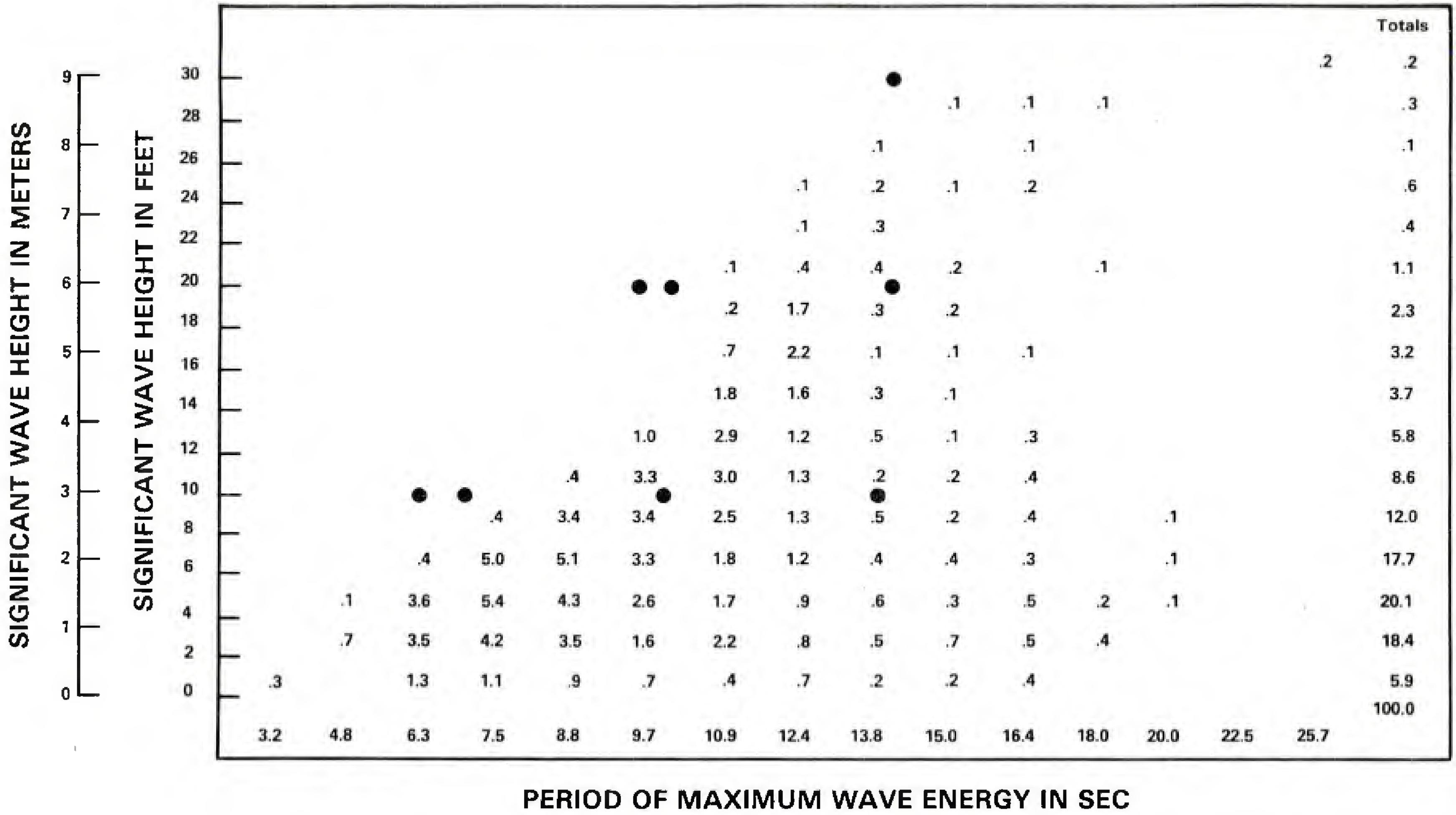
30										.9	1.7	2.7	1.4	.3	.5	7.5
28										.9	.3	1.4	.3		.2	3.1
26									.2	1.5	1.2	.6			.2	3.7
24								.5	.8	.8	1.2	.9	.2			4.4
22								.8	.9	1.2	1.5	.6	.3			5.3
20								.5	1.8	1.2	1.8	.5				5.8
18							.5	2.6	1.5	1.7	1.5	.6	.2			8.6
16							.6	3.5	2.3	1.4	2.7	.6				11.1
14							1.4	2.3	1.5	1.7	1.2	.9				9.0
12						.8	2.1	2.9	2.0	.9	.9	.3				9.9
10						2.7	2.4	1.4	1.4	1.7	.8	.2				10.6
8				.2	.6	4.0	1.1	2.0	.8	.8	.6	.2				10.3
6				.5	1.5	1.1	1.2	.6	1.1	1.2	.9	.2				8.3
4					.6	.3		.2	1.2							2.3
2			.2	.3	.2							.2				0.9
0																100.0
	3.2	4.8	6.3	7.5	8.8	9.7	10.9	12.4	13.8	15.0	16.4	18.0	20.0	22.5	25.7	

PERIOD OF MAXIMUM WAVE ENERGY IN SEC

FIGURE C.1 (CONTINUED)

SIGNIFICANT WAVE HEIGHT AND PERIOD

GRID POINT B **JULY-SEPT**



															Totals
														.2	.2
									.1	.1	.1				.3
								.1		.1					.1
							.1	.2	.1	.2					.6
							.1	.3							.4
						.1	.4	.4	.2		.1				1.1
						.2	1.7	.3	.2						2.3
						.7	2.2	.1	.1	.1					3.2
						1.8	1.6	.3	.1						3.7
					1.0	2.9	1.2	.5	.1	.3					5.8
				.4	3.3	3.0	1.3	.2	.2	.4					8.6
			.4	3.4	3.4	2.5	1.3	.5	.2	.4		.1			12.0
		.4	5.0	5.1	3.3	1.8	1.2	.4	.4	.3		.1			17.7
	.1	3.6	5.4	4.3	2.6	1.7	.9	.6	.3	.5	.2	.1			20.1
	.7	3.5	4.2	3.5	1.6	2.2	.8	.5	.7	.5	.4				18.4
.3		1.3	1.1	.9	.7	.4	.7	.2	.2	.4					5.9
															100.0
3.2	4.8	6.3	7.5	8.8	9.7	10.9	12.4	13.8	15.0	16.4	18.0	20.0	22.5	25.7	

FIGURE C.1 (CONTINUED)

TABLE C.1
SUMMARY WAVE STATISTICS FOR STRETCHED SSP REGIONS OF OPERATION

GRID POINT	MONTH(s)	SIGNIFICANT WAVE HEIGHT, ft					SIGNIFICANT WAVE HEIGHT, m				
		MINIMUM, 5 PERCENTILE	MEDIAN, 50 PERCENTILE	MAXIMUM, 95 PERCENTILE	MEAN	MOST PROBABLE	MINIMUM, 5 PERCENTILE	MEDIAN, 50 PERCENTILE	MAXIMUM, 95 PERCENTILE	MEAN	MOST PROBABLE
A	FEBRUARY	6	14	31	16	12-14	1.8	4.3	9.4	4.9	3.7-4.3
B	FEBRUARY	7	16	31	17	16-18	2.1	4.9	9.4	5.2	4.9-5.5
B	JULY-SEP	2	7	18	8	4-6	0.6	2.1	5.5	2.4	1.2-1.8

GRID POINT	MONTH(s)	MODAL WAVE PERIOD, SEC				
		MINIMUM, 5 PERCENTILE	MEDIAN, 50 PERCENTILE	MAXIMUM, 95 PERCENTILE	MEAN	MOST PROBABLE
A	FEBRUARY	9	13	19	14	12.4
B	FEBRUARY	9	13	19	14	12.4
B	JULY-SEP	6	9	16	10	8-11

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