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TECHNICAL EVALUATION OF U.S. COAST GUARD 180', 157' AND 133' BUOY TENDERS

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NOTICE

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16. Abstract

Three U.S. Coast Guard buoy tenders, BITTERSWEET (WLB 396), RED WOOD (WLM 685) and WHITE SAGE (WLM 544) were tested to obtain baseline characteristics for the 180', 157' and 133' class of tenders, respectively. These three ships were tested in calm water to obtain speed-power, fuel consumption, noise level and maneuvering data. Rough water seakeeping testing was accomplished on the CGC BITTERSWEET and on the CGC WHITE SAGE during mid-January 1987 in sea state 4 as two successive winter storms passed the Block Island Sound - Woods Hole, Massachusetts area. The CGC RED WOOD was rough water tested in a late spring storm in sea state 3 just north of Montauk Point, Long Island, New York.

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METRIC CONVERSION FACTORS

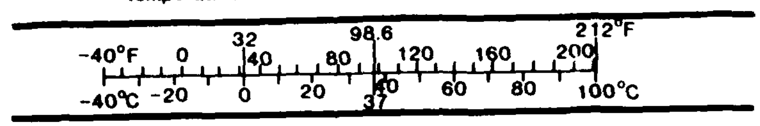
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENTS

Thanks to Robert Desruisseau for supplying the details for the description of the data acquisition system, the accelerometer characteristics, and other instrumentation used in the testing. He is also responsible for having processed the digital data for the seakeeping and maneuvering tests and generating most of the figures depicting that information.

Thanks to Robert Gibbons and again to Robert Desruisseau for their efforts in this testing effort; the tests could not have been accomplished without them.

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INTRODUCTION

In order to improve upon our existing buoy tender fleet, the engineering and operational characteristics of our present ships are evaluated using standardized, full scale ship tests. To do so requires testing in calm water to obtain powering and maneuvering data, and in rough water to obtain seakeeping and human response information. The data is collected at sea and then analyzed to obtain the engineering and operational characteristics. This data is then incorporated into the Vessel Data Base System for subsequent analyses and comparisons with other vessels. Full-scale trials offer the opportunity to see first hand the advantages of such operational characteristics as decreased ships motions or increased speed in a seaway. Trials also allow experienced personnel to recognize vessel shortcomings such as reduced range or increased difficulty of maintenance. By performing the same tests on Coast Guard cutters and candidate craft, data is available to make realistic comparisons of engineering and operational performance.

TEST OBJECTIVE

The objective of these tests was to obtain base line information to characterize the existing 180'(seagoing) "BALSAM" Class and 157'(coastal) "RED" Class and 133'(coastal) "WHITE SUMAC" Class buoy tenders in order to support the next generation buoy tender acquisition process. The standard calm water and rough water tests were run on all three ship classes.

VESSEL DESCRIPTIONS

Description and comparison of the vessels are greatly aided by use of a composite List of Particulars for the three classes of buoy tenders (See Table 1). The 180 and 133' tenders were built in WWII (1943). The 133' tenders were former Navy lighters adapted to Coast Guard buoy tending needs. The five "Red" class tenders were all built by the CG Yard between 1965 and 1972. Views of the vessels are shown in Figures 1B, 1R and 1W.

These vessels were originally used for buoy tending and for servicing manned lighthouses. Now, with few manned lighthouses, their large fuel capacity allows them to go for weeks on end without refueling, although for logistics purposes, the coastal tenders commonly return to their home port daily. These ships seldom tow another vessel, and in fact, the "WHITE SAGE" class does not have a towing bit.

INSTRUMENTATION

The heart of the shipboard instrumentation system is a 14 channel analog tape recorder. The output signals from the ship motion package, horsepower meters, accelerometers and other

TABLE 1
LIST OF PARTICULARS

	USCGC BITTERSWEET	USCGC RED WOOD	USCGC WHITE SAGE
HULL SHAPE	Icebreaking Round Bilge	Icebreaking Flat Bottom	Round Bilge
LOA	180′	157′	133′
BEAM	37′	33′	31′
DRAFT	12′6″	7′	8′
CREW OFFICER	6	4	1
CREW ENLISTED	47	27	20
DISPLACEMENT (L.T.)			
LIGHT	935	471	435
HEAVY	1025	572	550
PROPULSION (MDE)	Diesel-elect. Cooper-Bessimer 2 700 HP Gen. 1 1200 HP motor	2 Caterpillar 398 798 HP ea. (rated)	2 Caterpillar 353 425 HP ea. (rated)
GEAR RED.	None	2.9	3.41
MAX SPEED (K)	12	12.5	10
PROPELLER	Single 8′6″ dia. 84″ pitch	Two 40″ dia. 4 blades var. pitch	Two 56″ dia. 52″ pitch

TABLE 1
LIST OF PARTICULARS

	USCGC BITTERSWEET	USCGC RED WOOD	USCGC WHITE SAGE
RANGE (n.m.)			
OPT. SPEED	7200 (6K)	2450 (10K)	4200 (8K)
MAX SPEED	5200 (12K)	2100 (12.5K)	2500 (10K)
BOW THRUSTER	4000# Est. from 42" dia. prop @ 2100 engine rpm 208 HP (mech. drive)	Detroit Diesel 6061-A 155 HP @ 1800 rpm, Model 100 Gen. 125 KVA (elec. drive)	None
AUX. GEN.	50 KW 3 Phase 208 V	125 KVA 3 Phase 208 V .8 Power Factor	605 KW 3 Phase 208 V
FUEL CAP. (Gal. Usable)	28,000	17,620	10,900
PAYLOAD (S.TONS)			
BUOYS	50	20	50
WATER	75	75	50
FUEL	80	59	38
	205	154	138
OBSER. ROLL Period (sec.) (see p. 21)	8.5	6	5
BOOM CAP. (S. TONS)	20	10	10

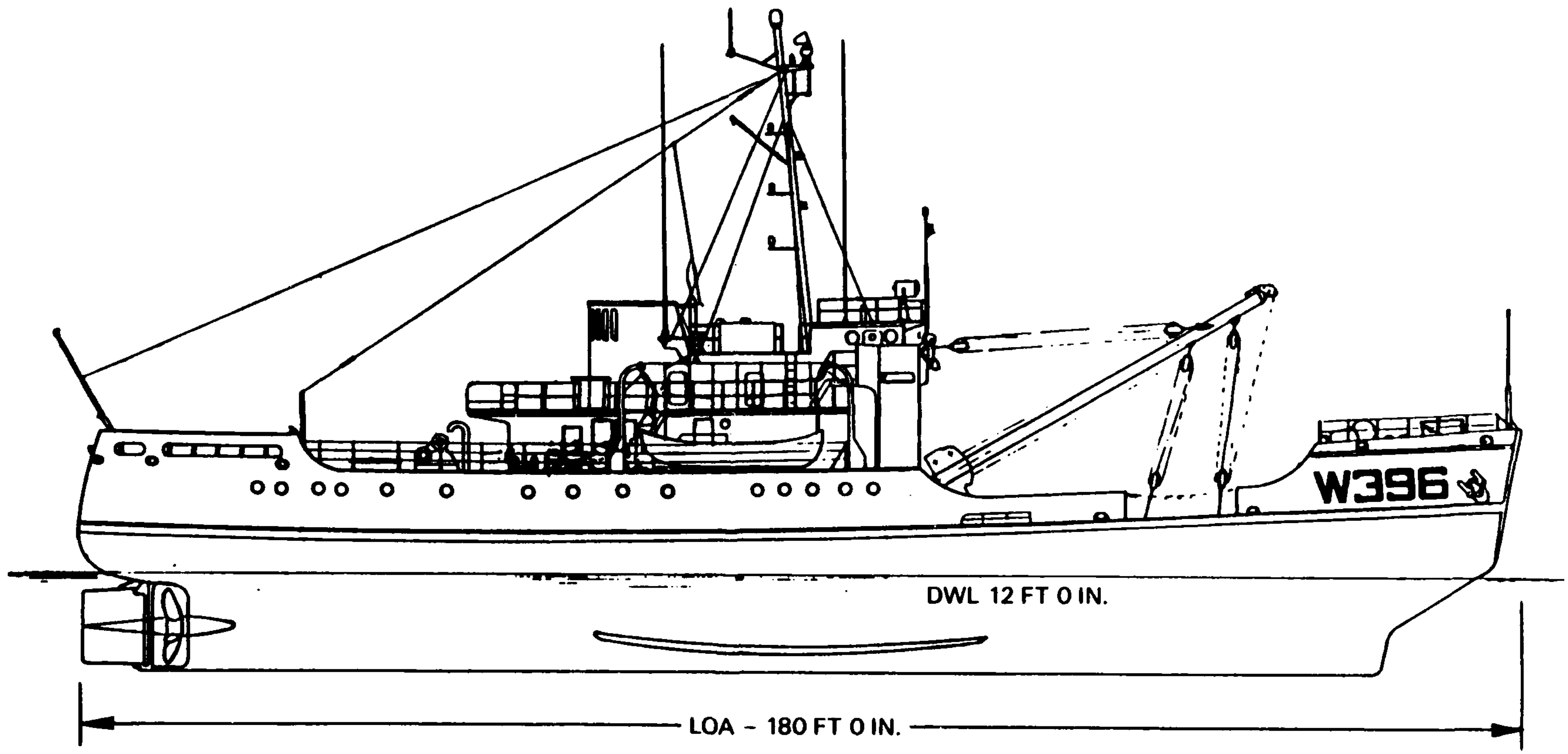


FIGURE 1B USCGC BITTERSWEET (WLB 389)

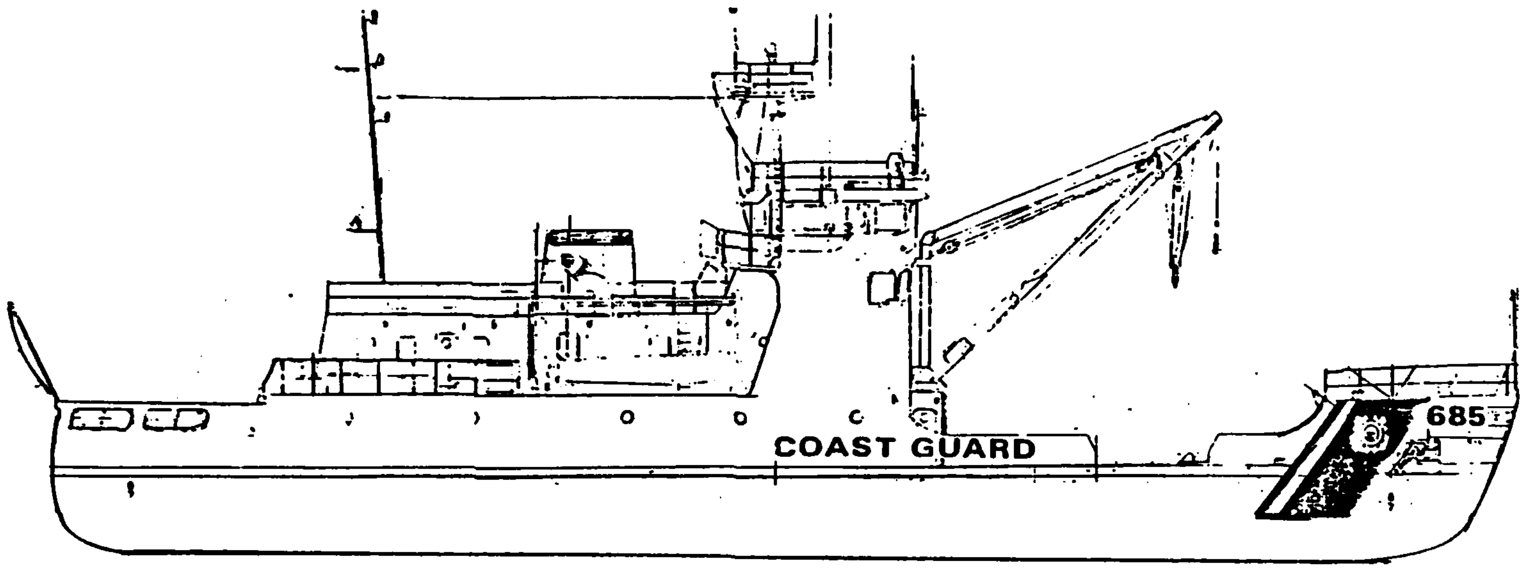


FIGURE 1R USCGC REDWOOD (157ft - WLM 685)

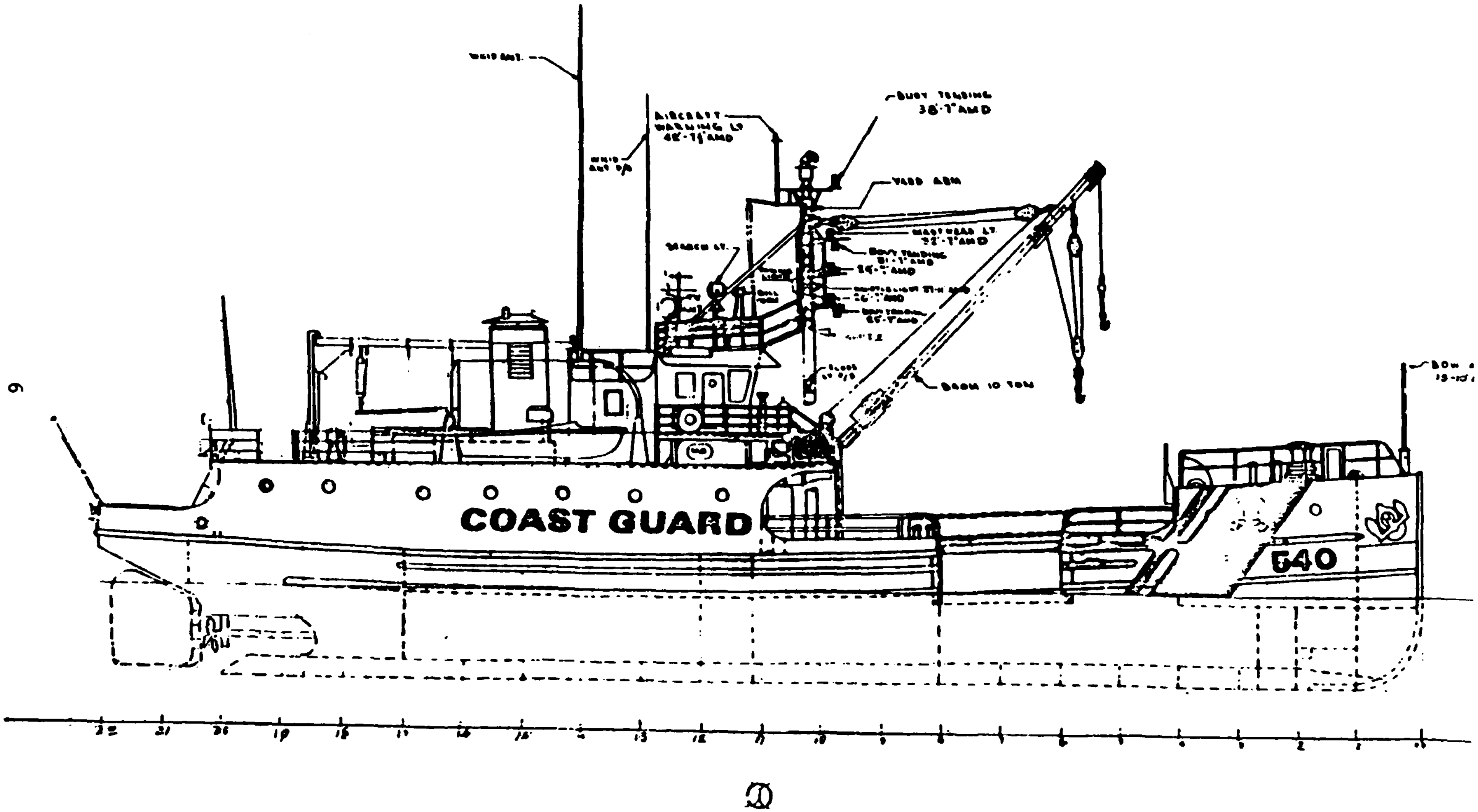


FIGURE 1W USCGC WHITE SAGE (133ft - WLM 544) instruments are routed to the recorder for continuous taping during tests. A block diagram of the data reduction system is in Appendix A, page A-2.

The instrumentation system includes a directional ENDECO 956 Wave Track buoy deployed for seakeeping tests so that actual sea conditions can be measured. The ENDECO receiver converts wave height and buoy tilt signals into an 8-bit binary code which is transmitted to the vessel where it is processed by an Otrona Attache microcomputer. Significant wave height and a wave energy direction vs frequency plot (See Figures 2) are produced on board. The wave data is also presented with sufficient statistical data to effectively characterize the sea state existing as having its own unique "signature".

Other instruments are read and recorded manually during testing; they include a sound level meter, fuel flow meters, and a human response meter. A description of transducers available, their associated instruments and characteristics is also listed in Appendix A.

TEST DESCRIPTION

The intent of this technical evaluation was to quantify the engineering and operational characteristics of the 180', 157' and 133' Coast Guard buoy tenders; accordingly, information was required in the following areas:

- Seakeeping Ability - Ship motion in waves and the ranges of seasickness and fatigue for crew members in response to heave.

- Maneuverability - Turning rate (spiral test) and rudder response (zig-zag maneuver).

- Speed, Power, and Fuel Consumption.

- Noise levels in living and machinery spaces.

To obtain this information a standard set of tests, shown below, were scheduled. These tests are described in detail in the General Test Plan (GTP) (Reference 1).

Description	GTP NUMBER
Principal Characteristics	1
Speed vs Power	3
Fuel Consumption and Endurance	4
Maneuverability - Spiral Test	8
Maneuverability - Zig Zag Maneuver	9
Motion in Waves	13
Noise Level	24
Seakeeping Ability - Physiological	37

ENDECO INC.
TYPE 956 DIRECTIONAL WAVE-TRACK BUOY

SEA KEEPING BITTERSWEET 22 JAN 87 WOODS HOLE MA.
INSTRUMENT 9560118 FILE: BITTOISW
22-JAN-87 AT 13:22:54 SAMPLE LENGTH : 256

######################## VARIANCE SPECTRUM ########################

ENTRIES ARE SCALED LINEARLY FROM 0 TO 50
PEAK VALUE CORRESPONDS TO SPECTRAL DENSITY OF .357 (FT-SQ/HZ/DEG)

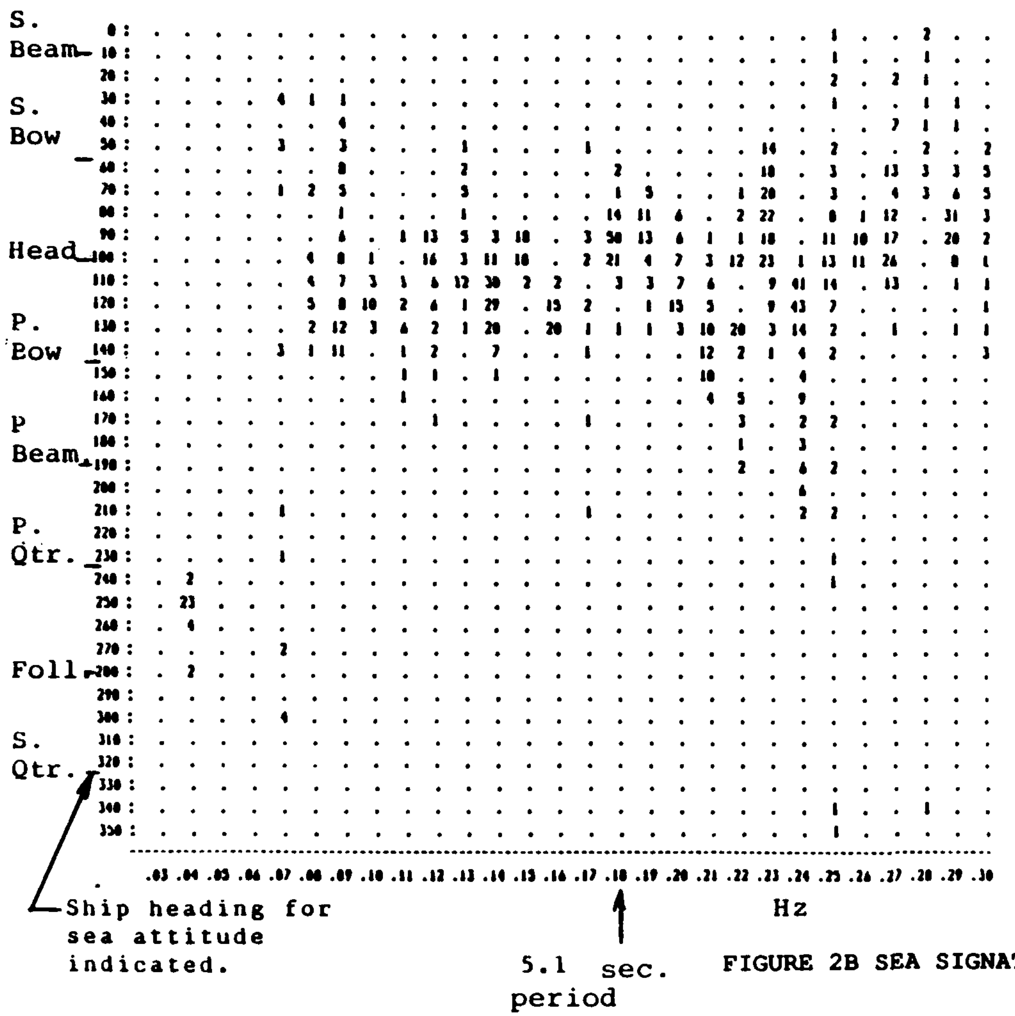


FIGURE 2B SEA SIGNATURE

#################### ZERO-CROSSING STATISTICS ####################

NBR WAVES	MAX PERIOD (S)	PERIOD OF MAX HEIGHT (S)	MAX HEIGHT (FT)	SIGNIFICANT PERIOD (S)	SIGNIFICANT HEIGHT (FT)	MEAN PERIOD (S)	MEAN HEIGHT (FT)	HEIGHT VARIANCE (FT)	ROOT-MEAN-SQ HEIGHT (FT)
60	10.0	5.0	8.0	4.7	4.4	4.2	2.7	2.2	3.1

PROFILE OF MAXIMUM WAVE AT 1.00 SECOND INTERVALS

-3.3 1.7 4.7 -1.5 -2.5 -.7 1.9

################## SPECTRAL ANALYSIS STATISTICS ##################

SIGNIFICANT WAVE HEIGHT (H 1/3) ... 4.46
ROOT-MEAN-SQUARE WAVE HEIGHT 3.16
AVERAGE PERIOD 4.90
AVERAGE ZERO CROSSING 4.67

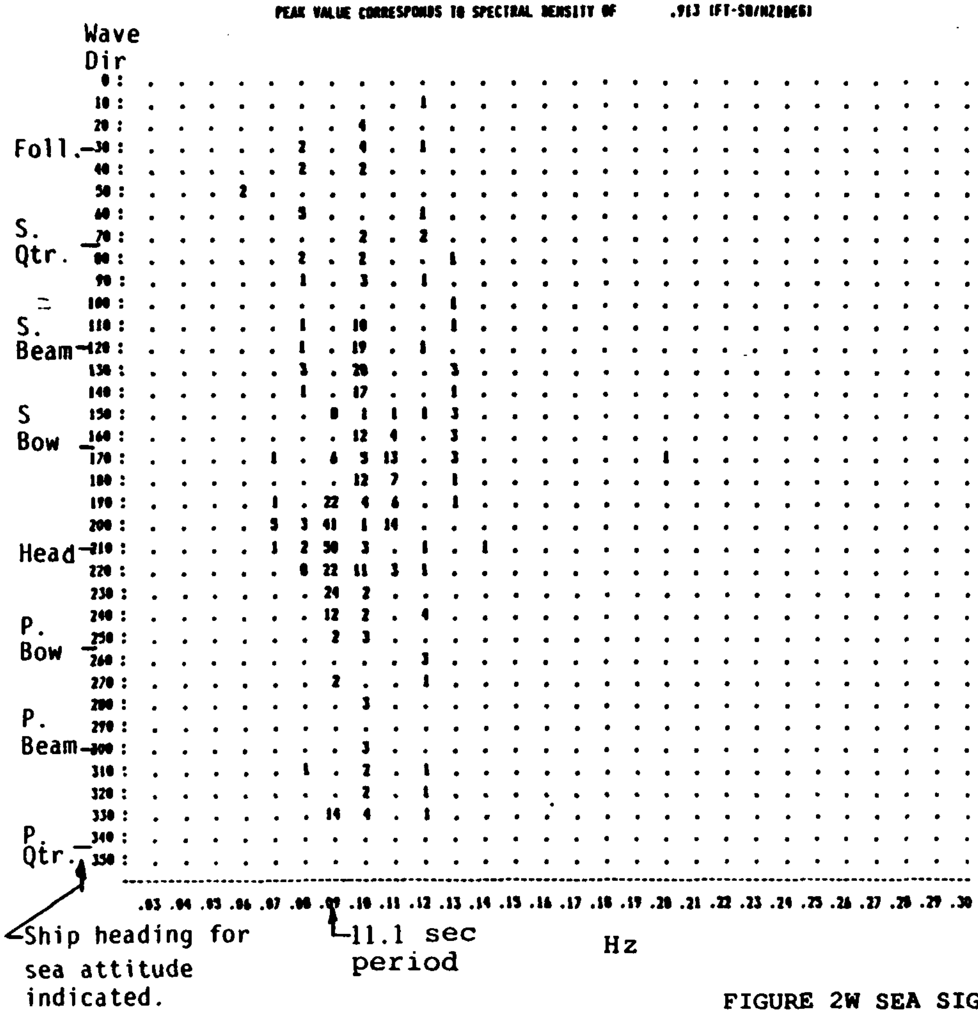
FREQUENCY BANDNUMBER	CENTER FREQUENCY (HZ)	CENTER PERIOD (S)	ENERGY DENSITY (FT-SQ/HZ)	MEAN DIRECTION (DEG)	STANDARD DEVIATION (DEG)
1	.030	33.3	.00	283.	1.8
2	.040	25.0	2.01	254.	3.3
3	.050	20.0	.00	286.	13.7
4	.060	16.7	.03	263.	8.0
5	.070	14.3	1.74	5.	23.8
6	.080	12.5	1.71	108.	6.4
7	.090	11.1	5.62	101.	7.0
8	.100	10.0	1.50	118.	2.3
9	.110	9.1	1.60	126.	5.7
10	.120	8.3	3.84	109.	4.1
11	.130	7.7	2.88	94.	4.6
12	.140	7.1	7.99	119.	2.6
13	.150	6.7	3.16	97.	1.4
14	.160	6.2	3.54	126.	1.8
15	.170	5.9	1.66	125.	6.2
16	.180	5.6	7.37	92.	1.7
17	.190	5.3	3.31	90.	2.3
18	.200	5.0	3.91	107.	2.4
19	.210	4.8	5.16	133.	4.3
20	.220	4.5	4.95	129.	4.3
21	.230	4.3	13.06	84.	3.0
22	.240	4.2	12.05	132.	3.8
23	.250	4.0	8.56	98.	6.7
24	.260	3.8	2.29	94.	2.8
25	.270	3.7	10.99	84	3.5
26	.280	3.6	2.42	39.	4.2
27	.290	3.4	8.93	83.	2.2
28	.300	3.3	3.32	88.	3.7

ENDECO INC.
TYPE 956 DIRECTIONAL WAVE-TRACK BUOY

WHITE SAGE SEAKEEPING
INSTRUMENT 9560118 FILE: TWOVOIGE
20-JAN-87 AT 12:26:03 SAMPLE LENGTH : 512

######################## VARIANCE SPECTRUM ########################

ENTRIES ARE SCALED LINEARLY FROM 0 TO 50
PEAK VALUE CORRESPONDS TO SPECTRAL DENSITY OF .913 (FT-SQ/HZ/DEG)



#################### ZERO-CROSSING STATISTICS ####################

NOR WAVES	MAX PERIOD (S)	PERIOD OF MAX HEIGHT (S)	MAX HEIGHT (FT)	SIGNIFICANT PERIOD (S)	SIGNIFICANT HEIGHT (FT)	MEAN PERIOD (S)	MEAN HEIGHT (FT)	HEIGHT VARIANCE (FT)	ROOT-MEAN-SQ HEIGHT (FT)
59	12.0	11.0	6.9	10.6	3.8	8.5	2.4	1.7	2.7

PROFILE OF MAXIMUM WAVE AT 1.00 SECOND INTERVALS

-1.5 .1 3.3 4.2 4.0 2.7 .3 -1.8 -2.7 -2.6 -1.8 -.2 1.0

#################### SPECTRAL ANALYSIS STATISTICS ####################

SIGNIFICANT WAVE HEIGHT (H 1/3) ... 4.27
ROOT-MEAN-SQUARE WAVE HEIGHT 3.02
AVERAGE PERIOD 9.82
AVERAGE ZERO CROSSING 9.49

FREQUENCY BANDNUMBER	CENTER FREQUENCY (HZ)	CENTER PERIOD (S)	ENERGY DENSITY (FT-SQ/HZ)	MEAN DIRECTION (DEG)	STANDARD DEVIATION (DEG)
1	.030	33.3	.00	345.	13.9
2	.040	25.0	.00	217.	19.9
3	.050	20.0	.11	182.	16.9
4	.060	16.7	1.28	79.	13.6
5	.070	14.3	3.07	207.	10.4
6	.080	12.5	7.86	140.	12.9
7	.090	11.1	41.60	213.	5.8
8	.100	10.0	31.69	149.	10.4
9	.110	9.1	10.09	166.	5.5
10	.120	8.3	6.39	226.	12.6
11	.130	7.7	4.77	143.	4.6
12	.140	7.1	1.43	174.	7.9
13	.150	6.7	.50	181.	5.4
14	.160	6.2	.40	180.	4.7
15	.170	5.9	.60	147.	8.8
16	.180	5.6	.39	13.	6.9
17	.190	5.3	.37	119.	7.7
18	.200	5.0	.38	167.	5.4
19	.210	4.8	.28	143.	7.0
20	.220	4.5	.29	99.	6.6
21	.230	4.3	.42	201.	7.1
22	.240	4.2	.13	131.	5.8
23	.250	4.0	.12	249.	7.3
24	.260	3.8	.06	339.	6.9
25	.270	3.7	.12	188.	7.8
26	.280	3.6	.14	270.	4.7
27	.290	3.4	.13	233.	5.7
28	.300	3.3	.23	188.	7.8

NOTE: Energy calculated for band 01 contains frequency components outside the range of the buoy.

FIGURE 2W SEA SIGNATURE

All tests were conducted in accordance with the General Test Plan.

The calm water tests were accomplished in early December, 1986 for the RED WOOD, just South of Groton, and shortly thereafter near Woods Hole, MA. for the BITTERSWEET and WHITE SAGE.

DATA REDUCTION

The raw data was collected at sea for motion in waves from a calibrated ship motion package. Data reduction back in the lab was required to convert the voltage readings recorded on an analog tape recorder to engineering units. Applicable statistics were computed with the use of a computer and analog to digital converter.

Some data, such as shaft rpm, horsepower and fuel flow were recorded by hand (directly from the instruments at the time of the tests). Ship speed was measured directly from the instruments at the time of the tests. Ship speed was determined by shaft rpm conversion and checked against Loran C. Noise levels were read with a sound level recorder at various locations in the the ship at specified power levels.

The seaway data was transmitted from the ENDECO buoy deployed and received on board the vessels. It was then reduced using ENDECO software on the Otrona computer to produce the wave energy, frequency-direction distribution and significant wave height, Figure 2B and Figure 2W. ENDECO wave data were not collected in conjunction with the RED WOOD seakeeping tests. The majority of the ship motion raw data, however, was reduced and processed at the Research and Development Center after the completion of the trial.

Processing of the wave buoy signal allows determination of the maximum wave energy direction so that the seakeeping tests on board the ships were run at ship headings related to the major swells, as determined by the sea signature (See Variance Spectrum). For each of the five legs (head, bow, beam, quartering and following seas) of the seakeeping runs, ship motion (roll, pitch and heave) were analyzed. The average of the highest one third (H(1/3)) and the average of the highest one tenth(H(1/10)) single amplitude motions were computed by the R&D Center software program GENPEAK.

The GENSES program runs on a Hewlett Packard (HP) 2000 Series computer and is responsible for converting analogue recorded signals to digital data in applicable engineering units. Up to 20 channels of analog data recorded on the Racal tape recorder(s) are digitized with the HP data acquisition control unit and HP digital voltmeter. The GENPEAK program then searches the digital file for peaks, records all peaks exceeding a defined limit (e.g., one degree of roll above or below the mean signal level) and then sorts these peaks from high to low. Subsequently, the H(1/10) and H(1/3) values are computed.

ANALYSIS AND RESULTS

ROUGH WATER

Motions

Seakeeping tests aboard the BITTERSWEET, WHITE SAGE, and RED WOOD were conducted in 4.5', 4.2' and 2.5' significant seas, respectively. The actual displacement at time of testing the 180', 157' and 133' buoy tenders was 1000, 498 and 476 LT, respectively.

Figure 2B gives the sea signature (frequency, direction spectrum and relative wave energy) for the sea state experienced by the BITTERSWEET resulting from a sudden encounter from a fog bank/squall line preceding a swiftly approaching Northeaster which would later that night bring 55 knot winds to the area (a confused sea state is shown). Figure 2W gives the sea signature data for the WHITE SAGE.

There was no sea signature collected for the seakeeping test run for the RED WOOD; a wave rider buoy was deployed but problems were encountered which prevented processing the signal which would have given marginal statistical data due to the low level (below 3 foot) sea state. Visual observation determined the wave height to be 2.5 ft (Marx Tables).

Polar plots of significant H(1/3) roll, pitch and heave data are presented in Figures 3-5. Tabular data is presented in Appendix C Tables C-1B, C-1R and C-1W, and includes the highest value, average of the 1/10 highest, average of the 1/3 highest, RMS and mean of the ship motion data. These plots show single amplitude excursions of roll, pitch and heave as a result of the existing sea state. The BITTERSWEET was tested at 9.5 knots, the RED WOOD at 12 knots and the WHITE SAGE at 8 knots. The RED WOOD was also tested at zero speed, similar to a buoy tending operation while recovering the wave rider buoy; this information is given in Table C-5R.

As shown in Figures 3B and 3R, the BITTERSWEET and RED WOOD are dramatically worse in rolling in beam and bow seas than in any other sea condition. The WHITE SAGE is slightly less susceptible to rolling in beam and following seas. The observed roll period for the BITTERSWEET, RED WOOD, and WHITE SAGE was determined by stopwatch to be 8.5, 6.0 and 5.0 seconds, respectively. This was accomplished after dropping large buoys or sinkers which resulted in large rolling motions and allowed measuring the roll period. These periods agree with the measured roll data obtained in following and head seas by the three gimbled gyro in the Humphries Motion Package.

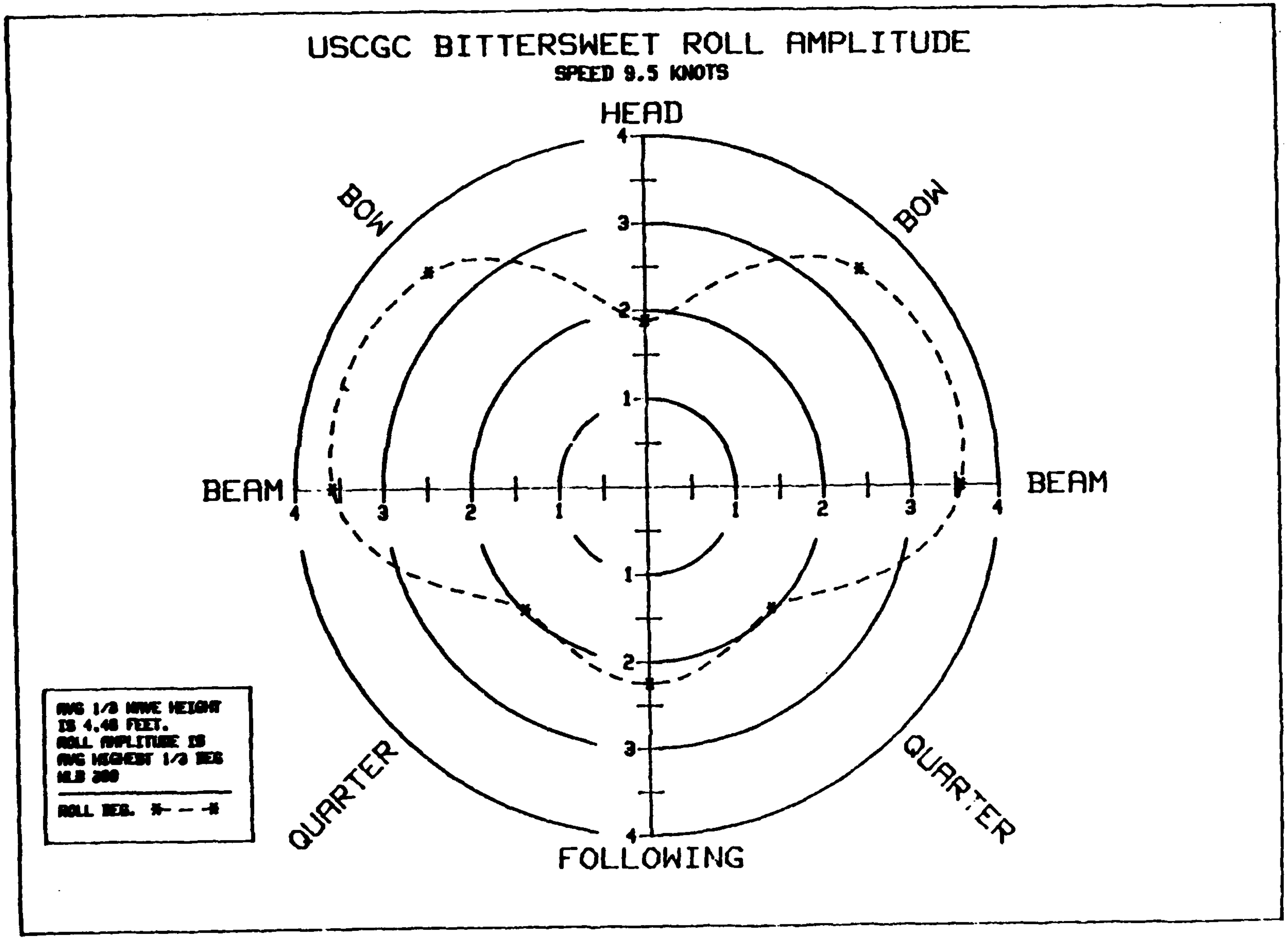


FIGURE 3B ROLL AMPLITUDE POLAR PLOT, 9.5 KNOTS

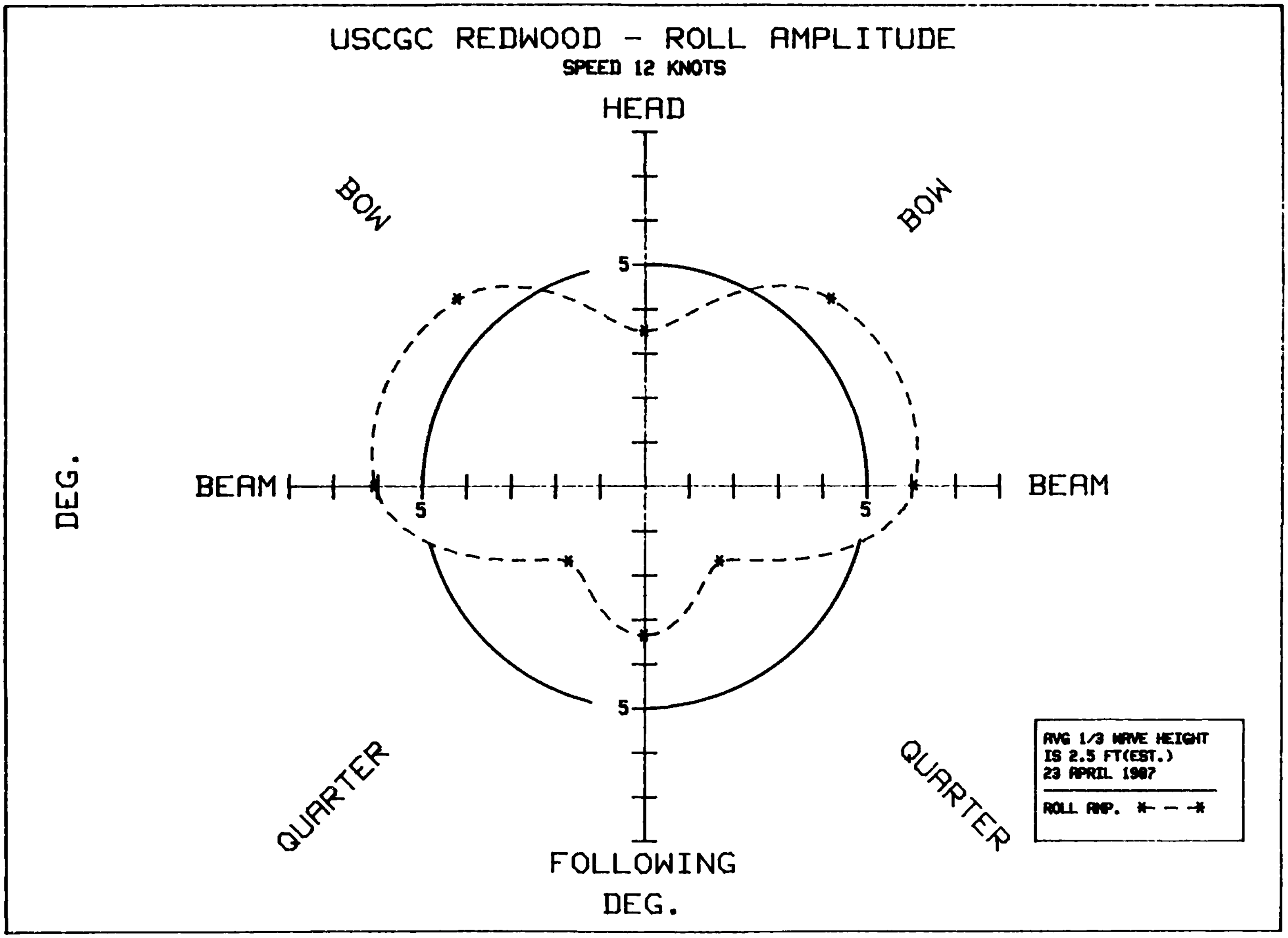


FIGURE 3R ROLL AMPLITUDE POLAR PLOT, 12 KNOTS

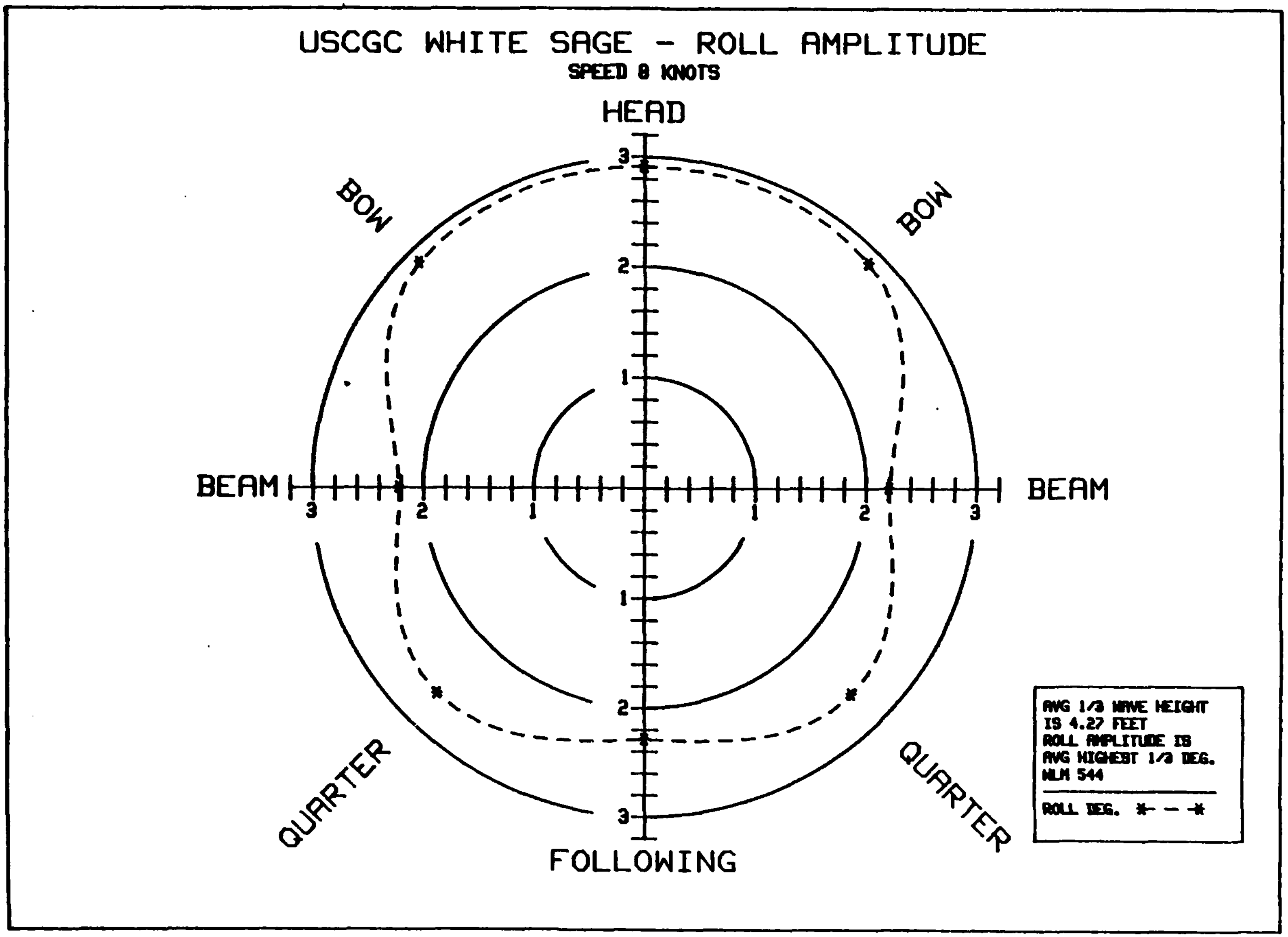


FIGURE 3W ROLL AMPLITUDE POLAR PLOT, 8 KNOTS

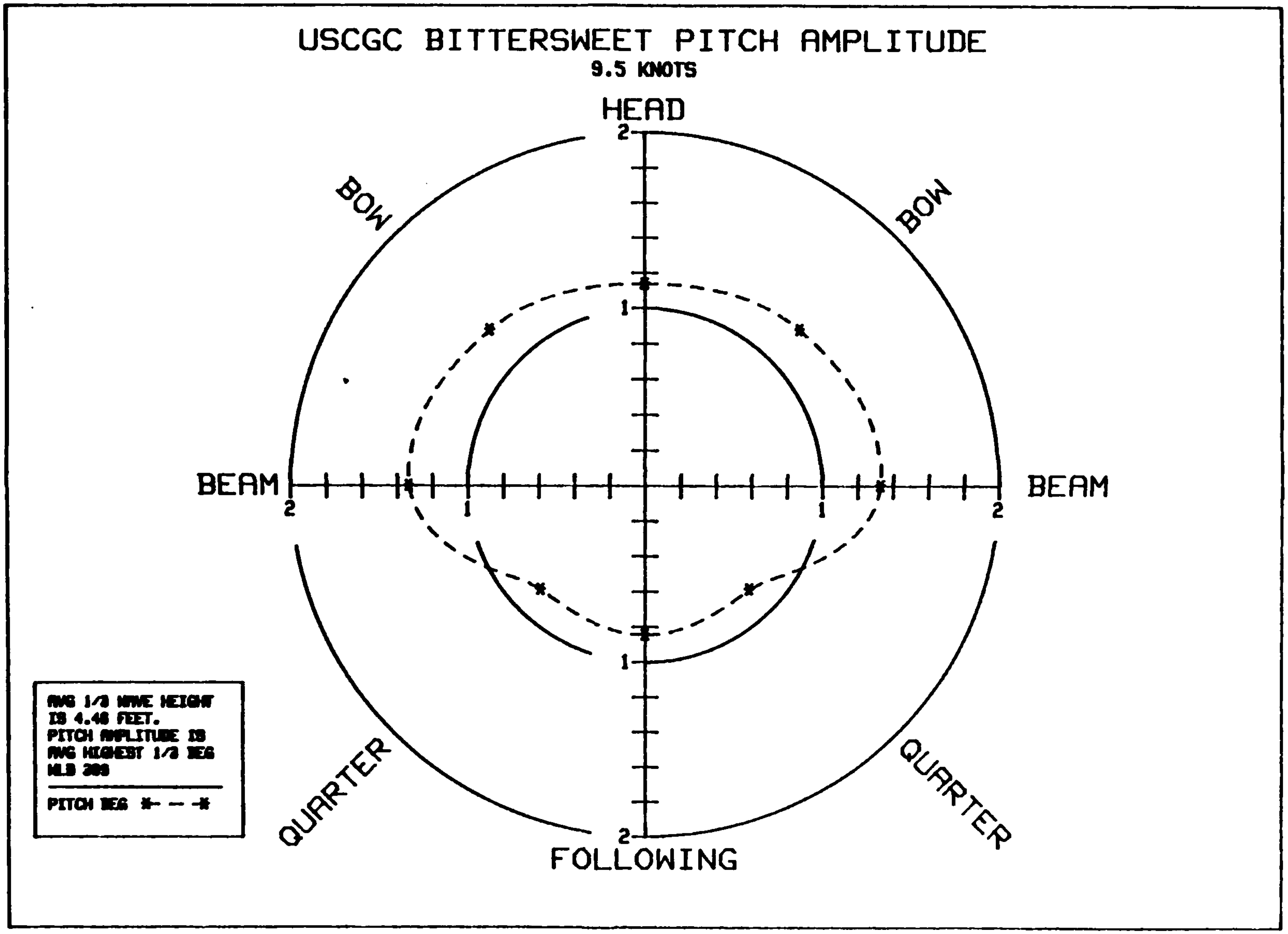


FIGURE 4B PITCH AMPLITUDE POLAR PLOT, 9.5 KNOTS

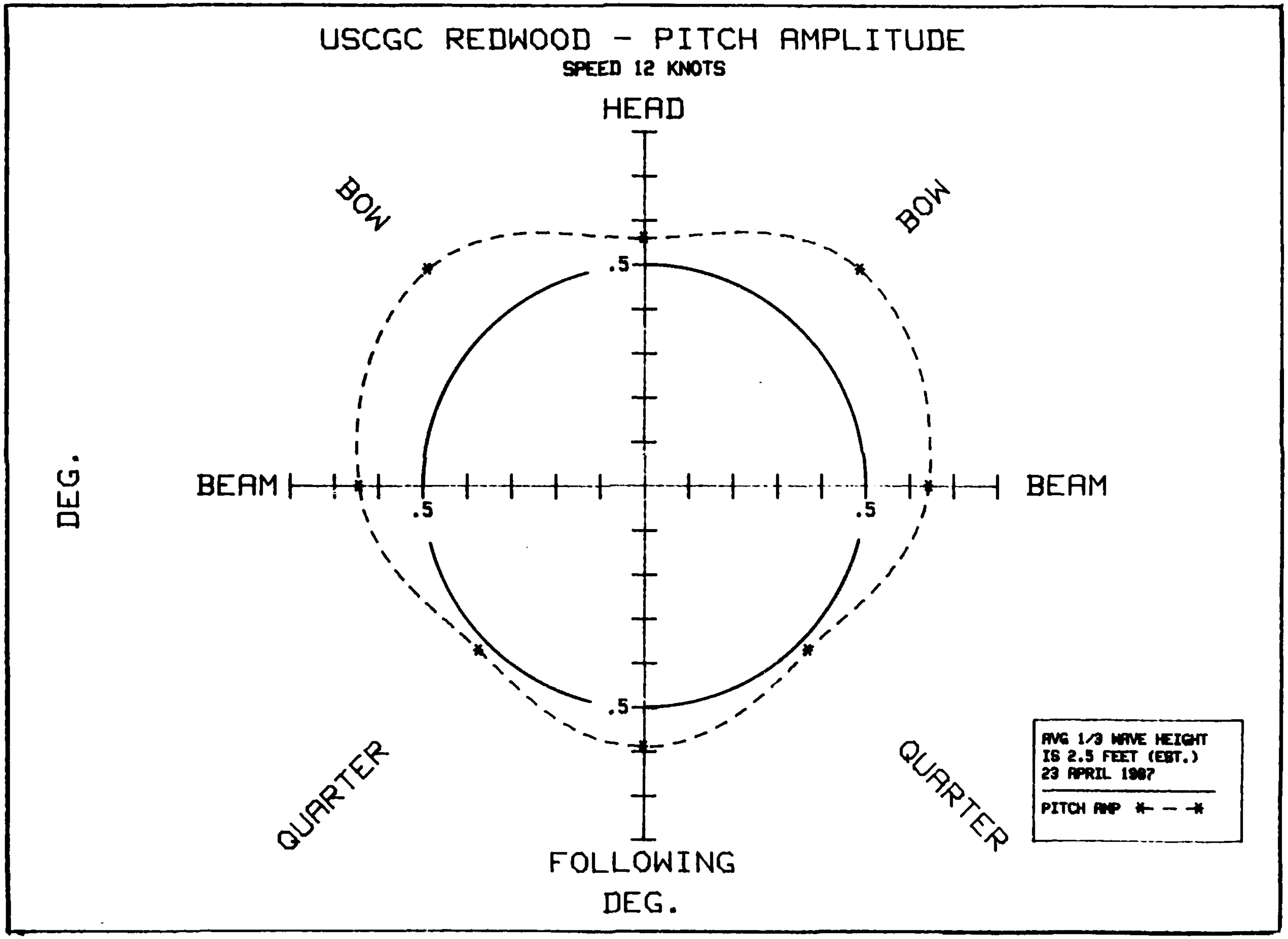


FIGURE 4R PITCH AMPLITUDE POLAR PLOT, 12 KNOTS

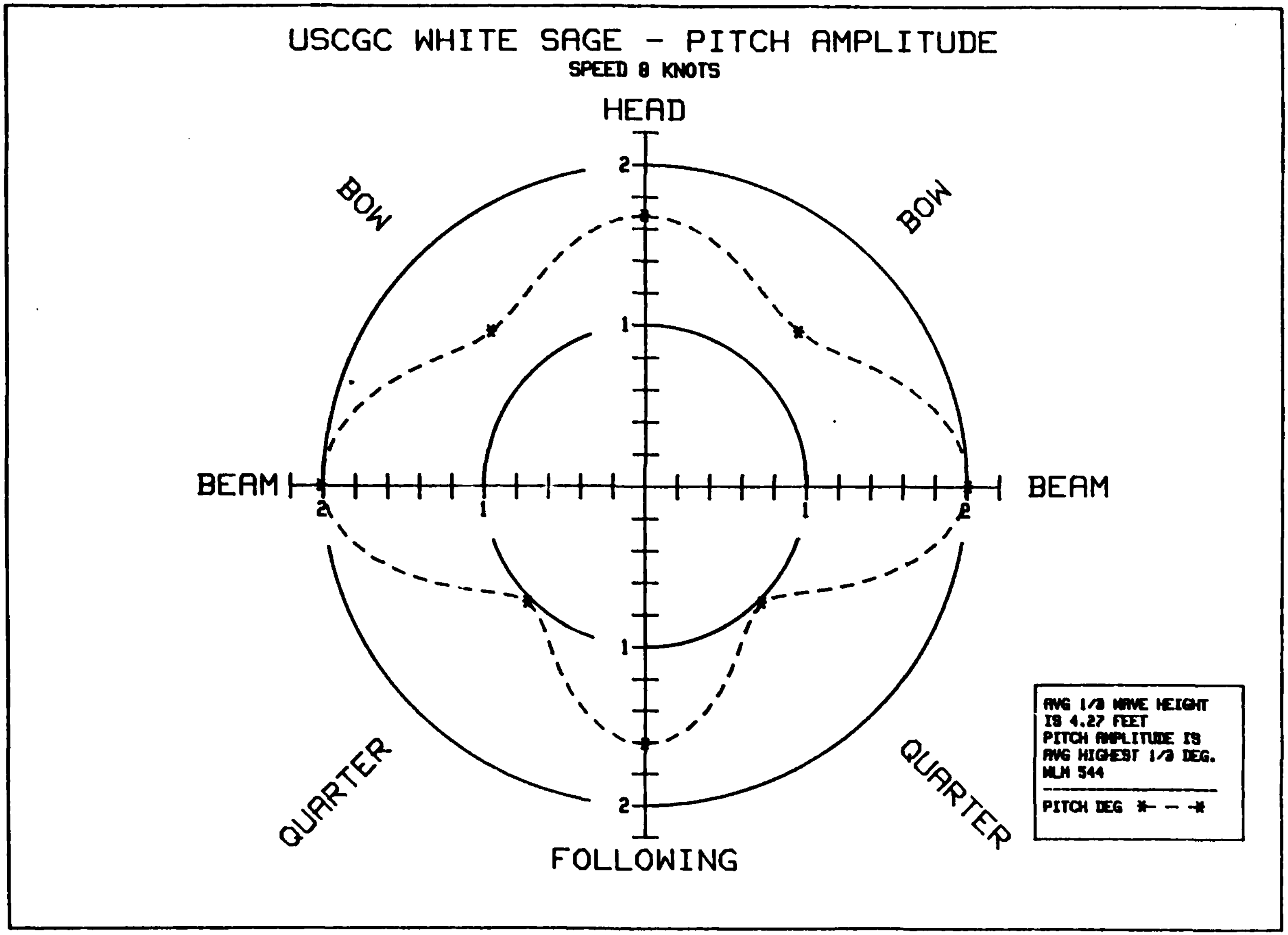


FIGURE 4W PITCH AMPLITUDE POLAR PLOT, 8 KNOTS

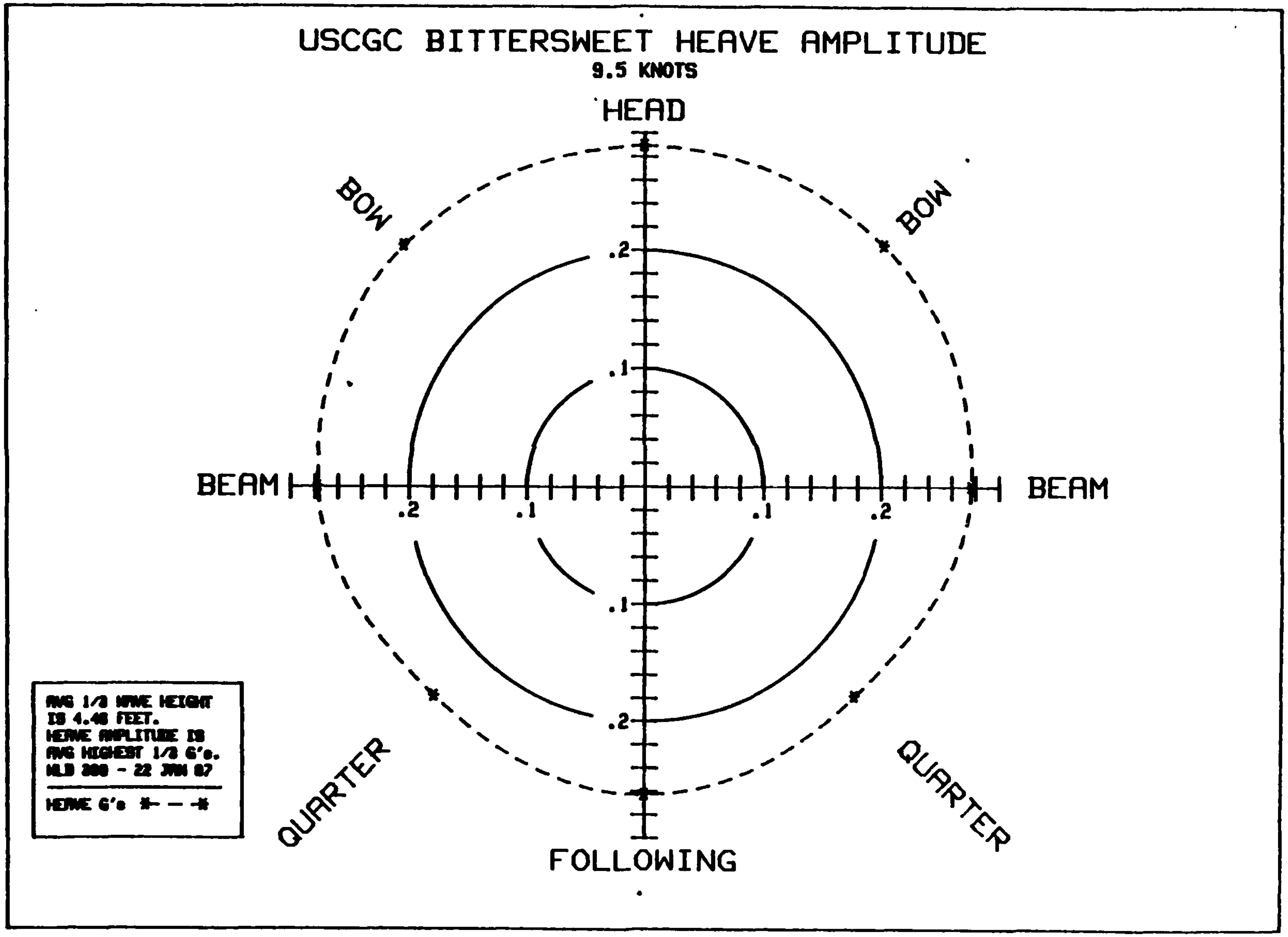


FIGURE 5B HEAVE ACCELERATION AT CG, POLAR PLOT, 9.5 KNOTS

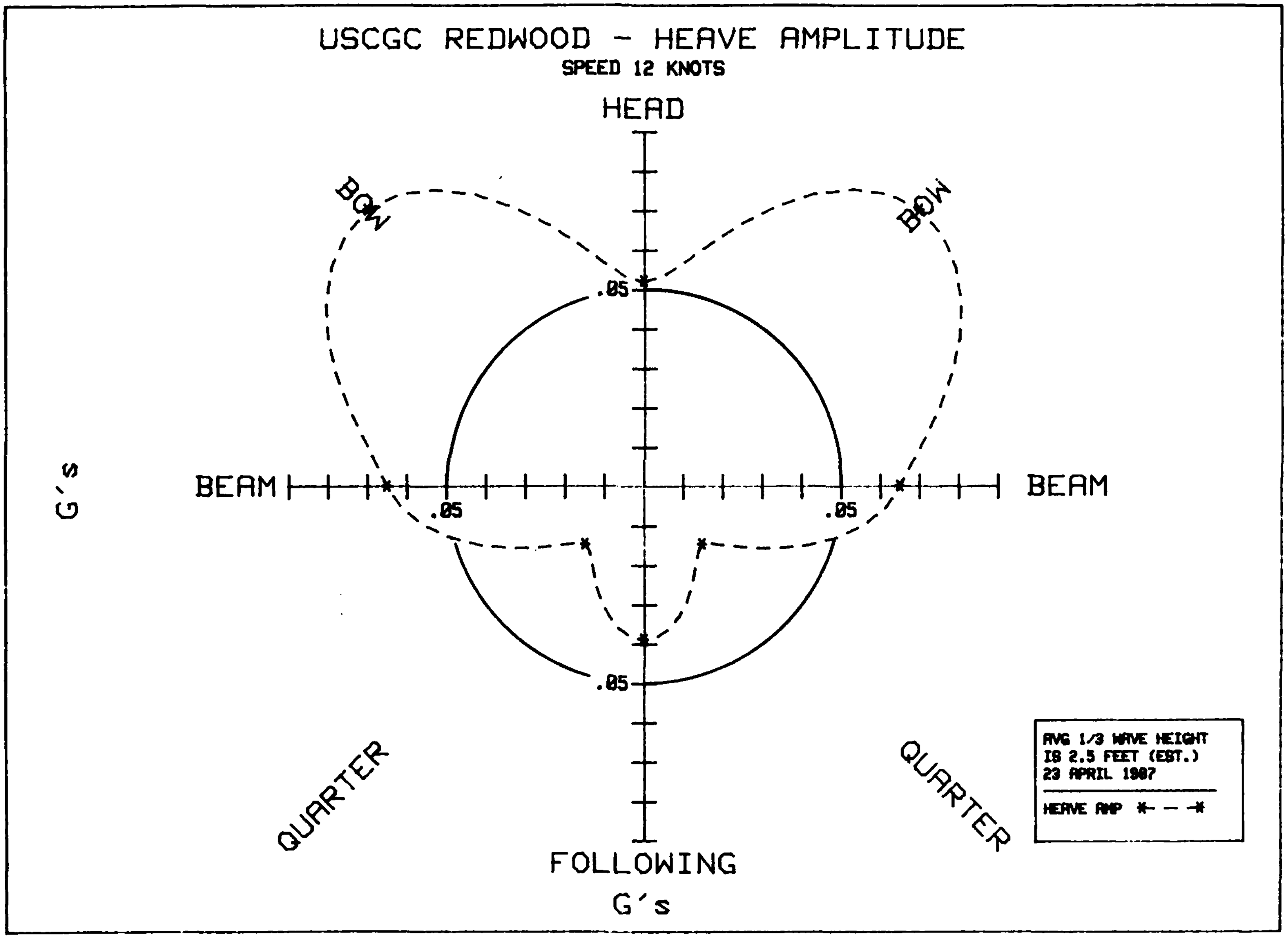


FIGURE 5R HEAVE ACCELERATION AT CG, POLAR PLOT, 12 KNOTS

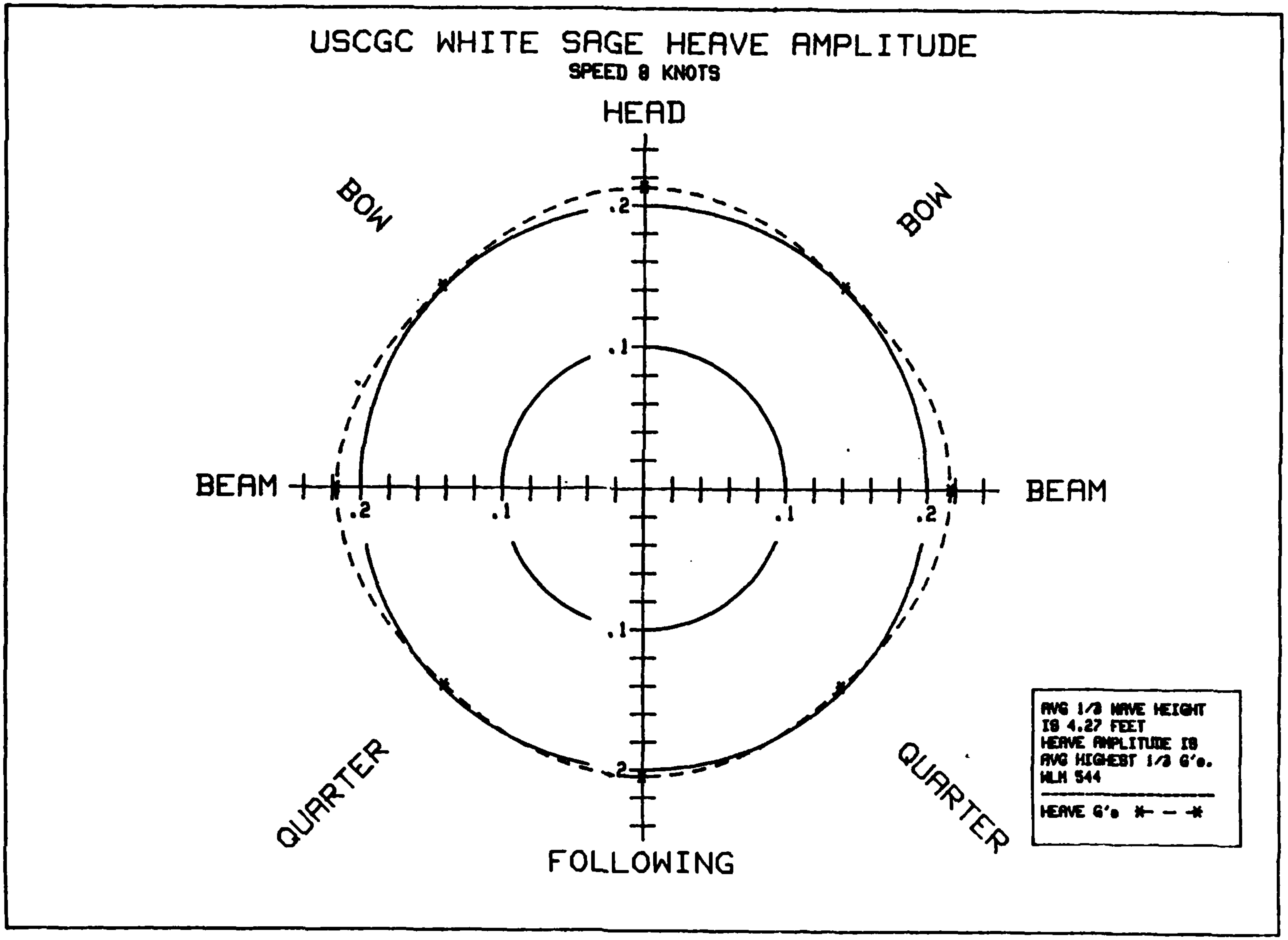


FIGURE 5W HEAVE ACCELERATION AT CG, POLAR PLOT, 8 KNOTS

Figure 4W shows the WHITE SAGE capable of pitching in almost the same degree regardless of sea direction. The combined pitching and rolling are apparently interacting (because of the hull configuration) to produce nearly isotropic motion . The flat bottomed RED WOOD also has a capability of pitching in almost any sea but responds in maximum pitching in bow seas (See Figure 4R). The BITTERSWEET has attenuated pitching motion with following and quartering seas as seen in Figure 4B.

Heave at the center of gravity (CG) for the BITTERSWEET and WHITE SAGE is quite uniform regardless of sea direction. Normally the WHITE SAGE cannot continue buoy tending when winds exceed 28 knots because it does not have the power to maintain its buoy tending station and must break away long before any significant sea develops. Similarly, the BITTERSWEET must break off its buoy tending operation somewhere in the vicinity of 35 knot wind even if operating in protected water because its large sail area develops a wind load which overwhelms the propulsion system at that point. Additional roll and pitch data collected on the 180' CGC MALLOW with no bilge keels is available for 10.4 and 4.3 ft significant seas as reported in Reference 3.

Figure 5R shows affinity for increased ship motion in bow seas for the RED WOOD. During the seakeeping tests and at other times aboard the RED WOOD, the observed seas were not above three feet. The crew of this ship had many stories concerning the ships poor roll motion characteristics in seas above 3 feet which are attributed its flat bottom design and high superstructure. Rolling was its worst attribute and 12-15 degrees rolls were experienced while maneuvering for the test in 2 1/2 to 3 foot seas.

CALM WATER

Maneuverability - Spiral

The Spiral Test Maneuver is designed to measure the basic steering ability of the ship. This is accomplished by turning the ship's rudder from 20 degrees right to 20 degrees left (and back to 20 degrees right) in small, successive rudder angle changes, each held long enough to determine the steady turning rates of each rudder angle. Good stability is present when there is a lack of hysteresis (open loop) on the curve of rudder angle and yaw rate. An open loop would indicate different turning rates at the same rudder angle attributed to the momentum of the ship turning left or right.

The spiral test for the BITTERSWEET and the WHITE SAGE should be singled out (See Figures 6B & 6W) as an example of excellent rudder action. Both have large rudders which allows almost instant response to the helmsman and are almost identical on Port and Starboard side. In addition, the BITTERSWEET with

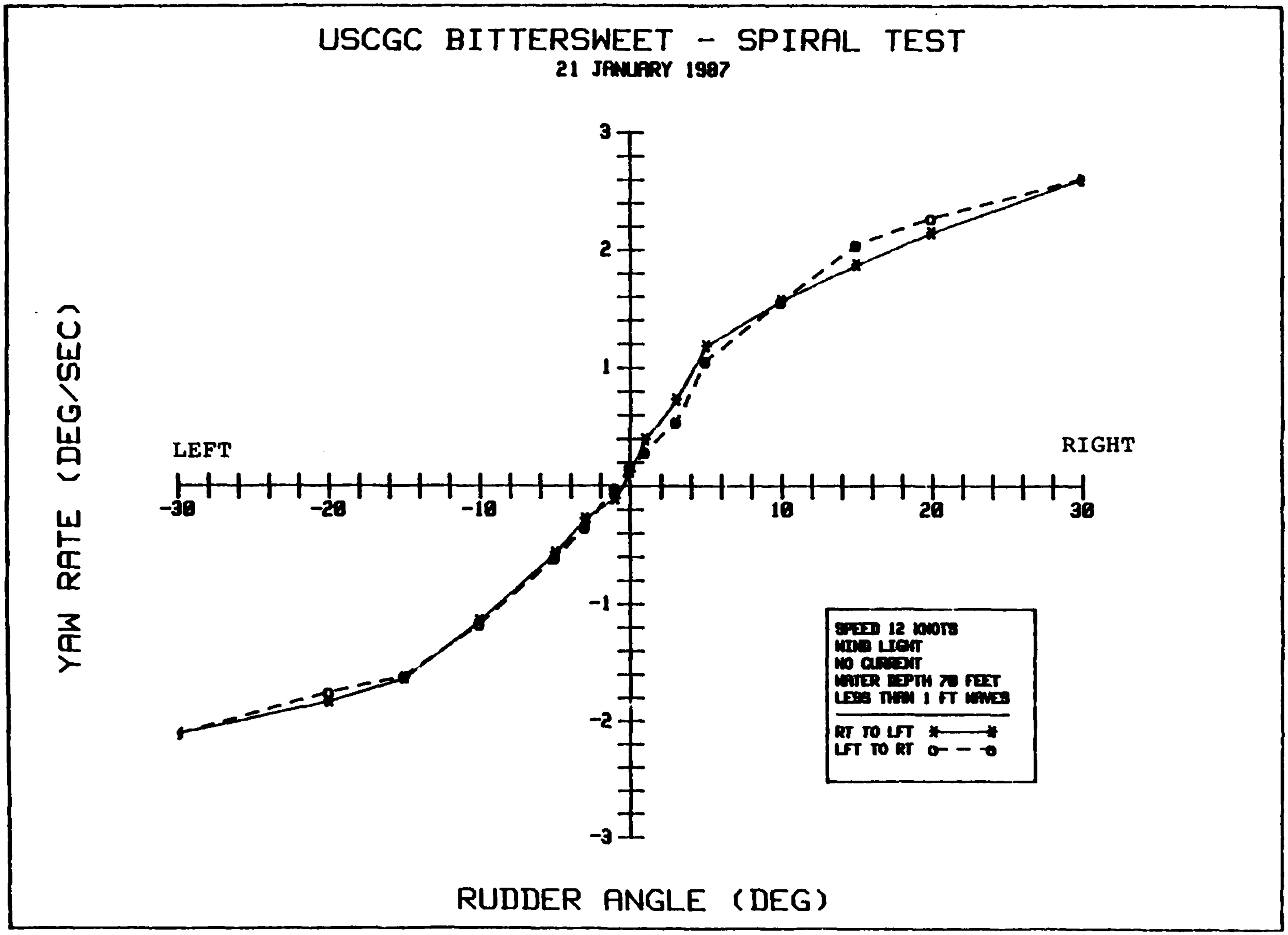


FIGURE 6B SPIRAL TESTS, 12 KNOTS

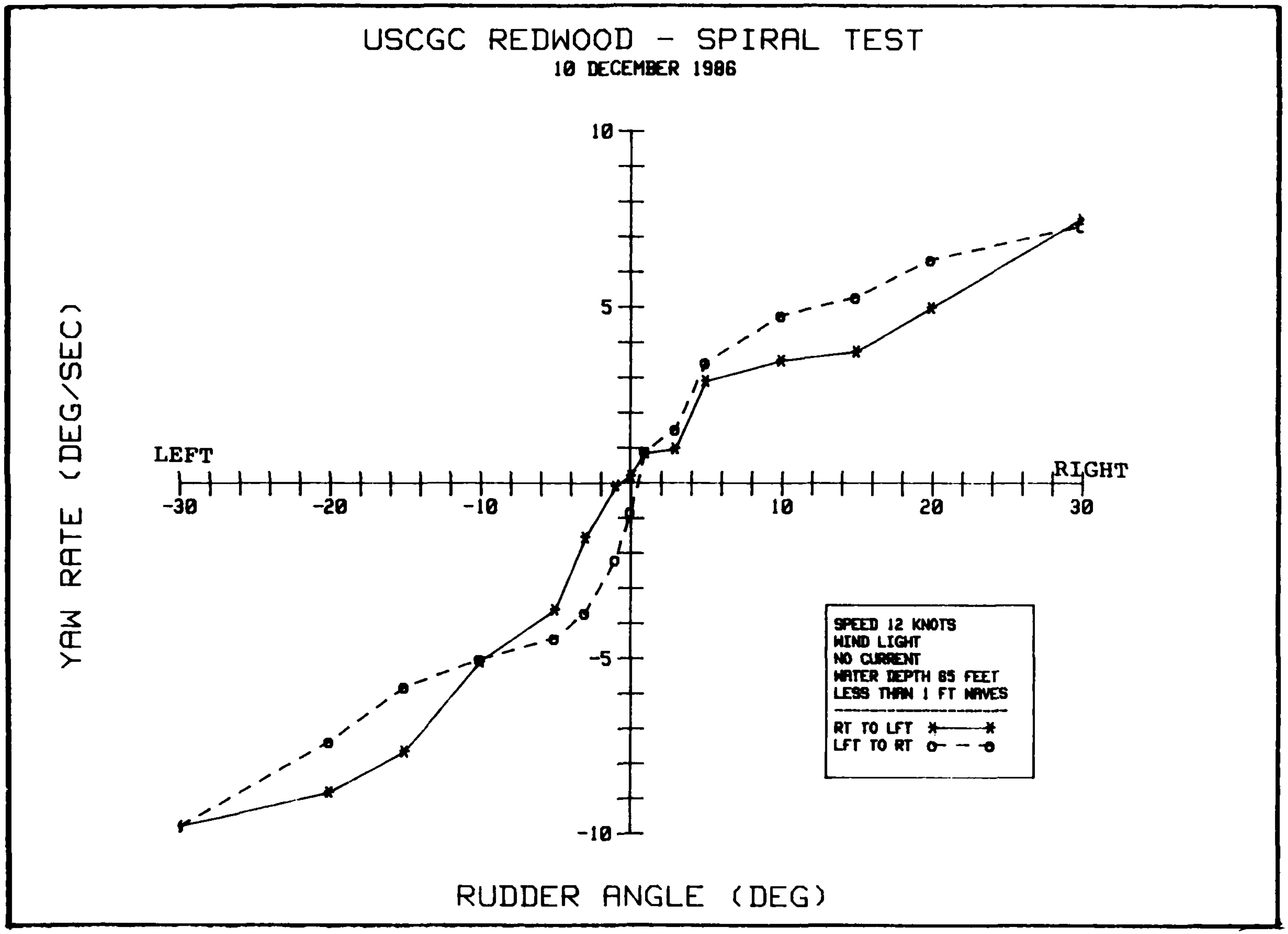


FIGURE 6R SPIRAL TESTS, 12 KNOTS

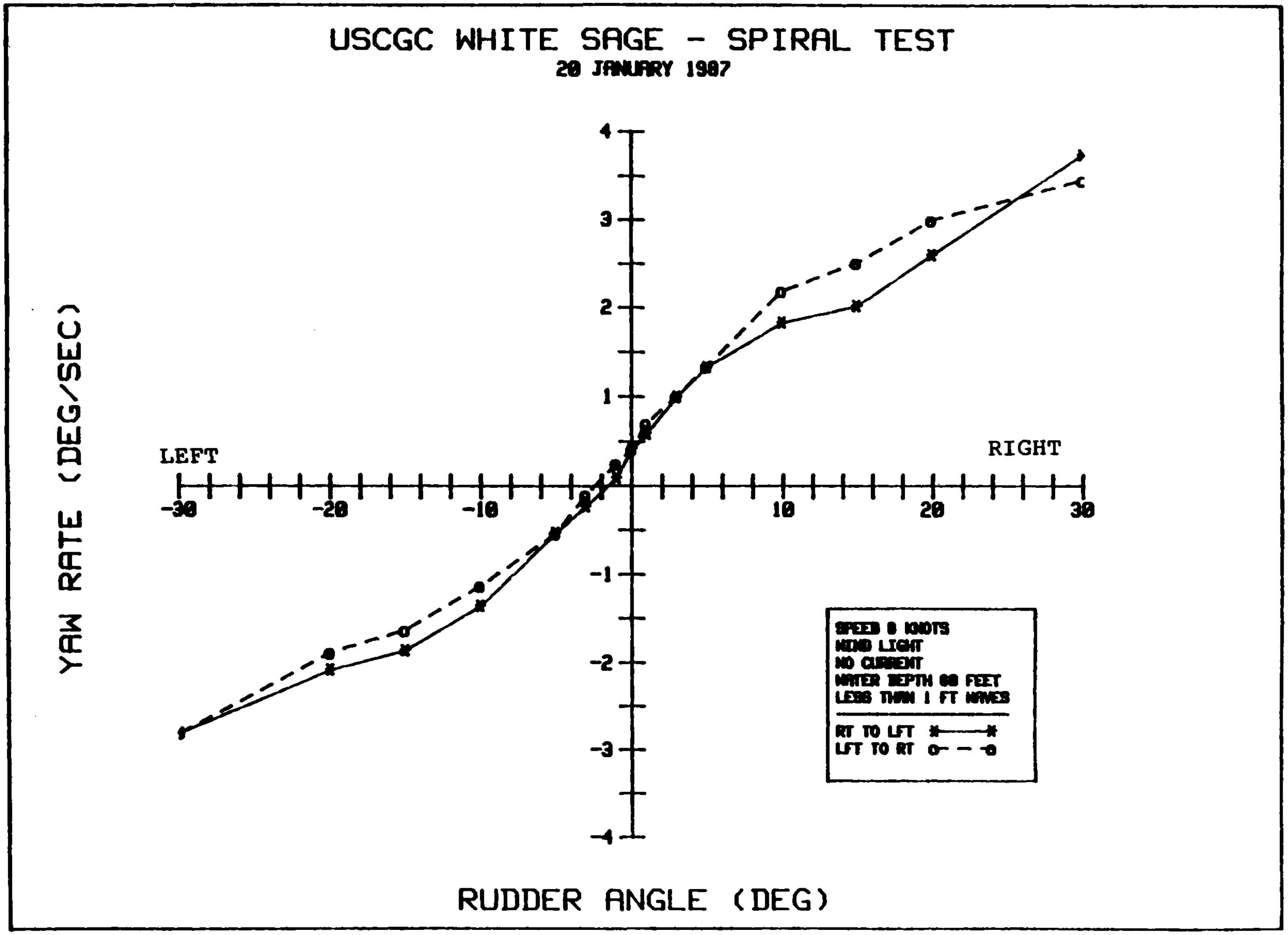


FIGURE 6W SPIRAL TESTS, 8 KNOTS

its diesel-electric drive can control shaft rotation down to approximately 1 rpm; this coupled with excellent rudder action and a 42" diameter bow thruster gives outstanding buoy tending capability under most conditions of wind and current.

The spiral test for the RED WOOD is considerably less impressive (See Figure 6R) and conjecture would say that its flat bottom hull and rudder combination is considerably less than ideal for a buoy tender. There is significant hysteresis between 10 and 25 degrees right rudder and at 0 to left 5 degrees rudder. A note copied from the Chart Table in the Wheel house addresses maneuvering with sternway:

> "There is absolutely no control of the vessel when backing down on both screws. Rudder has no effect. Stern swings rapidly and radically at full speed (to S'tbd). At slow speeds to 6 knots, it is possible to subdue swing by full use of bow thruster; at less than 6 knots astern, judicious intermittent use assists in re-establishing a backing line."

Maneuverability Zig-Zag

The results of the zig-zag maneuver are indicators of the ability of a ship's rudder(s) to quickly control the vessel heading. Factors such as speed of the rudder control system and rudder effectiveness, as well as stability of the ship come into play. All three classes of buoy tender tested exhibited a rudder turning time of approximately 8 seconds when turned from stop to stop (port to starboard and/or starboard to port).

The standard procedure for zig-zag is as follows:

a. The ship is steadied on a straight course at a preselected speed for about one minute. Once a speed is established, the power plant controls are not changed throughout the maneuver.

b. Rudder angle is deflected at a maximum rate to the left 20 degrees and held until the ship responds 20 degrees to the left of the base course.

c. At this point, the rudder is shifted 40 degrees, to right 20 degrees rudder and held until the ship responds in heading 20 degrees to the right of base course. This completes the overshoot test.

d. If a zig-zag test is to be completed, the rudder is again shifted 40 degrees to left 20 degrees rudder. This cycle is repeated once more.

Overshoot yaw angle is an indication of the amount of anticipation required of a helmsman while operating in restricted waters. The helmsman can use this information about overshoot to anticipate a point to ease the rudder when steadying upon a new course. The time to second execute is measured from the time the rudder is first shifted 20 degrees from amidship and ends with the ship's yaw angle changing 20 degrees This is an indicator of rudder effectiveness. A third indicator of rudder effectiveness is the "period." This is the time it takes vessels to cycle through two course changes. In these tests, it is the time starting with the first yaw angle reaching 20 degrees to port of base course cycling through 20 degrees to starboard of base course and ending when yaw angle again reaches 20 degrees to port, as shown in Figures 7B, 7R and 7W.

The effectiveness of the steering and rudder system in turning is measured by the time to reach second execute, and the overshoot in the zig-zag test. The zig-zag maneuver data is presented in Figure 7 in two speeds for each ship. The overshoot is greater and responsiveness is faster for the higher speeds on the BITTERSWEET and the RED WOOD.

From an operational point of view, the most important measure of rudder performance is the Time to Second Execute. This is the time, after the rudder has been set to a given angle, for the ship to come to the same yaw angle (20 degrees in this test). This is important for collision avoidance.

TACTICAL DATA

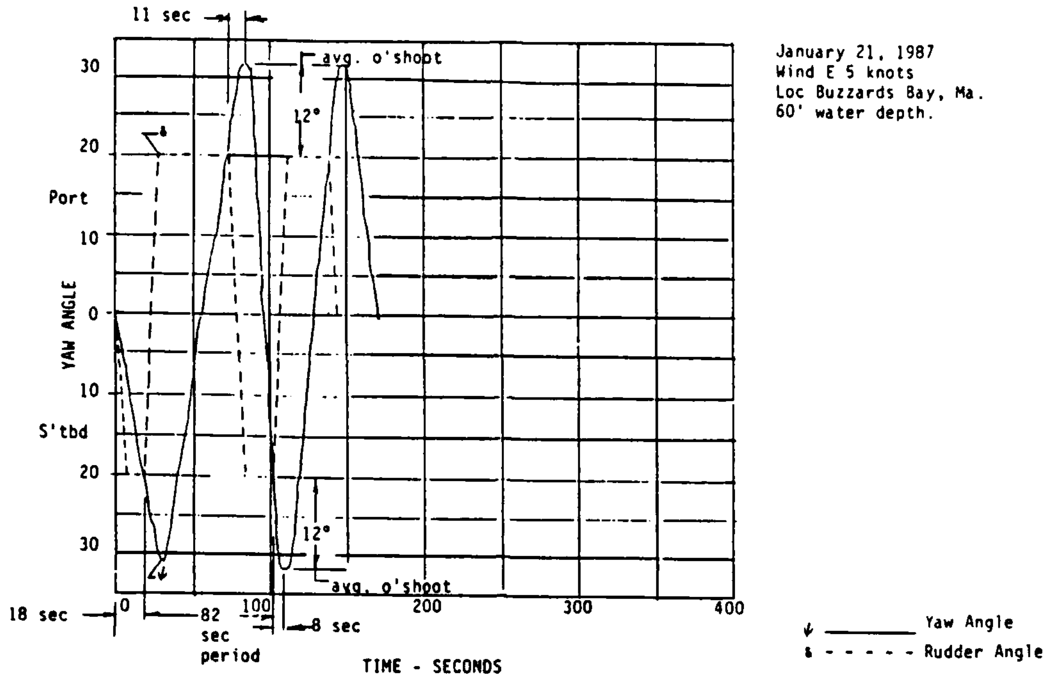
Table 2 summarizes Tactical Data for the buoy tenders. The tactical data was run at max speed and (except for the BITTERSWEET) at a lower speed (approx. 2/3 of max speed).

More testing was done on the Redwood because it apparently displayed a wider range of characteristics over its speed range and the Zig-Zag maneuver had previously shown less than ideal rudder control.

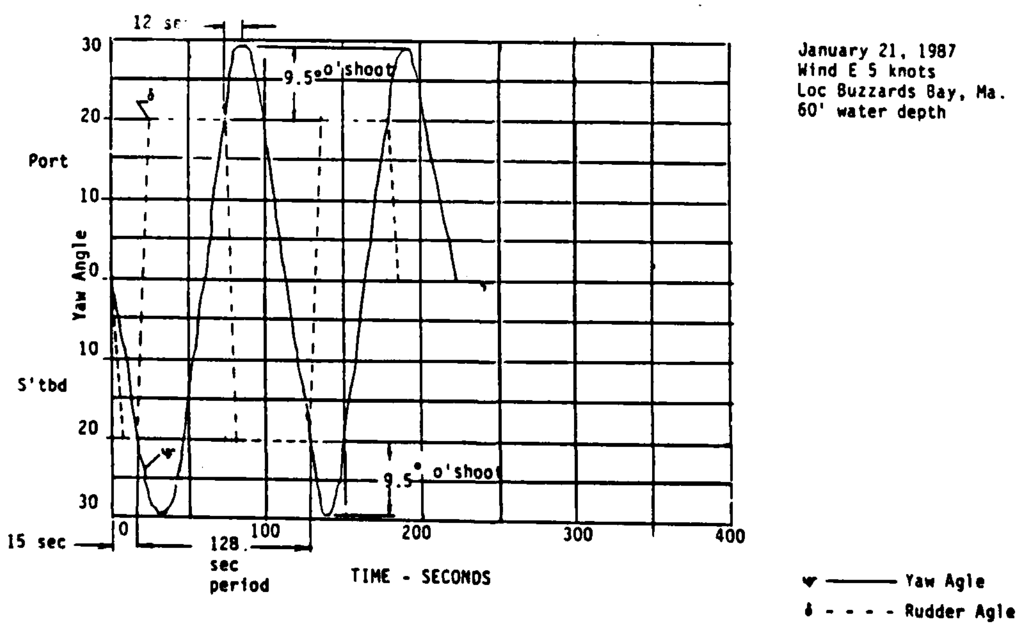
The data shows that the BITTERSWEET has the largest tactical diameter in shallow (10 degrees) turns at max speed (approximately twice as large as the RED WOOD), and almost three times as much as the RED WOOD in tight (30 degrees) turns at max speed.

The WHITE SAGE with its excellent maneuvering capability at any speed exhibits the ability to turn around in three times its length, at its max speed, with a 20 degree rudder.

Similarly, the BITTERSWEET, with 30 degrees rudder, can turn in 2.6 times its length at maximum speed.

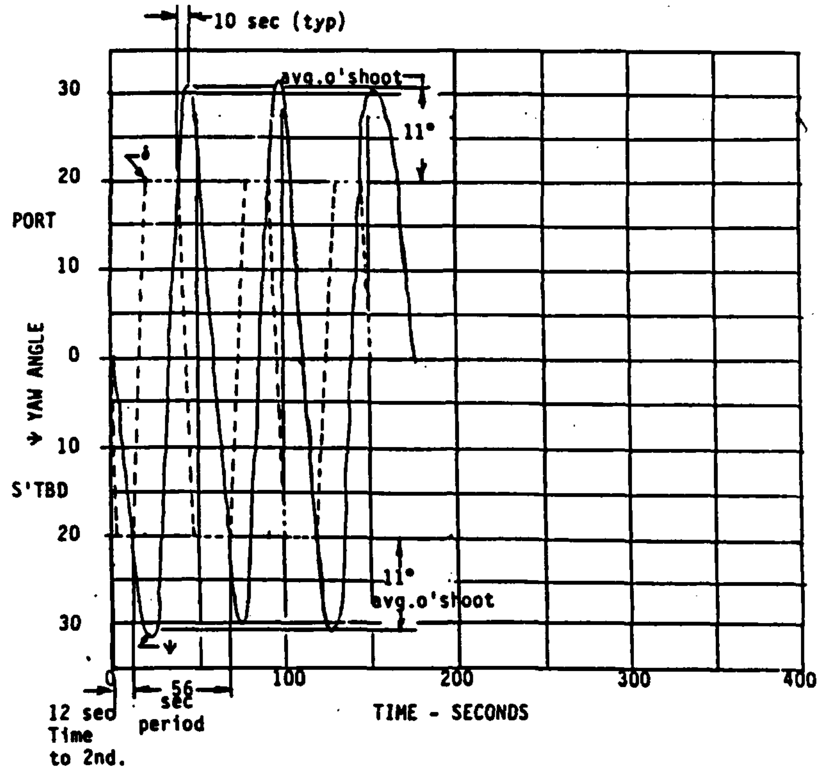


USCGC BITTERSWEET, 11.8 KNOTS



USCGC BITTERSWEET, 8 KNOTS

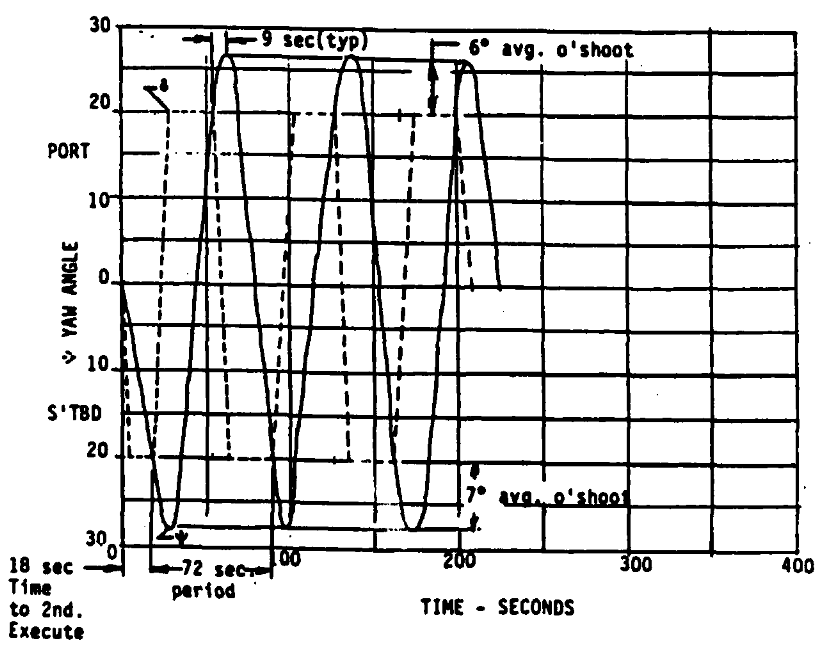
FIGURE 7B ZIG-ZAG MANEUVER, 8 & 11.8 KNOTS



December 10, 1986
Wind SSE 5 knots
Loc. 7 mi. South of New London, Ct.
65' water depth.

Yaw angle
Rudder Angle

USCGC REDWOOD ZIG-ZAG MANEUVER, 12 KNOTS

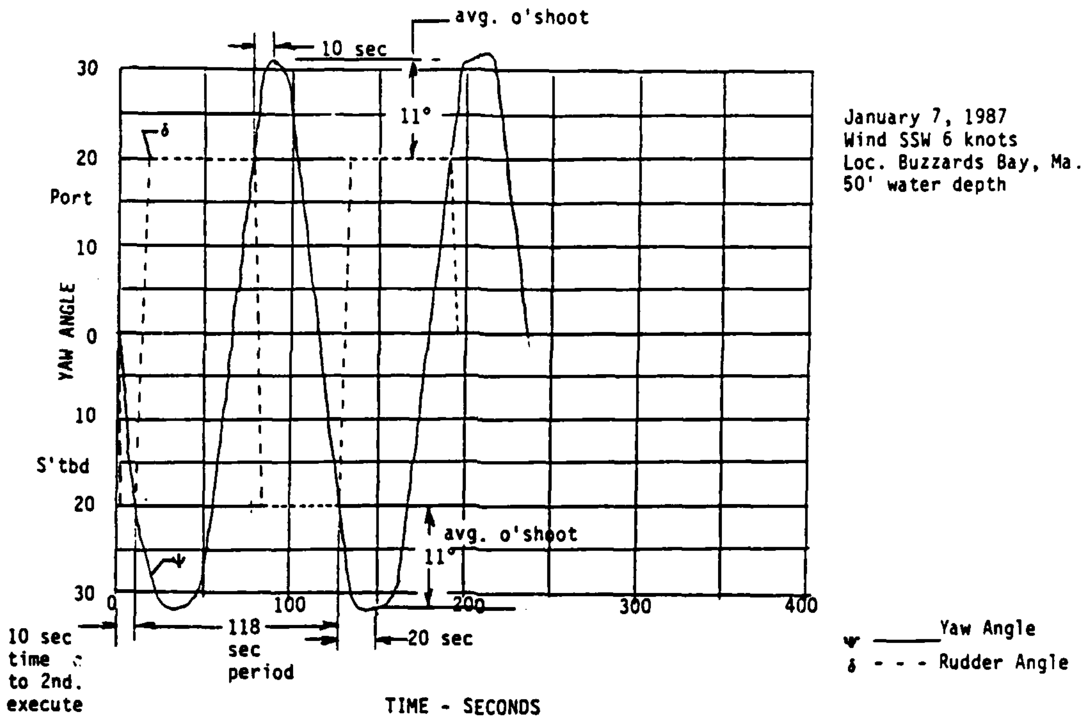


December 10, 1986
Wind SSE 5 knots
Loc. 7 mi. South of New London, Ct.
65' water depth.

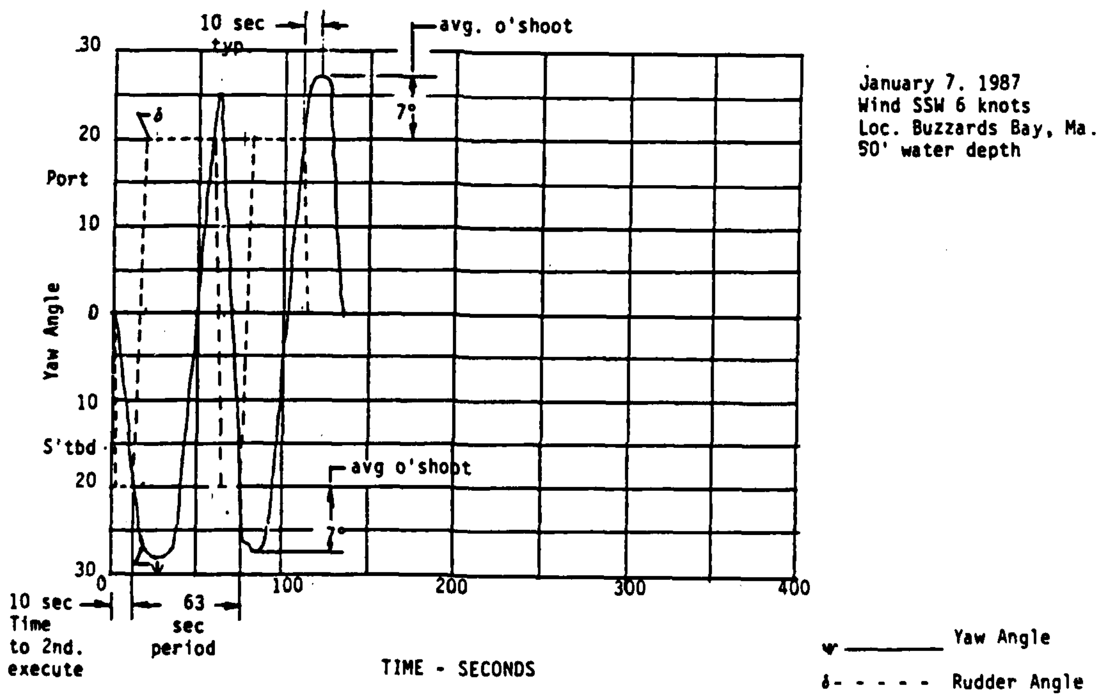
Yaw Angle
Rudder Angle

USCGC REDWOOD ZIG-ZAG MANEUVER, 9 KNOTS

FIGURE 7R ZIG-ZAG MANEUVER, 9 & 12 KNOTS



USCGC WHITE SAGE, 10 KNOTS



USCGC WHITE SAGE, 6 KNOTS

FIGURE 7W ZIG-ZAG MANEUVER, 6 & 10 KNOTS

TABLE 2 SUMMARY OF TACTICAL DATA

USCGC BITTERSWEET (WLB 389)
SUMMARY OF TACTICAL DATA (FEET)

SRPM	SPEED - K	TURN	TIME TO 360°	ADVANCE	TRANS	TACT DIA	TURN - RAD
189	11.8	10°P	4'24"	786	735	1419	786
189	11.8	10°S	4'45"	875	869	1732	888
189	11.8	30°P	2'25"	469	437	843	470
189	11.8	30°S	2'45"	494	507	1027	520

Note: Test was conducted with a 3° list to Port as a result of 20,000# buoy load on port side.

USCGC REDWOOD
SUMMARY OF TACTICAL DATA (FEET)

SRPM	SPEED - K	TURN	TIME TO 360°	ADVANCE	TRANS	TACT DIA	TURN -RAD
405	12	10° S	2'30"	590	435	760	300
	12	10° P	2'56"	730	470	900	365
	12	20° S	1'55"	550	375	630	240
	12	20° P	2'20"	528	477	510	250
	12	30° S	1'37"	460	320	450	145
	12	30° P	1'50"	550	160	320	150
350	8	10° P	5'30"	1030	720	1120	560
	8	20° P	3'45"	460	280	540	270
	8	30° S	2'34"	340	320	640	300
	8	30° P	3'00"	440	300	520	260

USCGC WHITE SAGE (WLM 544)
SUMMARY OF TACTICAL DATA (FEET)

SRPM	SPEED - K	TURN	TIME TO 360°	ADVANCE	TRANS	TACT DIA	TURN - RAD
Clutch Speed	6.2	20°S	2'53"	293	290	575	280
	6.2	20°P	2'44"	293	283	556	266
350	9.2	20°S	2'09"	356	331	637	316
350	9.2	20°P	2'09"	316	302	589	306

Maneuvering in Woods Hole, MA, the homeport of the BITTERSWEET and the WHITE SAGE, demonstrates the excellent low speed maneuverability of these two ships. The channel coming through the shallows extends almost to the dock, but the WHITE SAGE with relative ease (and no bow thruster) negotiates what has to be considered a tight berthing in good time; the BITTERSWEET requires more attention to precise detail, and use of the bow thruster, to compensate for its added length and twice the draft of the WHITE SAGE.

POWERING

The Speed vs Power relationship for the buoy tenders is presented in Figures 8B, 8R, and 8W. Where applicable, the data for Port and Starboard shafts have been plotted individually to show the close matching of power on the two shafts over the full range of power. The combined power is the sum of the power on two shafts. All performance data plotted is available in tabular form in Appendix C, Tables C2 - C3.

The speed-power relationship for the BITTERSWEET was obtained by reading the electrical panel (volts & amperes) to obtain electrical power going to the DC propulsion motor. An overall electrical efficiency of 96% was used to calculate the power delivered to the shaft (and plotted on the speed-power Figure 8B). Attempting to strain gauge the 12" diameter solid spool connecting the propulsion motor to the propulsion shaft resulted in only a few micro inches of torsional strain at maximum power. This was in the same magnitude of variation due to temperature compensation and was considered to be beyond state-of-the-art torque measurement. Consequently, the electrical power was measured (with recently calibrated ship's meters, +/- 1% accuracy). The BITTERSWEET has a nearly linear 100HP/knot power response over the speed range of 6-12 knots.

The RED WOOD has power take-off units on both its propulsion engines. The port side engine drives a hydraulic pump to power the boom, while starboard engine drives another hydraulic pump to drive the bow thruster.

The RED WOOD also shows a nearly linear 100HP/knot response for speed increases. This is not strictly true over the speed range of 7.5 to 10 knots because as will be explained in the discussion on Fuel Consumption, there is a discontinuity in the speed-power and fuel consumption in this speed range. Ships force has experienced what they believed to be a shaft problem at 1000 ERPM (350 SRPM) which coincides with the 7.5 knot point of discontinuity.

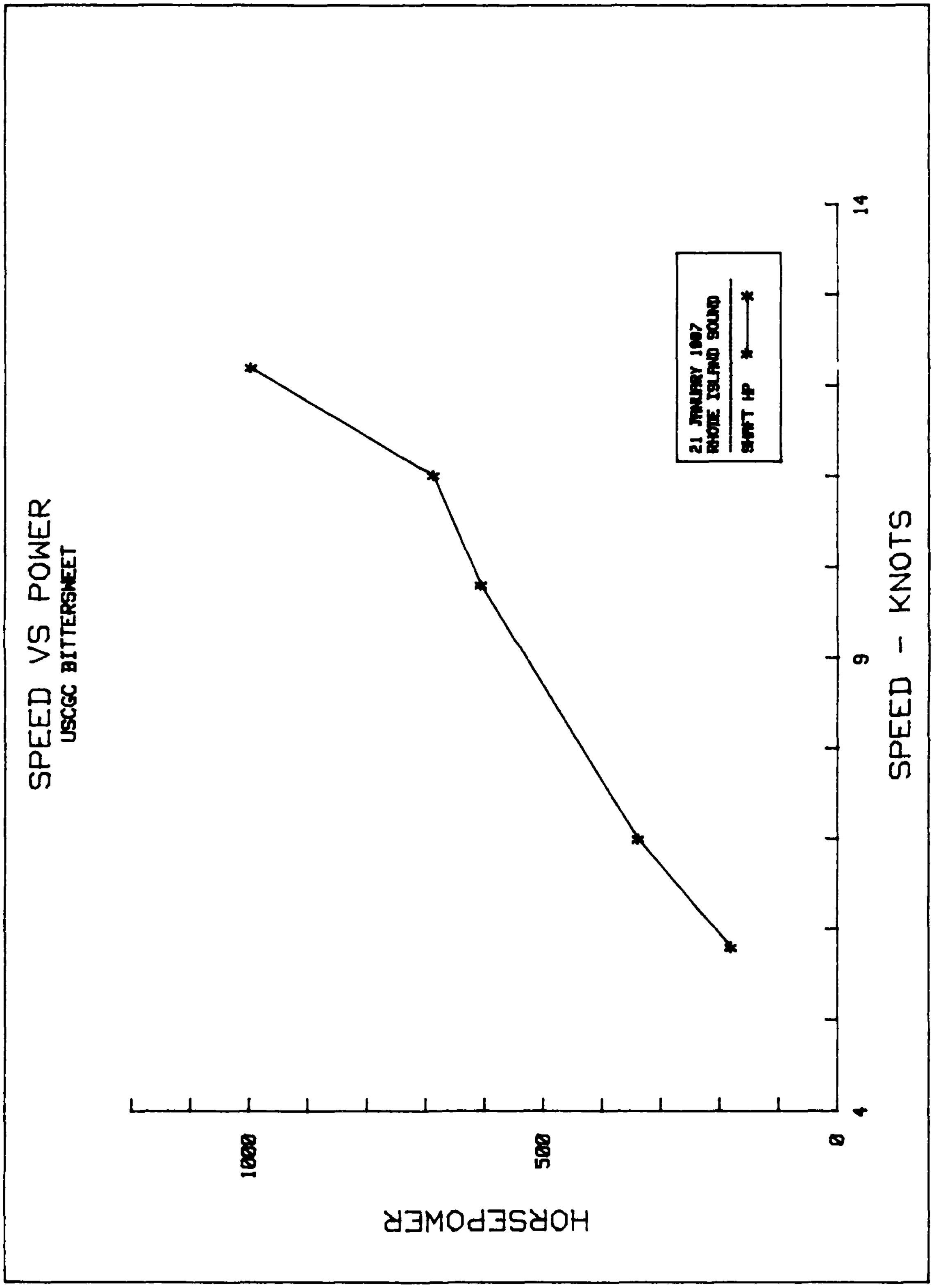


FIGURE 8B SPEED vs POWER

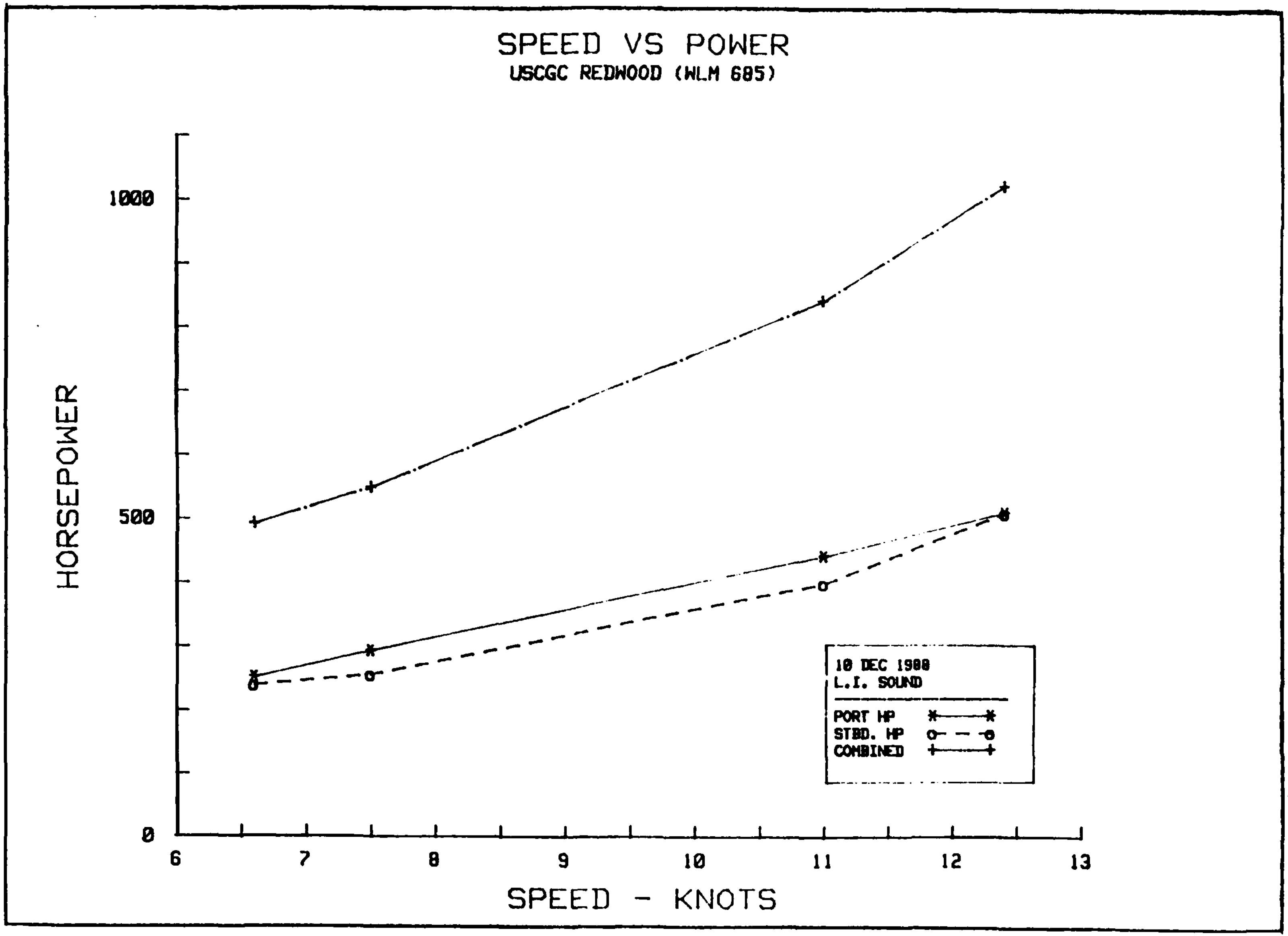


FIGURE 8R SPEED vs POWER

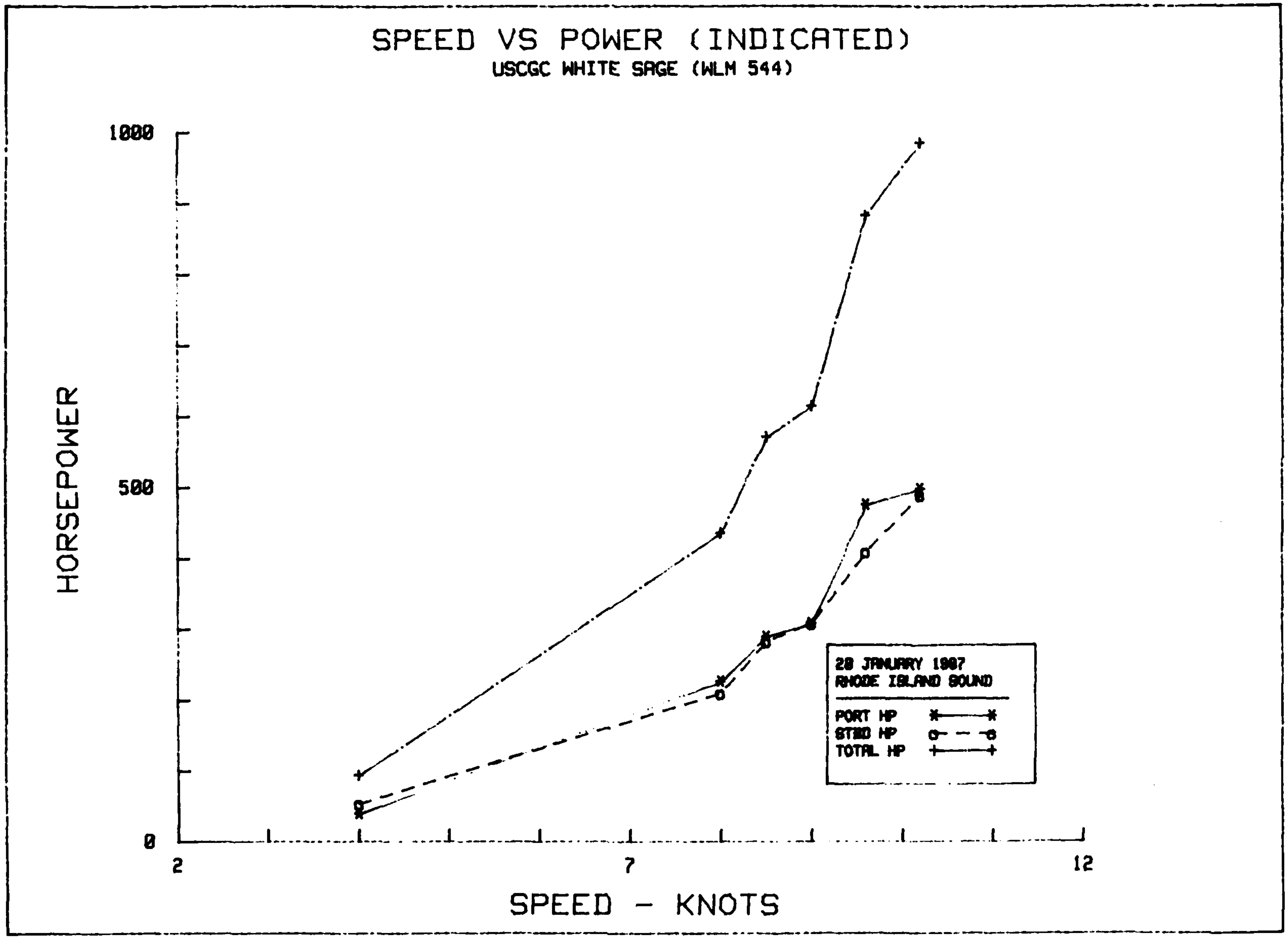


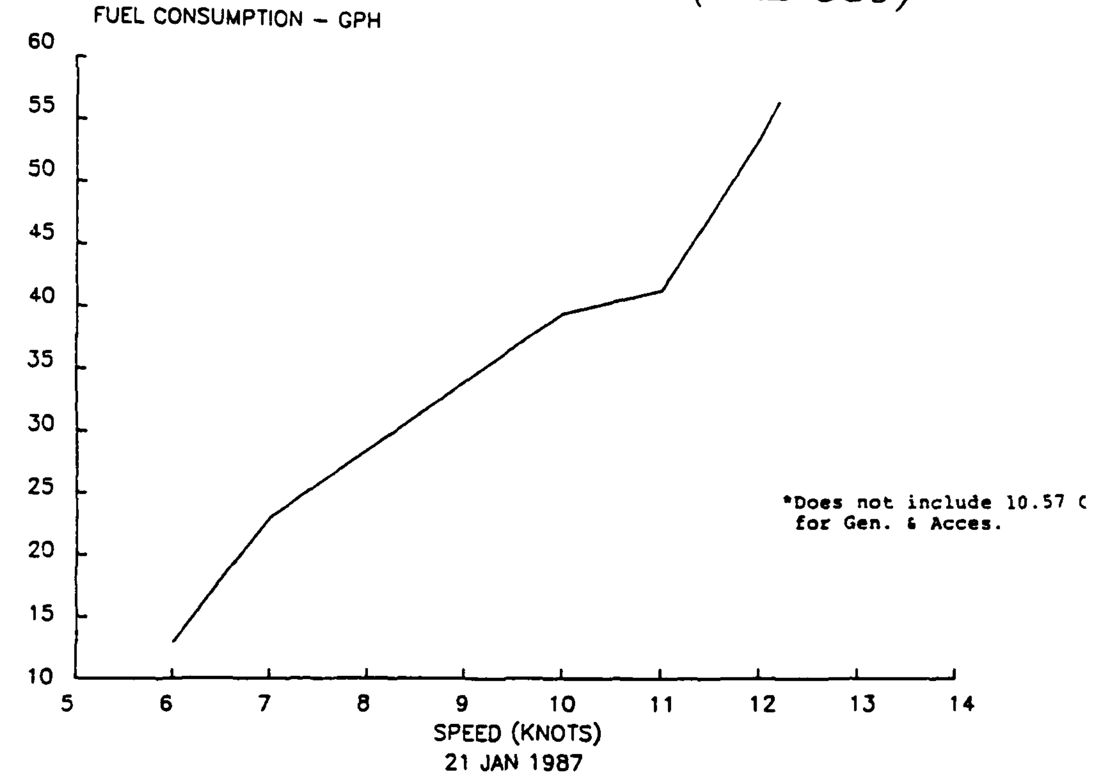
FIGURE 8W SPEED vs POWER

A dramatic increase in power is required to drive the WHITE SAGE beyond 8 knots and persists for the remainder of the speed-power curve. This condition is reflected in Figure 9W, Fuel Consumption and Efficiency vs Speed, when fuel consumed doubles for an increase of speed from 9.2-10.2 knots. The effect of this is a precipitous decrease of range and endurance as seen in Figures 10W and 11W.

Another way of observing the marked increase in power required for the WHITE SAGE beyond 8 knots is to observe that below 8 knots approximately 88 HP/knot increase is required, but above 8 knots this requirement jumps to approximately 300 HP/knot, an increase of approximately 3.5 times. Carrying this further, fuel efficiency below 8 knots is at the rate of 2.5 gal/knot but increases to approximately 15.4 gal/knot at higher speeds, increasing fuel consumption by a factor of 6.

The speed-power relationship for the WHITE SAGE needs further discussion. The engines for this ship are rated 425 HP @ 1225 ERPM. The speed-power test on this ship was accomplished with great difficulty; the port side engine was observed to have a torsional oscillation (observed with a stroboscope) which was at the limit of the range capability of the measuring equipment; the starboard engine was also oscillating, but it was within range of the torque measuring equipment. This situation resulted in instrumentation derived output HP that was above the rated values. The fuel consumed over this speed power range indicates power delivered to be <u>less</u> than the rated speed-power output for this engine (estimated 40-50 HP less). We believe this to be the effect of propulsion engine and/or system imbalance.

FUEL CONSUMPTION VS SPEED
USCGC BITTERSWEET (WLB 389)



FUEL EFFICIENCY VS SPEED (CALC)
USCGC BITTERSWEET (WLB 389)

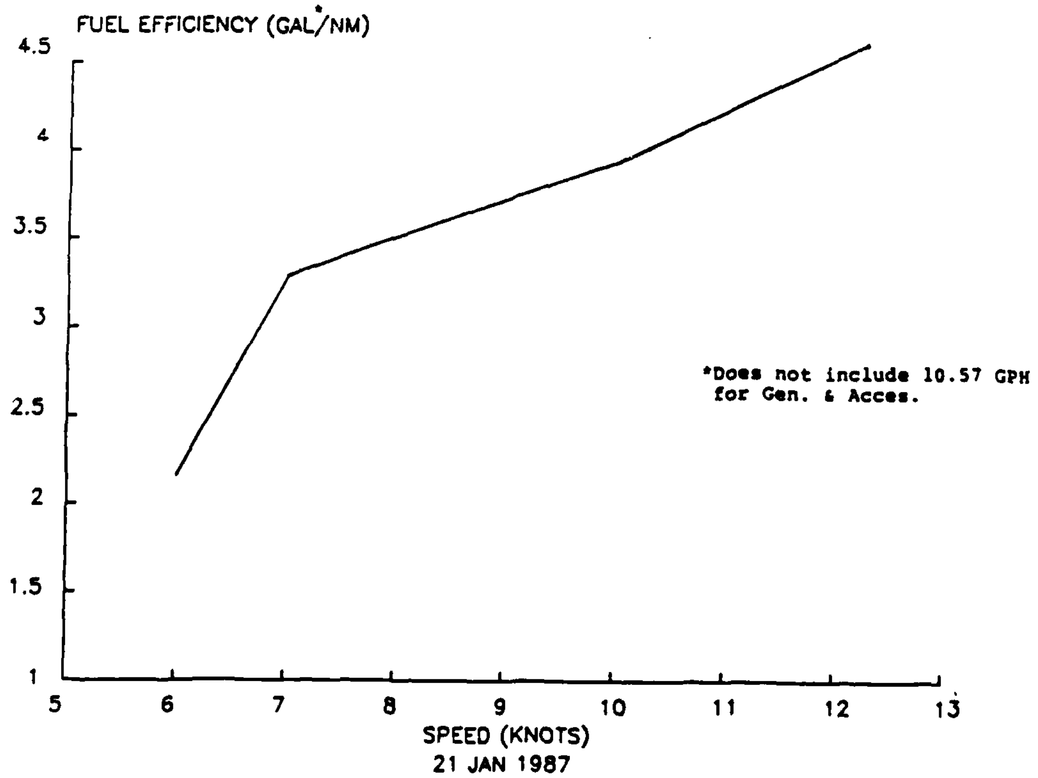
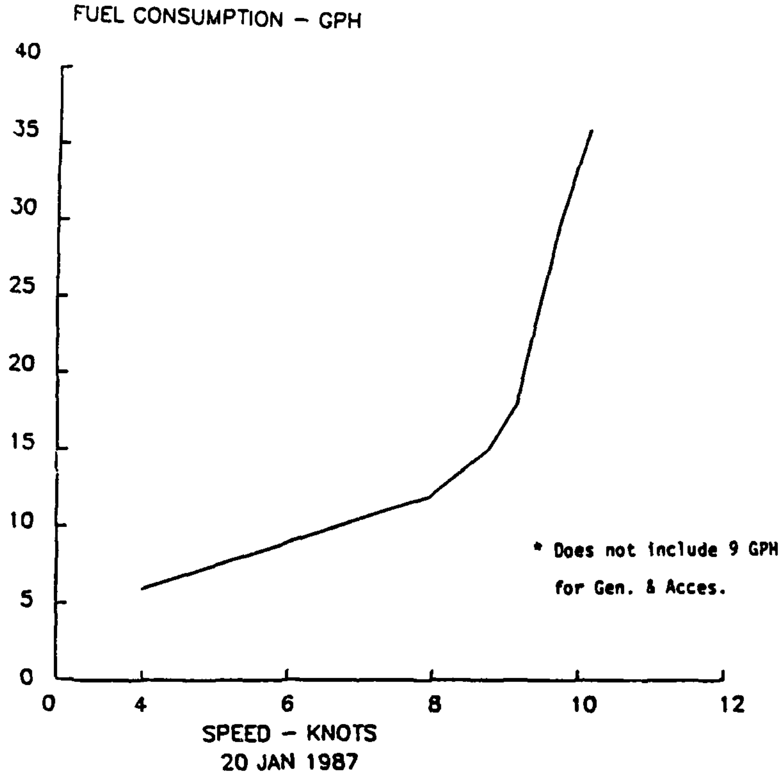


FIGURE 9B FUEL CONSUMPTION and EFFICIENCY vs SPEED

FUEL CONSUMPTION VS SPEED
USCGC WHITE SAGE (WLM 544)



FUEL EFFICIENCY VS SPEED
USCGC WHITE SAGE (WLM 544)

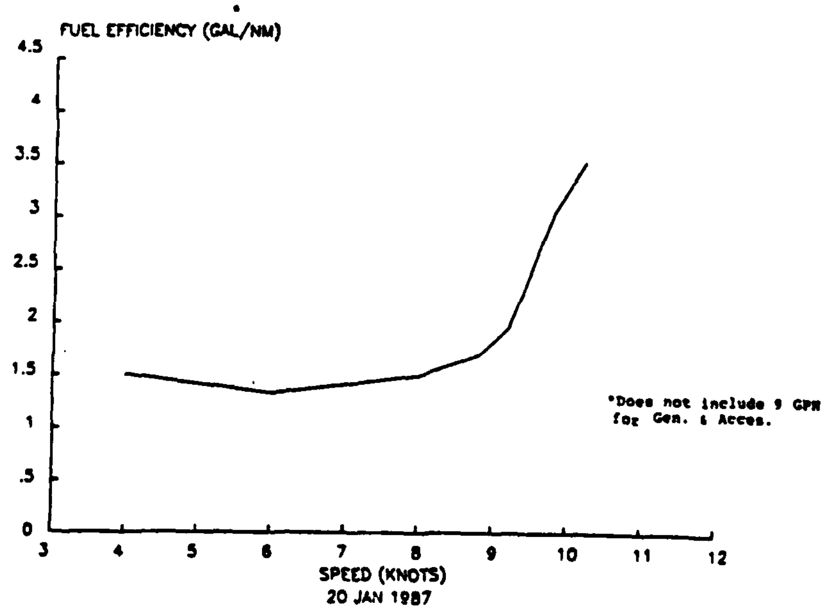


FIGURE 9W FUEL CONSUMPTION AND EFFICIENCY vs SPEED

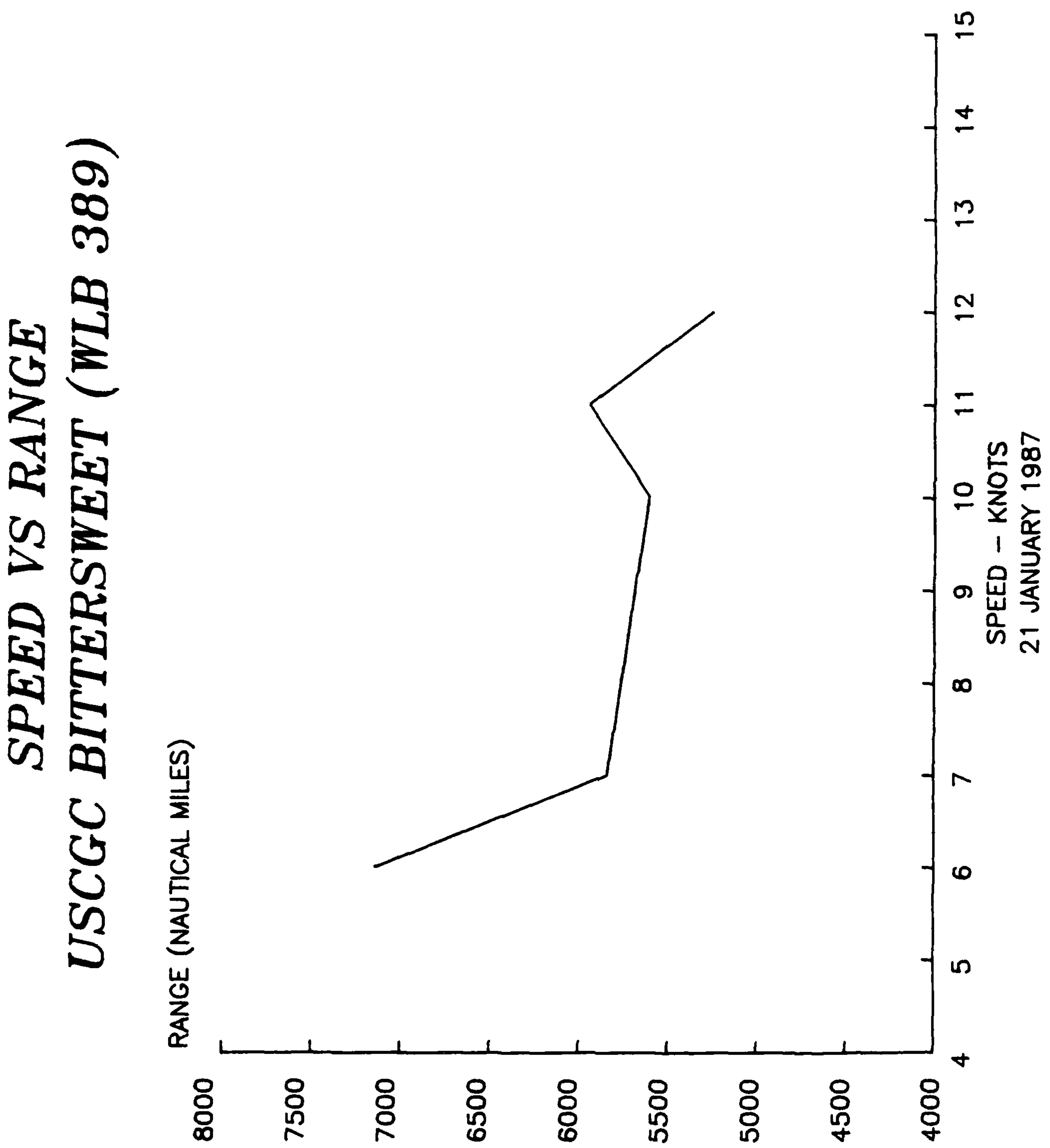


FIGURE 10B SPEED vs RANGE

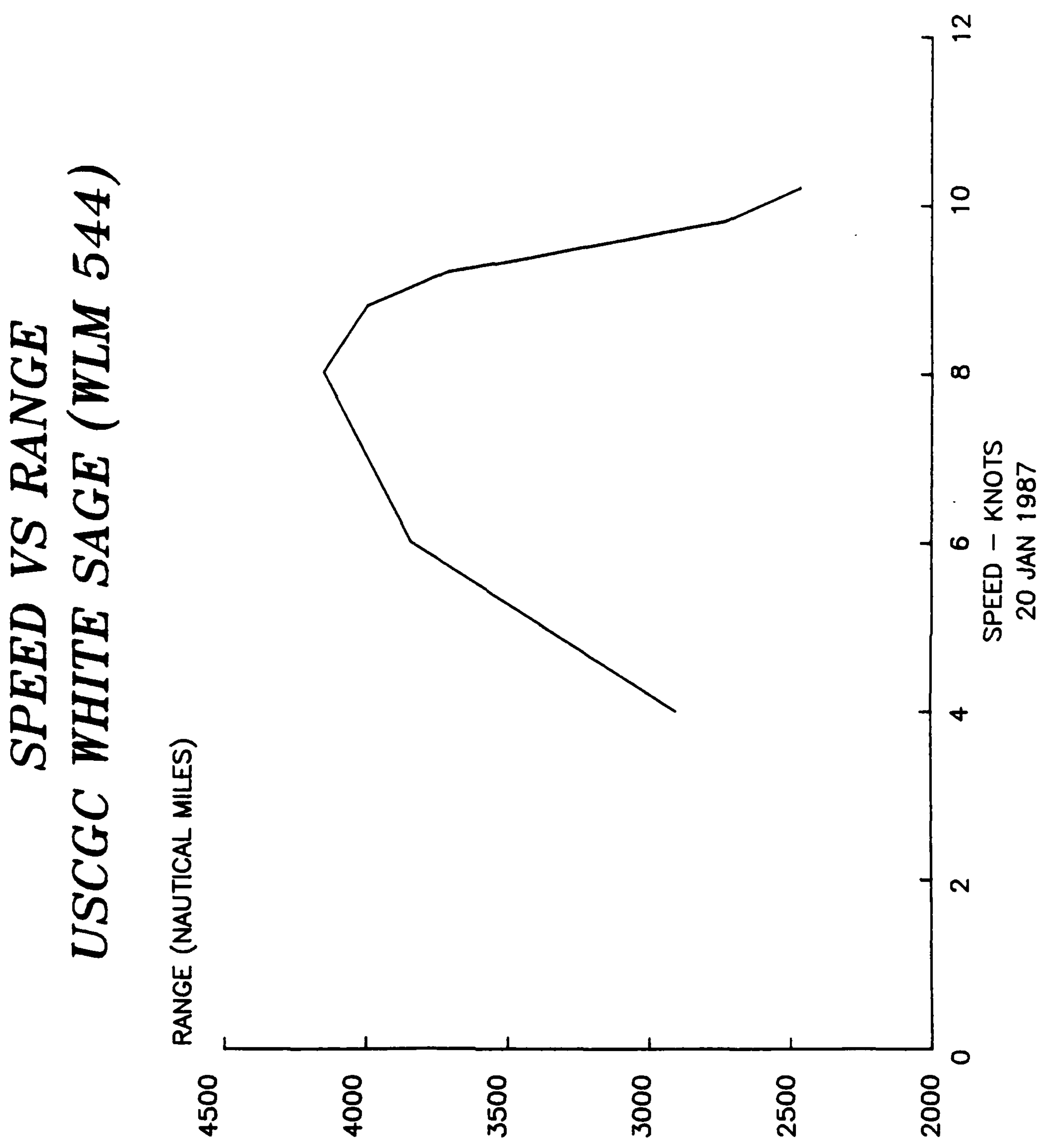


FIGURE 10W SPEED vs RANGE

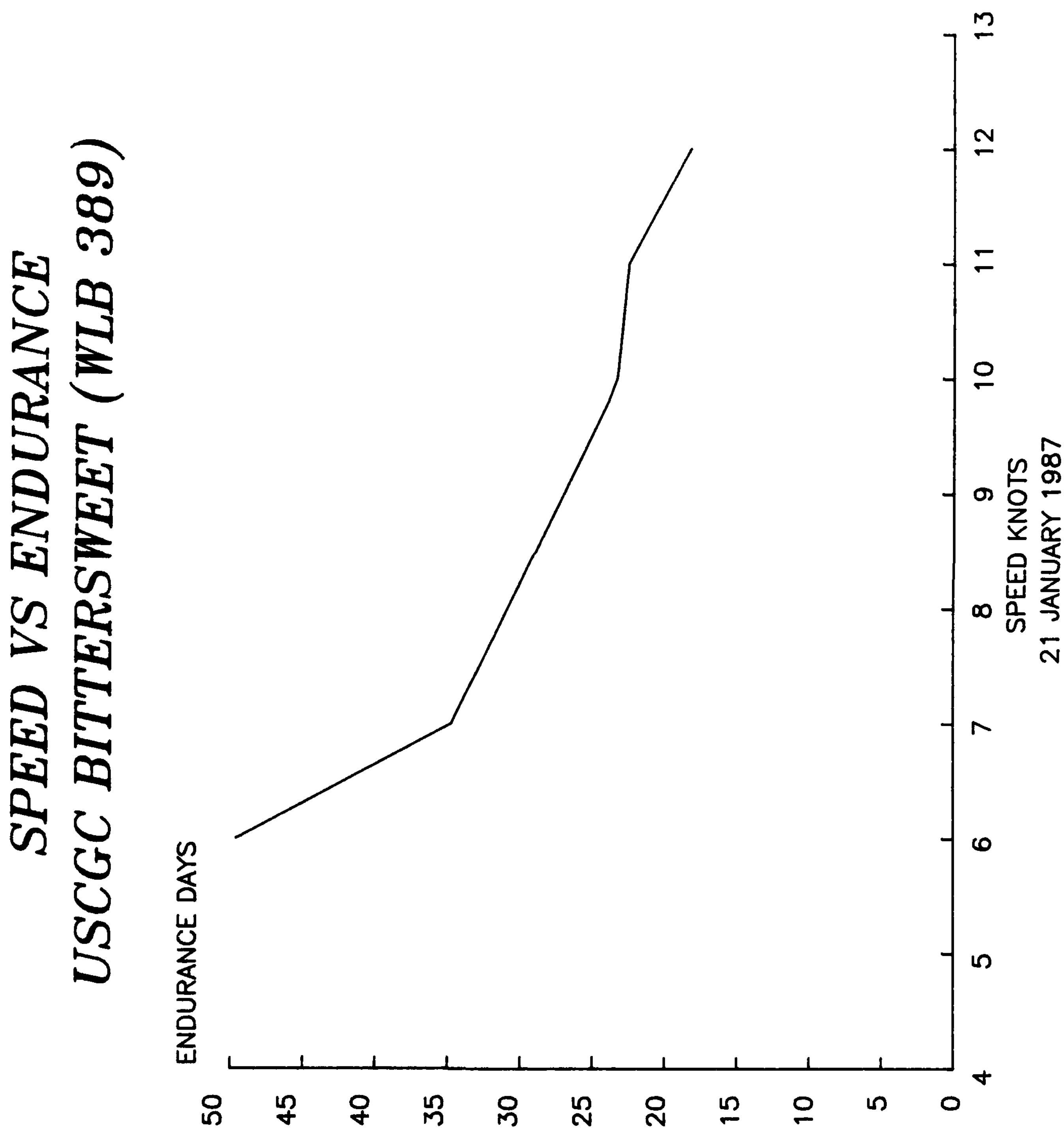


FIGURE 11B SPEED vs ENDURANCE

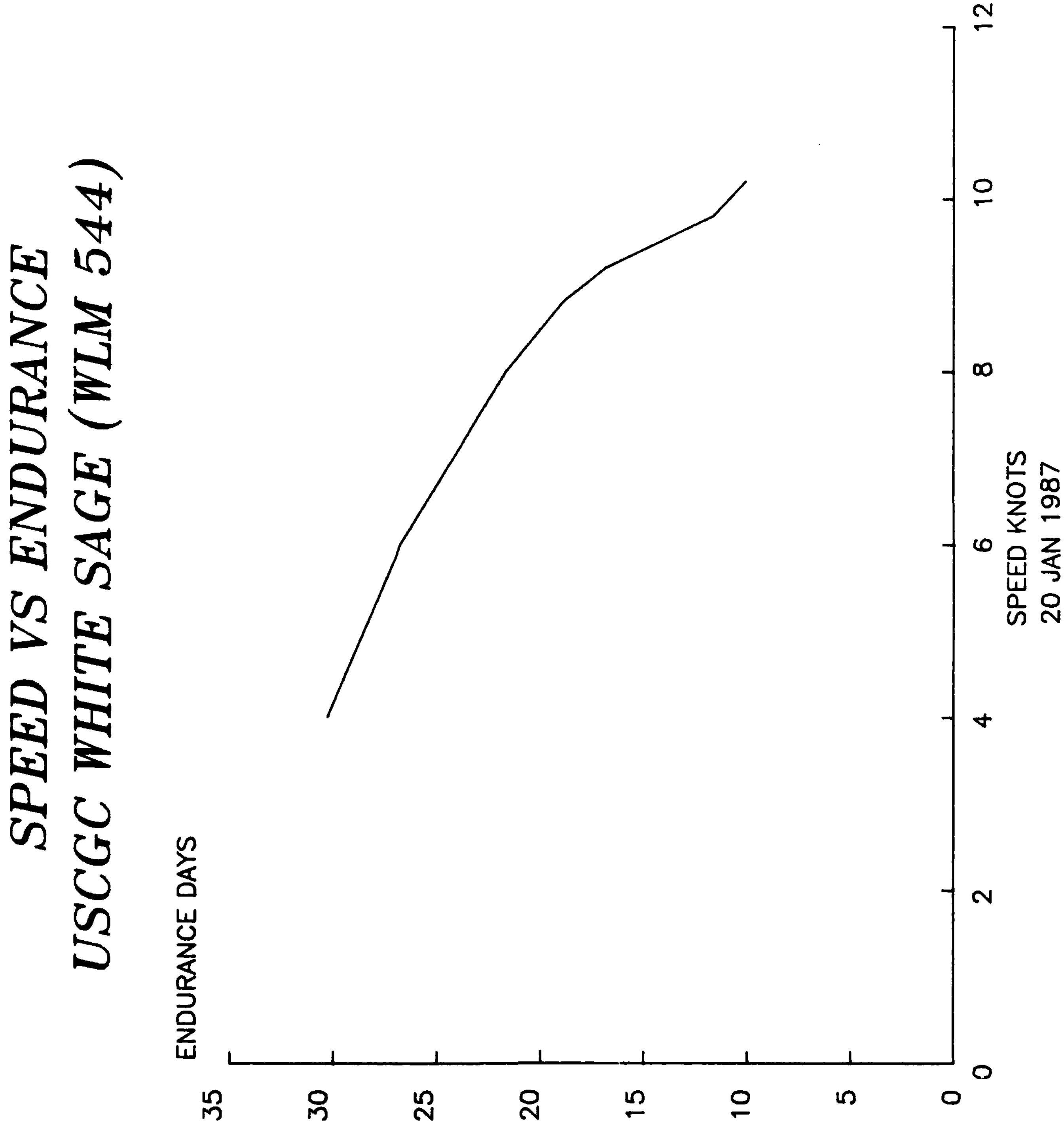


FIGURE 11W SPEED vs ENDURANCE

FUEL CONSUMPTION

The data on fuel consumed (measured by in-line fuel meters) is used to generate a wealth of information including fuel efficiency (FE), vessel endurance (E), range (R) and specific fuel consumption (GPH) at specific points on the speed-power curve:

		Units
GPH	= Main Engine Fuel consumption at speed V ...	Gal/hr
h	= Ship Service Gen. & other accessories cons.(constant)	Gal/hr
GPD	= (GPH +h)24	Gal/day
V	= Ship speed (kts)	kts
I.E.	= Main engine fuel efficiency (gal/nm)	Gal/nm
A	= Actual fuel capacity of tanks (gal)	Gals
UF	= Usable fuel for operations (gals)	Gals
U.E.	= Utilization efficiency (fuel that is usable)	var. %
E	= Vessel endurance at speed V (days)	Days
R	= Vessel range at speed V (nm)	nm

(1) FE = GPH/V

(2) E = A/GPD

(3) R = 24 x E x V

Speed, efficiency, endurance and range are all a function of fuel flow. Figures 9, 10 and 11 give respectively Fuel Efficiency vs speed, Range vs speed, and Endurance vs speed for the 180' WLB and 133' WLM. Figures for the 157' WLM (CGC RED WOOD) were not plotted due to the scarcity of repeatable data as described below. The information given in these figures is quite useful despite the fact that coastal buoy tenders seldom run for any extended length of time other than traversing to or from home port with 6 to 8 hours of buoy ops. in between. The seagoing 180' WLB does routinely go on long patrols. However, these presentations allow important information such as shown on Figure 10W, that 8 knots is by far the optimum running speed for the WHITE SAGE.

Needless to say, range is decreased and endurance is increased when the tenders stop to accomplish boom operations on a daily basis.

With regard to the fuel efficiency, range, and endurance data for CGC RED WOOD, some explanation is warranted. The RED WOOD does not operate in the speed range 7.5 to 9.5 knots because there are long standing problems associated with running in this speed range. Consequently, the speed-power-fuel consumption was accomplished with great difficulty. Clutch speed for the RED WOOD is 6.6 knots (both engines engaged). Data was first obtained at 6.6 and 7.5 knots. Attempts to obtain data in the range 7.5 to 10 knots was at first unsuccessful so this range was passed over and data was obtained at 11.3 and 12.4 knots before returning to the troublesome mid-range of speed to conduct more testing. What was found was that after setting port and starboard throttles closely to matching ERPM, the engines would operate at first one level and then another (which could be monitored with difficulty by taking repeated readings on the engine inlet and outlet in-line fuel meters and HP meters for each engine). The engine tachometers could not maintain a steady indicated RPM, the HP meters indicated first high then low, with corresponding increase and decrease in fuel flow to match engine change. The change in engine output and fuel consumption was at times long enough to obtain two or three quick readings at a throttle setting before the engine was off running at a different level, but most of the operation can be characterized as being unstable, and only occasionally repeatable. A stroboscope was used to monitor engine RPM and indicated only a slight oscillation. For this reason, the data are presented in Table C-3R but were not plotted due to the lack of consistent and repeatable data in the range 7.5 to 9.5 knots. Pinpointing the cause of this discontinuity was beyond the scope of this technical evaluation.

The speed-power test was conducted in 80 to 100 feet of water, so that shallow water varying resistance effects are discounted. Some other hydrodynamic consideration associated with the flat bottomed hull shape or some other consideration was responsible for the non-repeatability exhibited in the range 7.5 to 9.5 knots.

Single engine operation is not normally practiced for the RED WOOD and the WHITE SAGE so no single engine propulsion tests were run on them. The WHITE SAGE had data which was gathered at the original sea trials for the WHITE SAGE and it was entered on the Speed-Power Figure 12W for comparison purposes.

NOISE LEVELS

As shown in APPENDIX Table C4, all of the engine rooms and adjacent machinery spaces exceed the recommended OSHA STD 1910.95

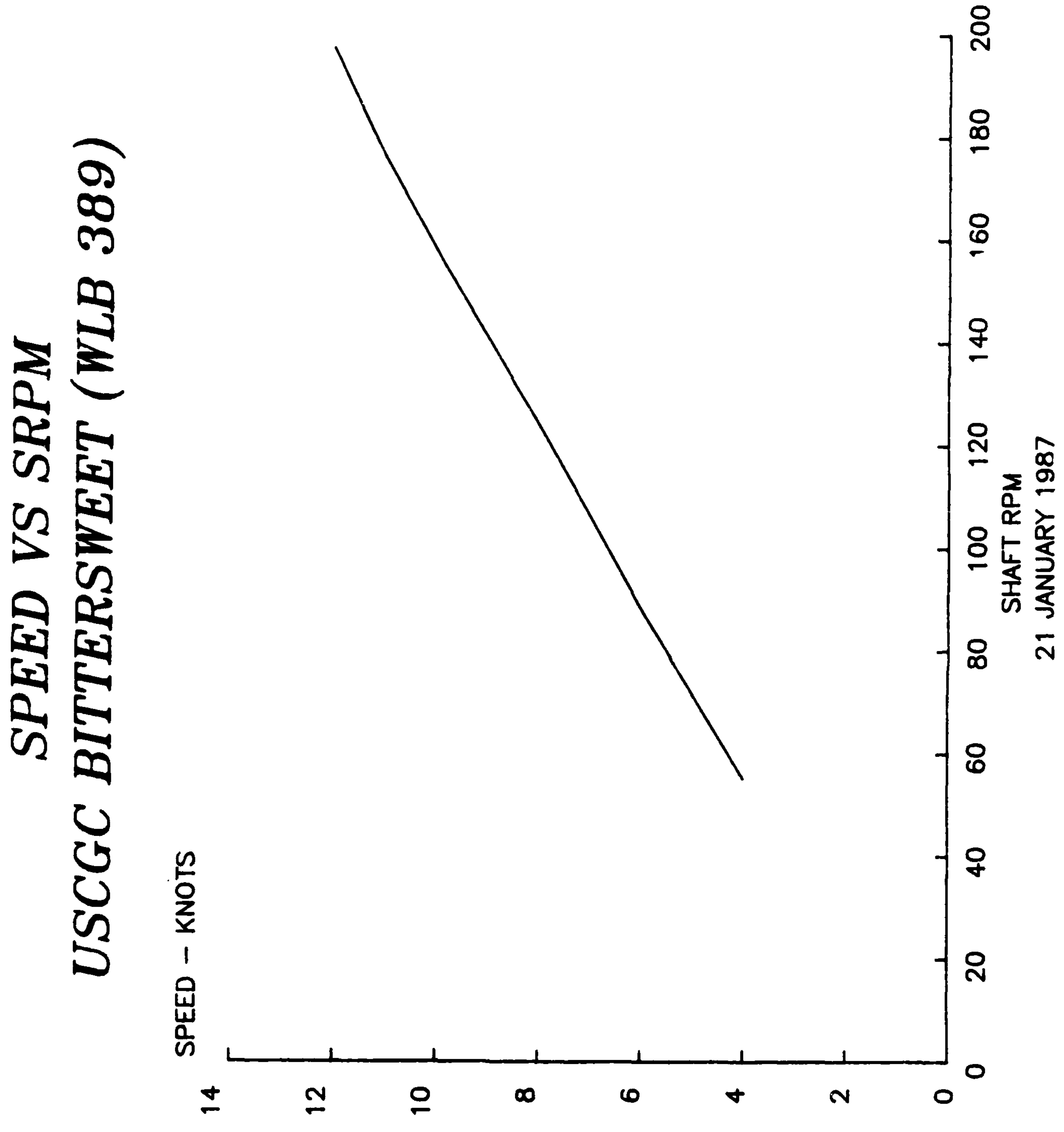


FIGURE 12B SPEED vs SRPM

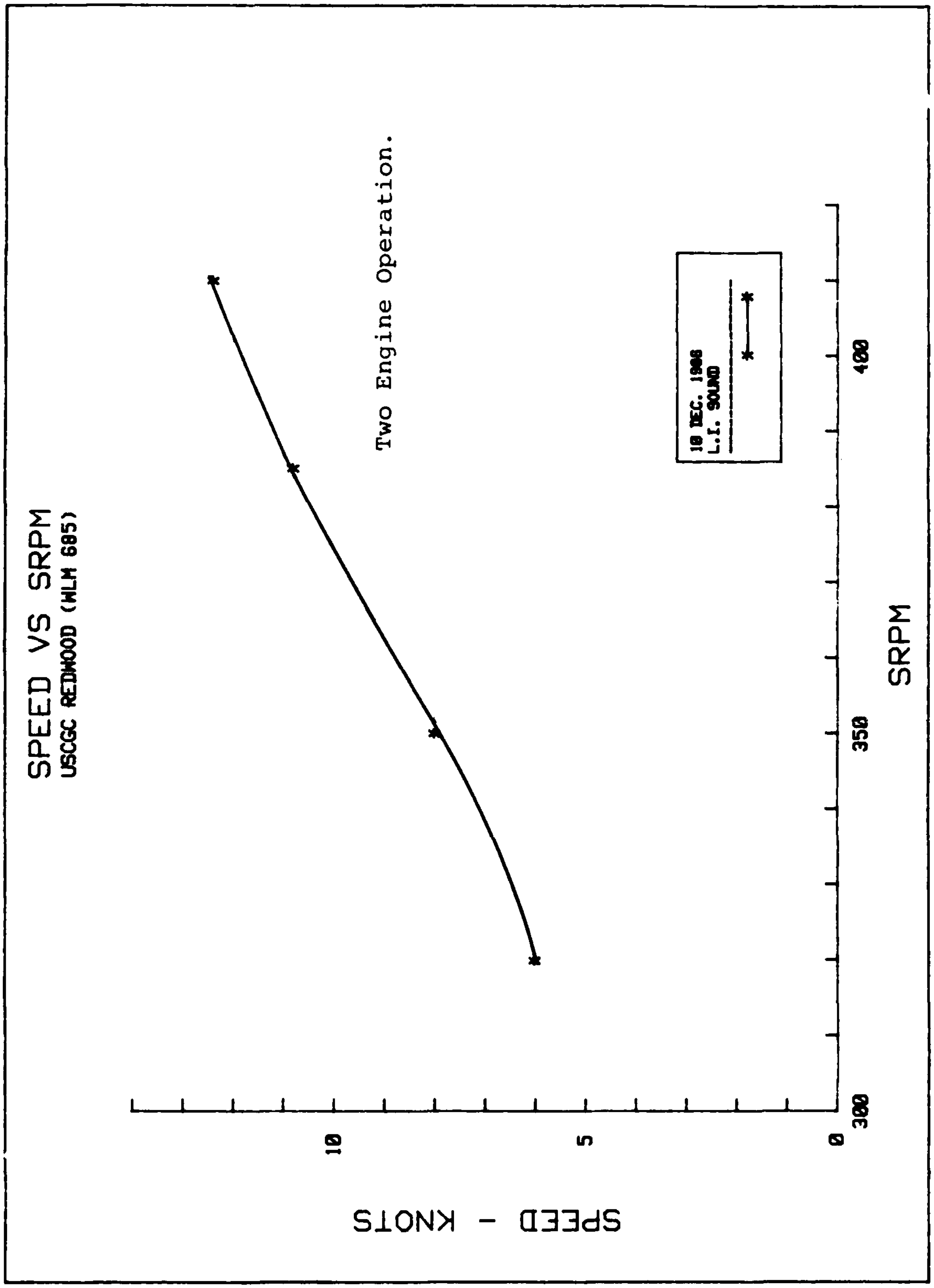


FIGURE 12R SPEED vs SRPM

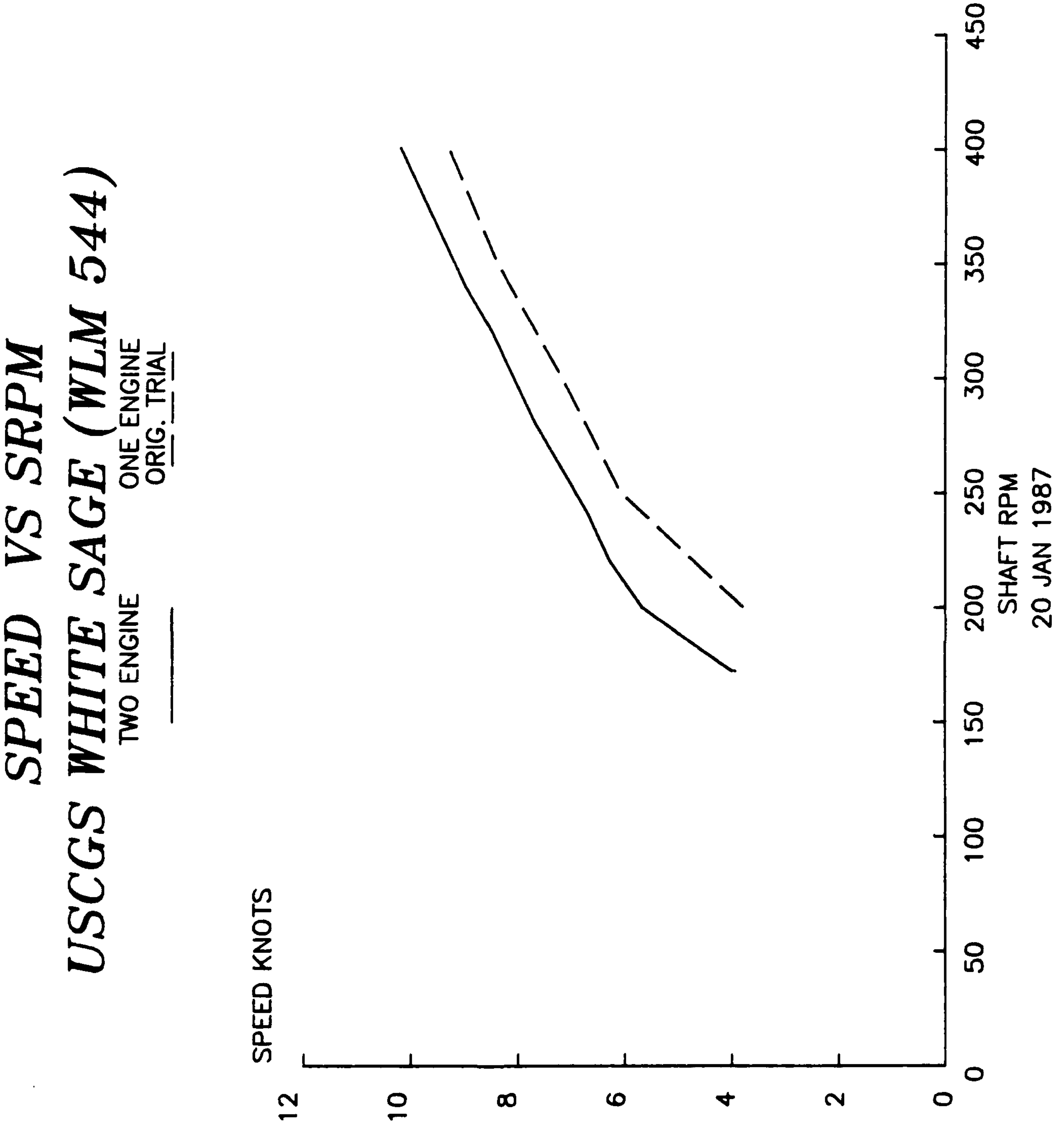


FIGURE 12W SPEED vs SRPM

and require ear protection. Most of the other areas of the ship are below the 85 dbA for 16 hour exposure limit. There are two areas on the BITTERSWEET which are extremely noisy when the hydraulic system for the boom is activated. There are peak noises exceeding 98 dbA in the passage outside the Ship's Office which last for approximately 3-4 seconds; the second area with noises exceeding 100 dbA is the Armory, accessible from Crew's Berthing, which is extremely noisy (all the time that Boom Hydraulics is activated).

SUMMARY

The objective of this technical evaluation (Techeval) was to obtain baseline information to characterize the existing 180' "BALSAM" Class seagoing buoy tender, and the 157' "RED" and 133' "WHITE SUMAC" Class coastal buoy tenders in order to support the next generation buoy tender acquisition process. Standard calm water and rough water tests were run on all three ship classes to characterize seakeeping ability, maneuverability, and speed-power and fuel consumption efficiency. In addition, noise level data was collected in the living and machinery spaces; and subjective data was collected from buoy tender crews to characterize the overall operational effectiveness of each class.

Each class was designed and used for a different environment and aids to navigation servicing capability spanning offshore open water conditions to protected coastal conditions. Each class is significantly different in length, displacement, powering and steering configuration. Although this report is not intended to be a comparative analysis, general observations can be made from the principal characteristics and tactical data as summarized in Tables 1 and 2, and the TECHEVAL data as presented throughout the report.

Polar plots of roll (ship's heading vs. degree of roll) show that the 157' (CGC RED WOOD) tender is particularly susceptible to roll in beam seas in only 2.5 foot seas, while the 133' (CGC WHITE SAGE) and 180' (CGC BITTERSWEET) have better roll stability in 4.5 foot seas. Pitch characteristics and amplitudes are roughly the same for all three classes. Polar plots of heave acceleration show that heave at the center of gravity for the 180' and 133' tenders is quite uniform regardless of sea direction. Heave acceleration at the center of gravity on 157' tenders is more pronounced with seas off the bow. No direct comparison can be made on overall seakeeping ability due to the difference in significant wave heights during the various tests. All three buoy tenders have an observed natural roll period in the range of expected wave encounters during buoy tending operations (5 to 8.5 seconds) while all stop which is undesirable for tending buoys.

The spiral test for maneuverability showed that the 180' and 133' tenders exhibit good maneuverability characteristics (lack of hysteresis) due to their large rudders which enhance steering responsiveness. The spiral test for the 157' tender is somewhat less impressive as the flat bottom hull and rudder combination may be less than ideal for responsiveness. The zig-zag maneuverability test showed that overshoot and responsiveness is faster at higher speeds in the 180' and 157' tenders. Direct comparison of zig-zag test maneuverability characteristics for the three classes of tenders is difficult due to the different test speeds. Tactical data for the three classes indicates that the 157' tender has twice the turning rate as the other two tenders at 8-12 knots using rudder control only.

The speed vs. power plot for the 133′ tender CGC WHITE SAGE (Figure 8W) shows a dramatic increase in power required beyond 8 knots which persists for the remainder of the speed-power curve, resulting in decreased range and endurance. The 180′ (CGC BITTERSWEET) and 157′ (CGC RED WOOD) have a nearly linear 100 HP/knot power response over the range 6-12 knots (Figures 8B and 8R), except that an unexplained discontinuity was noted at 7.5 to 10 knots for the CGC RED WOOD. The 180′ CGC BITTERSWEET and 133′ CGC WHITE SAGE are relatively fuel efficient as shown in Figure 13. Although the data for CGC RED WOOD are not plotted for reasons previously described, the values in Table C-3R indicate that the 157′ WLM has a much higher fuel consumption than the other two classes within its normal operating speed range. All three classes are relatively slow with maximum speeds between 10 and 12 knots and have the large range and endurance required for their mission.

Noise levels on all three classes in engine room spaces exceeded OSHA recommendations and required ear protection. Most of the other areas of the ship were below the 85 dBA for 16 hour exposure limit, with excessive noise in some locations when the hydraulic system for the boom is activated.

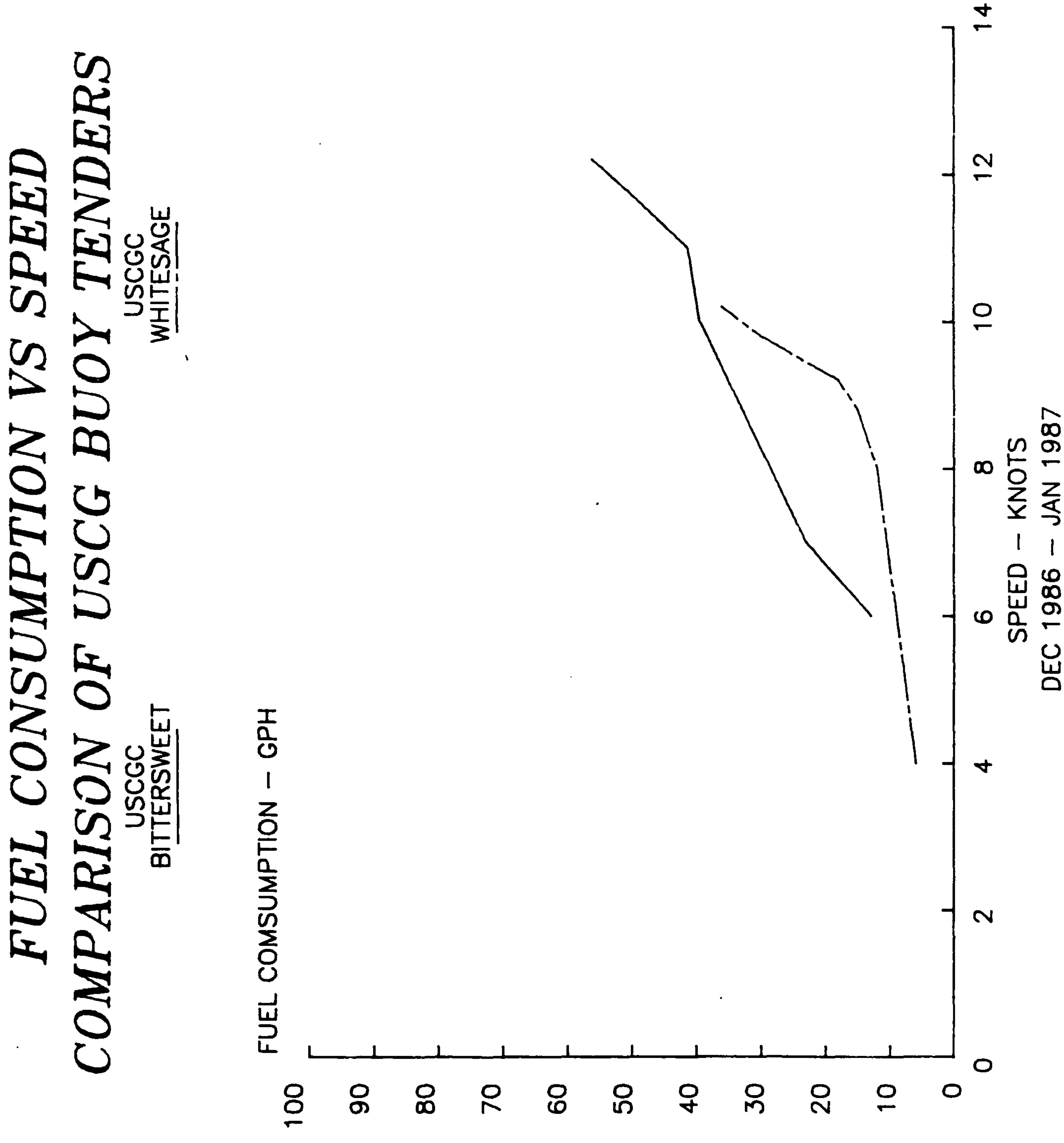


FIGURE 13 FUEL CONSUMPTION vs SPEED COMPARISON

REFERENCES

1. Goodwin, M., "General Test Plan for Marine Vehicle Testing", USCG, June 1981.

2. Strickland, A.T., Side-By-Side Buoy Tending Trials of the Swath Ship SSP KAIMALINO and the USCGC CUTTER MALLOW (WLB-396), NOSC Technical Report 963, August 1985 FINAL REPORT.

3. Coe, T.J., Side by Side Buoy Tender Evaluation Seakeeping and Maneuvering Comparison of the USCGC MALLOW (WLB-396) and SSP KAIMALINO (Semi-Submersible Platform), USCG R&D Center Report No. CG-D-34-84, Government Ascension No. ADA 153 613.

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APPENDIX A
EQUIPMENT DESCRIPTION

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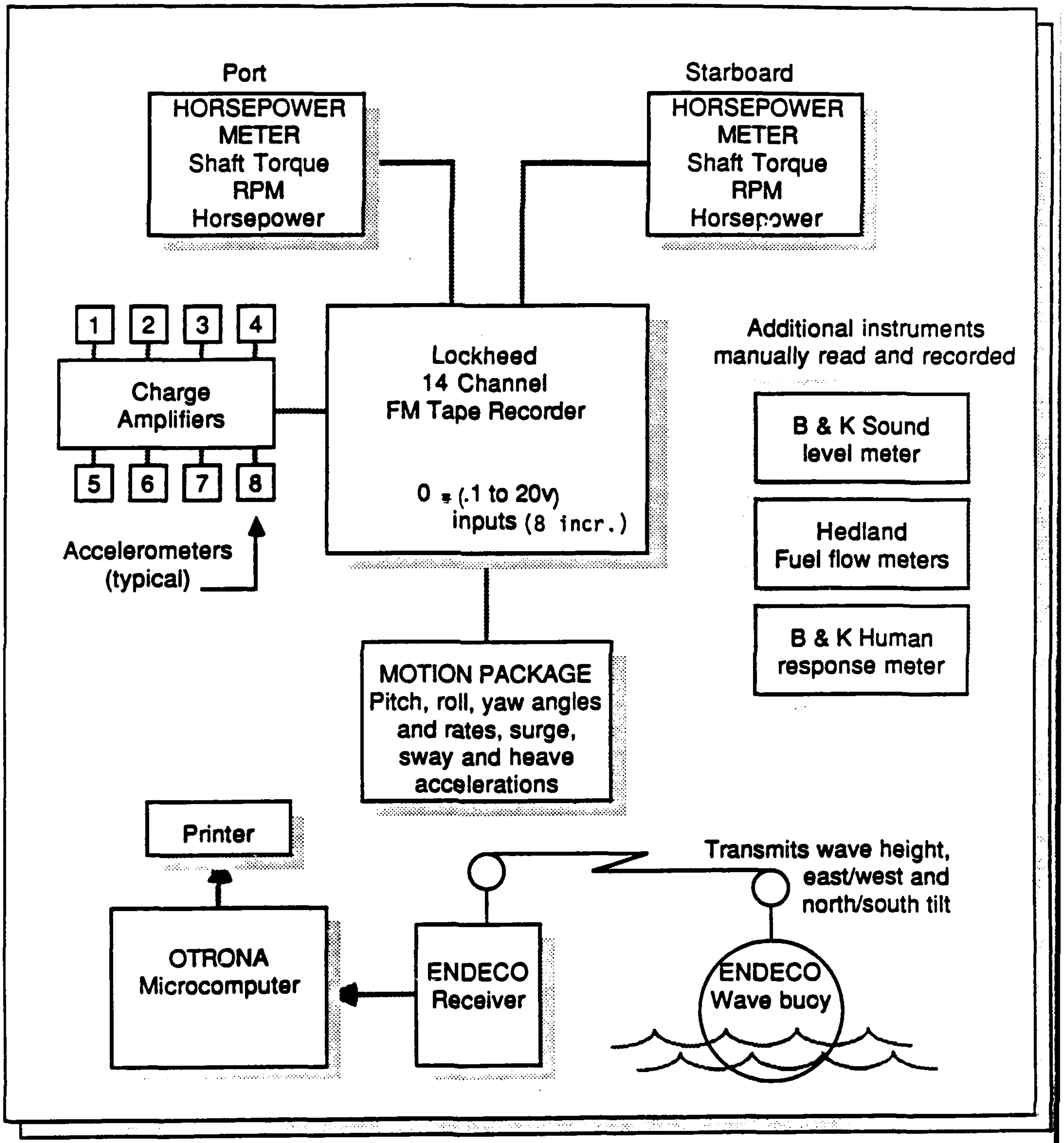

FIGURE A-1 BLOCK DIAGRAM OF DATA ACQUISITION SYSTEM

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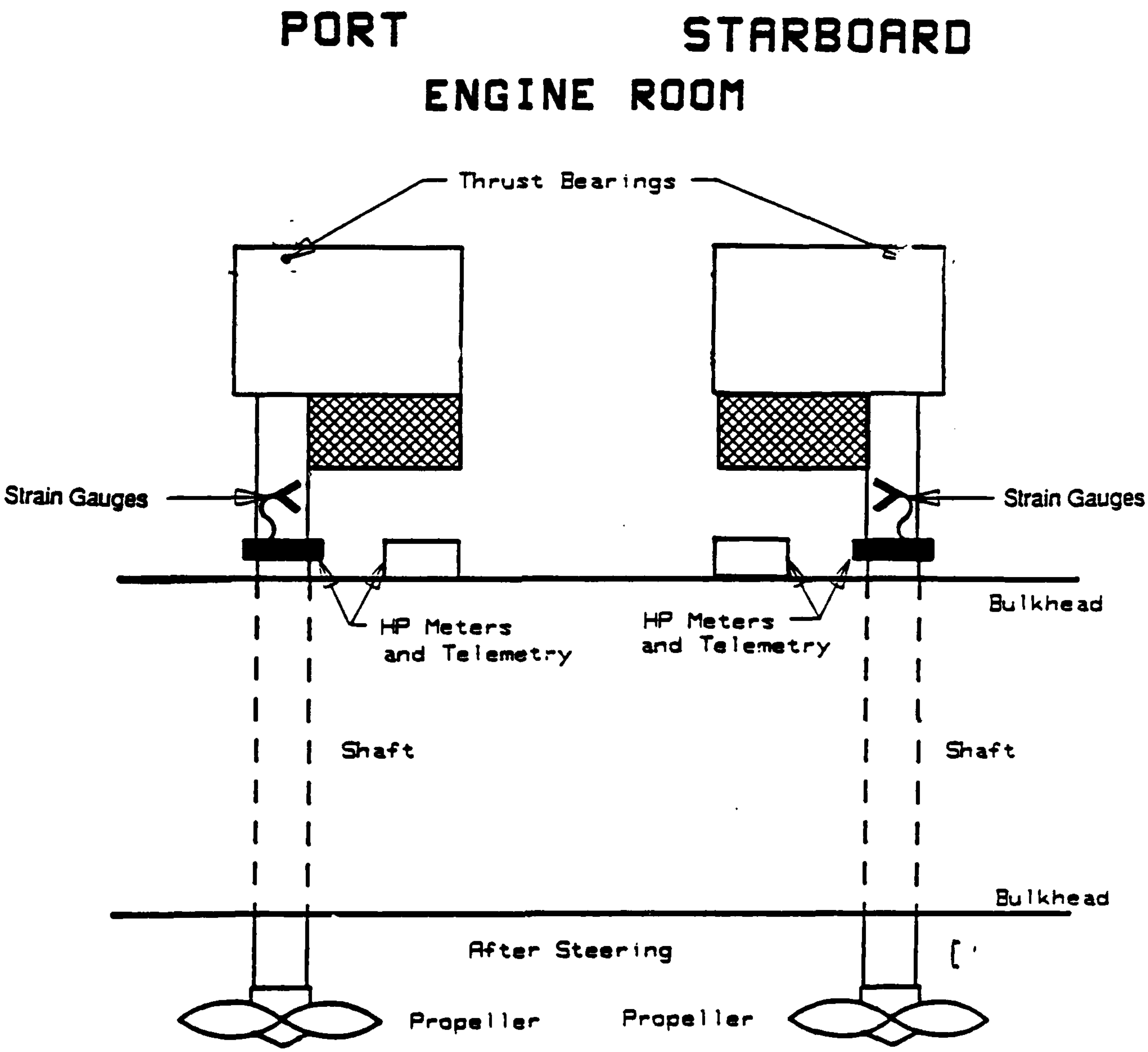

FIGURE A-2 PROPULSION-SHAFT POWER MEASUREMENT

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TABLE A-1

TABLE OF ACCELEROMETER CHARACTERISTICS

BRUEL & KJAER TYPE	SERIAL NO.	CHARGE SENSITIVITY (pC/g)
4368	1108856	53.3
"	1108857	50.7
"	1108858	50.9
"	1108859	54.0
4384	999340	9.84
"	1042978	98.6
"	1060892	9.88
"	1051631	9.92
"	1051741	9.98
"	1012012	96.5

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TABLE A-2

DESCRIPTION OF INSTRUMENTATION

EQUIPMENT	DESCRIPTION
SHIP MOTION PACKAGES (2) HUMPHREY, Inc.	This unit consists of a vertical gyro, a vertically stabilized three-axis accelerometer assembly, a directional gyroscope, a three-axis rate gyro assembly and all necessary power supplies and power switching relays. Nine outputs are available at ± 1 or ± 5 volts full scale with or without a 10 Hz low pass filter. Full-scale outputs can be varied as the table below indicates.
Pitch Angles	± 45°, 25° or 10°
Roll Angles	± 45°, 25° or 10°
Yaw Angles	± 175°
Pitch and Roll Rate	± 60, 30 or 10 deg/sec
Yaw Rate	30, 10 or 5 deg/sec
Surge & Sway Acceleration	± 1.0 or 0.5 G's
Heave Acceleration	± 2.0 or 0.5 G's
STORE 14D ANALOG TAPE RECORDER Lockheed Electronics Company (2)	This analog tape recorder can record up to 14 channels including one voice channel which records on channel 14 and overruns data if recorded on that channel. It has seven variable speeds from 15/16 IPS up to 60 IPS. It can attenuate signals from 0.1 to 20 volts peak to peak normalizing the recorded signal to 1 volt peak to peak output.
ENDECO 956 WAVE TRACK BUOY	This orbital following wave buoy measures wave height and direction. It transmits three digital signals; wave height, buoy tilt (East-West), and buoy tilt (North-South) to a remote receiver usually deployed with the test vessel. The digital signals are recorded and analyzed using an Otrona 8:16 microcomputer. The data can be analyzed using either a "LONGUEST-HIGGONS" or "DIGITAL BAND PASS FILTERING" method. The output is Significant Wave Height (H 1/3) and significant period as well as a plot of wave energy vs. frequency and direction. This allows for a determination of the major swell direction and quantification of the extent of a undirectional or confused sea state. Directional accuracy is ± 10°. It can be moored with an accumulator mooring system for long-term monitoring situations.

HUMAN-RESPONSE VIBRATION METER Type 2512 Bruel & Kjaer (B&K) Marion, MA	Measures vibration from a tri-axial accelerometer for the evaluation of vibration on the human body in agreement with current ISO standards for Hand-Arm and Whole-Body (including motion sickness) measurement. The complex relationship between level, frequency and time is automatically taken into account in the compututation of equivalent continuous vibration level and exposure dose. Outputs are printed on thermal paper with the use of a Alphanumeric Printer type 2312. Outputs are automatically printed at preselected intervals in the form of: Current Time, Elapsed Time, Peak Acceleration (dB), Equivalent Exposure (dB) and Percent of a particular ISO standard selected which has been reached at that elapsed time.
TRIAXIAL SEAT ACCELEROMETER Type 4322 (used with B&K Meter Type 2512)	This accelerometer is especially designed for detecting vibration motion in connection with the measurement of whole-body vibration and can be put under the buttocks of a seated person.
Frequency Range:	0.1 H_z to 2 kHz (± 5%)
Charge Sensitivity:	1 pC/ms^{-2} ± 2% 10 pC/g
Piezoelectric Material:	PZ27 Delta Shear Configuration
ACCELEROMETER CHARGE AMPLIFIERS Type 2635 and 2651 Bruel & Kjaer Marion, MA	Various ship vibration measurements are made using Bruel & Kjaer (B&K) accelerometers and charge amplifiers. The output of the charge amplifiers are recorded on magnetic tape. Two types of B&K accelerometers are used; they are the 4368 and the 4384. Two types of charge amplifiers are used; they are the Model 2635 and the Model 2651. The 2365 is a battery operated (stand alone) charge amplifier with transducers sensitivity conditioning from 0.1 to 10.99 pC/ms^{-2}.
Frequency Range:	
Acceleration	.2Hz to 100kHz
Velocity	1Hz to 10kHz
Displacement	1Hz to 1kHz
	The Model 2651 charge amplifier needs a power supply (and is packaged in a pack of four amplifiers with the power supply); transducer sensitivity conditioning settings of 0.1, 1, and 10 mV/pC.

TABLE A-2 (cont'd)

Frequency Range:
Acceleration .003 to 200kHz

General B&K accelerometer information follows:

Model	Charge Sensitivity	Frequency Range	Temperature Range (deg. C)
4368	4.8 pC/ms^{-2}	.2 to 5000	-74 to 250
4384	1 ± 2%	.2 to 9200	-74 to 250

FUEL FLOW METERS
HEDLAND
Racine, WI

In-line flow meters are direct reading units requiring no electrical connections or readout devices. Scales are based on a specific gravity of 0.84 for fuel oil. Accuracy is within ± 5% of full scale.

HORSEPOWER METER 1202A (2)
ACUREX AUTODATA,
Mountain View, CA

The 1202A measurement system measures shaft torque and rpm and calculates horsepower from that information (HP = Torque x rpm x Constant). The shaft is strain gauged for torque. A transmitter collar and antenna are bolted to the shaft in order to power and transmit FM signals from the strain gauge bridge. Three simultaneous analog outputs are provided at the readout box (Torque, HP and rpm). Calibration using a shunt resister is usually conducted because a known torque load is difficult to apply to a vessel in the water. This method simulates a torque load by shunting a gauge with a known value of resistance.

SPECIFICATIONS

Accuracy:	Torque	± 1% of full scale
	rpm	∓ 0.25% of full scale
	Horsepower	± 1.5% of full scale

SOUND LEVEL METER TYPE 213H
Bruel and Kjaer
Marlborough, MA

This hand-held sound level meter measures levels from 50 to 130 dB with A or C weighting filters. It can be used with fast or slow response. Calibration is done by using a Sound Level Calibration unit Type 4230. The sound pressure level of the calibrator is 93.6 dB.

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APPENDIX B

BUOY TENDING QUESTIONNAIRE

BUOY TENDING QUESTIONNAIRE

The buoy tending questionnaire (pages B-3 through B-7) was distributed prior to the ships becoming actively engaged in buoy tending operations. This form had been previously utilized in a side-by-side trial of SSP KAIMALINO (SWATH) and the 180' CGC MALLOW (WLB) for comparison purposes in buoy tending operations (See Reference 3). Limited information was obtained from the questionnaire due to the difficulty of completing four to six of them during a very intensive work schedule.

The consensus of the answers received can be succinctly summarized by saying that the ship must effectively respond by working into the prevailing force presented by wind and current. When a bow thruster is not available this can present a problem in some wind-current situations.

Some aspects of buoy tending, i.e., bringing the buoy on-board, lashdown of the buoy in rough seas, releasing of the sinker and/or chain and buoy, always present a dangerous condition. Working with the articulated buoy with its flanged sections beneath the vertical buoy has to be classed as one of the more dangerous and thus respected operations of all buoy tending operations observed.

The BITTERSWEET and WHITE SAGE testing was accomplished during buoy operations in the Newport, RI, to Gloucester, MA area. On several days the wind chill was 0 and below 0°F, and the lack of protected space for the helmsman operating on the wings of the bridge (in view of the buoy and sinker) became quite obvious when exposed parts of face and hands turn first blue and then black when protracted buoy operations were encountered. The crew on the buoy deck during cold weather operation have the luxury of physical exertion and freedom to cover exposed parts which the helmsman does not. It is recommended that a portable, clear windbreak be made available for severe cold weather days at exposed steering locations.

In addition to the questionnaire, a video camera was used to record about two hours of buoy tending operations by each ship. The RED WOOD record contains the complete record of assembly and setting a large articulated buoy at the head of the Thames River in New London, Connecticut.

BUOY TENDING QUESTIONNAIRE

RUN # ______ NAME ____________________ RATE/RANK __________

DATE ______________ TIME __________ SHIP ______________

BUOY TYPE ______________

PHASE I. MANEUVERING FOR BUOY RECOVERY

a. Describe the degree of difficulty experienced maneuvering the ship alongside the buoy.

Very difficult ______
Moderately Difficult ______
Not difficult ______
A piece of cake ______

b. Rank the influence each of the following has or could have on the maneuverability of the ship during this phase of the trials (1 has greatest influence on maneuverability. 7 has least influence).

Controlability of screw turns ______
Power available at the screw ______
Rudder ______
Bow Thruster ______
Screw separation coupled with differential thrusting ______
Visibility from the pilot house ______
Other (specify) ______

c. Did environmental factors and their affect on the ship influence the maneuverability of the ship. These factors include wind, waves, currents, visibility and other weather conditions. If yes, how?

d. Did any aspect of the ship design or performance affect the ability to pass the line through the bale of the buoy? Such factors might include height of the deck above the water and ship motions including roll, pitch or heave.

PHASE II. BUOY RECOVERY AND LASHDOWN

a. Describe the degree of difficulty experienced lifting the buoy aboard.

Very difficult ____________
Moderately difficult ____________
Not difficult ____________
A piece of cake ____________

b. If your answer to a. was "very difficult" or "moderately difficult", please explain the cause of the difficulty.

c. Did any aspect of bringing the buoy on board present a safety hazard? If yes, please describe.

d. Describe the degree of difficulty experienced recovering the chain and sinker.

Very difficult	________
Moderately difficult	________
Not difficult	________
A piece of cake	________

e. If your answer to d. was "very difficult" or "moderately difficult", please explain the cause of the difficulty.

f. Did any aspect of chain and sinker recovery present a safety hazard? If yes, please describe.

g. Did any aspect of buoy lashdown present a safety hazard? If yes, please describe.

III. PREPARATION OF THE BUOY FOR SETTING

a. Were there any aspects of preparing the buoy for setting that were noticeably difficult? If yes, please explain.

b. Were any safety hazards present during preparation for buoy setting? If yes, please describe.

IV. BUOY SETTING

a. Describe the degree of difficulty experienced maneuvering the ship to the drop point.

Very difficult	________
Moderately difficult	________
Not difficult	________
A piece of cake	________

b. To what extent did the method of navigating (horizontal sextant readings) influence the ability of the craft to quickly maneuver to the drop point?

None	________
Very Little	________
Some	________
Lots	________

c. On the average, how much time delay existed between the taking of horizontal sextant readings and the delivery of navigation information to the helmsman?

________Sec

d. Back in Phase I, Item b., you ranked the influence of various ship characteristics on the ability to maneuver the ship. Would you change this ranking for this phase of the trials? Note changes below

Controlability of screw turns	________
Power available at the screw	________
Rudder	________
Bow thruster	________
Screw separation coupled with differential thrusting	________
Visibility from the pilot house	________
Other (specify)	________

e. Did environmental factors such as wind waves or currents influence the maneuverability of the ship? If yes, in what way?

f. Did the design or performance of the ship influence the ability to take horizontal sextant readings? If yes, please describe this influence.

g. Did any aspect of the release of the sinker, chain and buoy present a safety hazard? If yes please describe.

h. Overall, how would you rate this ship in support of this exercise?

Excellent	____________
Good	____________
Fair	____________
Poor	____________

i. What were the most attractive features or characteristics of this ship in the conduct of this exercise?

j. What were the most undesirable features or characteristics of this ship in the conduct of this exercise?

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APPENDIX C
DATA TABLES

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TABLE C-1B
USCGC BITTERSWEET
SEAKEEPING DATA

RELATIVE SEA DIR.	DATA TYPE AVG	ROLL ANGLE (DEG)	ROLL RATE (DEG/SEC)	PITCH ANGLE (DEG)	PITCH RATE (DEG/SEC)	HEAVE (G's)	SURGE (G's)	SWAY (G's)
HEAD SEAS	HIGH	2.564	1.959	1.492	2.311	0.562	0.031	0.046
	1/10	2.236	1.738	1.136	1.630	0.361	0.023	0.031
	1/3	1.878	0.616	0.906	1.341	0.289	0.020	0.026
	RMS	1.361	0.484	0.668	0.953	0.213	0.016	0.020
	MEAN	1.245	0.464	0.621	0.862	0.196	0.015	0.019
BOW QTR	HIGH	5.008	2.123	2.582	3.173	0.502	0.030	0.102
	1/10	4.116	1.591=	1.568	2.098	0.367	0.023	0.079
	1/3	3.463	1.257	1.237	1.718	0.288	0.020	0.065
	RMS	2.510	0.906	0.903	1.228	0.207	0.016	0.047=
	MEAN	2.273	0.816	0.827	1.107	0.187	0.017	0.043
BEAM	HIGH	5.664	2.764	1.986	2.294	0.515	0.024	0.090
	1/10	4.545	1.730	1.613	1.801	0.348	0.022	0.071
	1/3	3.575	1.345	1.332	1.559	0.277	0.019	0.058
	RMS	2.518	0.951	0.995	1.140	0.202	0.016	0.042
	MEAN	2.221	0.850	0.928	1.051	0.186	0.015	0.039
STERN QTR	HIGH	2.960	0.872	1.393	0.793	0.508	0.024	0.038
	1/10	2.518	0.695	1.009	0.657	0.315	0.021	0.027
	1/3	1.978	0.581	0.833	0.544	0.252	0.019	0.023
	RMS	1.408	0.446	0.632	0.420	0.189	0.015	0.017
	MEAN	1.257	0.424	0.598	0.402	0.176	0.015	0.017
FOLLOWING SEAS	HIGH	4.094	1.071	1.500	0.948	0.475	0.026	0.035
	1/10	2.858	0.798	1.119	0.648	0.325	0.022	0.024
	1/3	2.251	0.620	0.847	0.531	0.263	0.018	0.020
	RMS	1.523	0.467	0.650	0.405	0.196	0.015	0.016
	MEAN	1.283	0.436	0.609	0.384	0.183	0.014	0.015

TABLE C-1R
USCGC RED WOOD
SEAKEEPING DATA

RELATIVE SEA DIR.	DATA TYPE AVG	ROLL ANGLE (DEG)	ROLL RATE (DEG/SEC)	PITCH ANGLE (DEG)	PITCH RATE (DEG/SEC)	HEAVE (G's)	SURGE (G's)	SWAY (G's)
HEAD SEAS	HIGH	6.16	9.12	0.831	2.60	0.081		
	1/10	4.47	6.00	0.668	2.11	0.063		
	1/3	3.49	4.46	0.559	1.76	0.052		
	RMS	2.52	2.93	0.438	1.26	0.038		
	MEAN	2.26	2.33	0.422	1.13	0.036		
BOW QTR	HIGH	10.06	13.72	1.098	4.61	0.172		
	1/10	7.53	9.57	0.842	2.87	0.123		
	1/3	5.96	7.30	0.691	2.28	0.099		
	RMS	4.17	4.76	0.523	1.67	0.078		
	MEAN	3.68	3.68	0.496	1.49	0.075		
BEAM	HIGH	11.37	14.99	1.01	3.24	0.118		
	1/10	7.93	9.36	0.785	2.26	0.082		
	1/3	6.07	6.94	0.644	1.82	0.065		
	RMS	4.18	4.55	0.497	1.26	0.047		
	MEAN	3.58	3.55	0.475	1.10	0.043		
STERN QTR	HIGH	3.49	6.61	0.729	1.44	0.029		
	1/10	2.94	4.49	0.628	1.04	0.028		
	1/3	2.41	3.13	0.526	0.829	0.021		
	RMS	1.75	2.06	0.429	0.584	0.014		
	MEAN	1.59	1.61	0.418	0.525	0.012		
FOLLOWING SEAS	HIGH	7.47	9.16	0.932	2.23	0.068		
	1/10	4.46	5.12	0.714	1.47	0.048		
	1/3	3.37	3.61	0.591	1.09	0.039		
	RMS	2.37	2.39	0.449	0.76	0.029		
	MEAN	2.06	1.89	0.427	0.66	0.027		

TABLE C-1 W
USCGC WHITE SAGE
SEAKEEPING DATA

RELATIVE SEA DIR.	DATA TYPE AVG	ROLL ANGLE (DEG)	ROLL RATE (DEG/SEC)	PITCH ANGLE (DEG)	PITCH RATE (DEG/SEC)	HEAVE (G's)	SURGE (G's)	SWAY (G's)
HEAD SEAS	HIGH	4.098	5.266	2.454	2.173	0.442	0.039	0.049
	1/10	3.546	3,853	2.116	1.898	0.271	0.031	0.035
	1/3	2.911	2.641	1.681	1.582	0.213	0.026	0.029
	RMS	2.058	1,771	1.223	1.130	0.154	0.020	0.022
	MEAN	1.847	1.407	1.117	1.028	0.140	0.019	0.021
BOW QTR	HIGH	4.721	4.439	2.059	2.206	0.411	0.035	0.054
	1/10	3.613	2.970	1.668	1.678	0.257	0.027	0.044
	1/3	2.871	2.135	1.349	1.368	0.201	0.023	0.035
	RMS	2.031	1.457	0.985	0.990	0.146	0.018	0.027
	MEAN	1.798	1.204	0.907	0.905	0.134	0.017	0.025
BEAM	HIGH	3.396	4.434	4.189	3.870	0.443	0.045	-.035
	1/10	2.749	2.796	2.577	2.514	0.279	0.035	0.029
	1/3	2.213	2.088	2.008	1.980	0.217	0.029	0.024
	RMS	1.554	1.416	1.476	1.477	0.156	0.022	0.019
	MEAN	1.362	1.184	1.344	1.353	0.141	0.021	0.018
STERN QTR	HIGH	4,895	4.594	1.582	1.433	0.390	0.025	0.052
	1/10	3.365	2.601	1.315	1.138	0.252	0.024	0.041
	1/3	2.647	1.964	1.027	0.886	0.198	0.021	0.036
	RMS	1.897	1.346	0.748	0.644	0.144	0.017	0.027
	MEAN	1.601	1.134	0.687	0.589	0.132	0.017	0.025
FOLLOWING SEAS	HIGH	4.106	4.908	2.085	1.229	0.464	0.043	0.044
	1/10	2.869	2.702	1.911	1.084	0.263	0.035	0.035
	1/3	2.290	1.954	1.613	0.861	0.205	0.029	0.029
	RMS	1.621	1.331	1.189	0.622	0.148	0.021	0.024
	MEAN	1.436	1.108	1.102	0.569	0.135	0.023	0.020

TABLE C-2B
USCGC BITTERSWEET

SPEED VS HORSEPOWER (CALC)

SPEED	SHAFT HP*	VOLTAGE	CURRENT (AMPS)	SRPM
4	-	100	Close to zero	4
5.8	180.8	290	500	100
7	339.1	320	850	125
9.8	605.9	360	1350	155
11	686.9	380	1450	175
12.2	997.3	500	1600	200

* Overall efficiency of 93% was used to calculate shaft power from indicated power.

TABLE C-2R
USCGC RED WOOD
SPEED VS HORSEPOWER

SPEED	HORSEPOWER PORT	STBD	TOTAL	SRPM (NOM)
6.6	252	240	492	330
7.5	293	256	549	342
11.0	443	400	843	390
12.4	512	512	1024	420

TABLE C-2W
USCGC WHITE SAGE
SPEED VS HORSEPOWER

SPEED	HORSEPOWER PORT	HORSEPOWER STBD	TOTAL	SRPM (NOM)
4.0	39.2	54.0	93.2	170
8.0	224.7	208.9	433.6	295
8.5	287.4	281.7	569.1	310
9.0	306.0	306.6	612.6	340
9.6	473.1	407.7	880.8	370
10.2	495.5	487.4	982.9	400

TABLE C-3B
USCGC BITTERSWEET
SPEED VS FUEL CONSUMPTION (CALC)

SPEED	GPH*
6	12.95
7	23.00
9.8	38.27
10	39.47
11	41.28
12	53.445
12.2	56.142

*Based upon known 1200GPD usage (Ship's Force) for all engines and acces. for steady 10K steaming for a 24 hour period. A s.f.c. of .433#/HP-Hr. was calculated at 10K.

TABLE C-3R
USCGC RED WOOD
SPEED VS FUEL CONSUMPTION

SPEED	GPH
6.6	39.0
7.5	60.0
11.0	72.0
12.4	93.0

TABLE C-3W

USCGC WHITE SAGE

SPEED VS FUEL CONSUMPTION

SPEED	GPH
4.0	6.0
6.0	8.0
8.0	12.0
8.8	15.0
9.2	18.0
9.8	30.0
10.2	36.0

TABLE C-4B
USCGC BITTERSWEET

SOUND SURVEY (12 KNOTS)

LOCATION	SOUND LEVEL $(d_b)_A$	SOUND LEVEL $(d_b)_C$	
Lookout (abv. Bridge)	65	84	
Chart Rm.	82	98	01 Deck
Bridge	63	86	
Buoy Deck	71	92	
PO Berthing	70	85	
PO Head	75	87	
CPO Perthing	72	83	
LT's Off.	72	84	
Eng. Off.	71	89	
S.R. (Aft of Eng. Off.)	69	88	
Aft Steering	73	92	1st Deck
Ward Rm.	69	88	
S.R. (Fwd of W.R.)	69	89	
S.R. (Aft of S.O.)	71	86	
Ship's Office	72	94.5	
CPO Mess	74	88	
Crew's Mess	79	88	
Galley	79	84.5	

TABLE C-4B (Continued)

LOCATION	SOUND LEVEL $(d_b)_A$	SOUND LEVEL $(d_b)_C$	
Fwd Deck	64	80	
EM Shop	62	78	
BCS	62	72	
Laundry	65	82	
Crew's Berthing	63	78	2nd Deck
Crew's Head	70	78	
Crew's Berthing Aft	74	85	
Crew's Head Aft	72	84	
Upper Eng. Rm.	107	111	
Upper Motor Rm.	93	99	
MK Shop	88	92	2nd Deck
- - - - - - - -	- - - -	- - - -	- - - -
Lower Motoro Rm.	92.5	104	
Lower Eng. Rm.	109	114	
Thruster Space	72	83*	

*Note: During Buoy Ops., (zero speed) with Detroit Diesel

@ 1900RPM 109C

@ 900RPM 102C

TABLE C_4R

USCGC REDWOOD

SOUND SURVEY (11 KNOTS)

LOCATION	SOUND LEVEL $(d_b)_A$	SOUND LEVEL $(d_b)_C$
Crew's Mess	75	92
Ward Rm.	67	84
S.R.(Port Side)	62	84
Capt's Qtr.	60	83
Paint Locker	60	85
CPO Qtrs.	66	86
Ship's Off.	72	88
Crew's Qtr.	78	94
P.O. Berthing	72	94
Fantail	83	100
Seamen's Berthing	75	98
Firemen's Berthing	72	89
1st. Class Berthing	72	89
S.R.	66	86
S.R. (Fwd)	67	84
Mach. Shop	90	105
Eng. Rm.	90	110

AD-A190 742 TECHNICAL EVALUATION OF US COAST GUARD 180' 157' AND 2/2
133' BUOY TENDERS(U) COAST GUARD RESEARCH AND
DEVELOPMENT CENTER GROTON CT J BELLEMARE JAN 88

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TABLE C-4W

USCGC WHITE SAGE

SOUND SURVEY (10 KNOTS)

LOCATION	SOUND LEVEL $(d_b)_A$	SOUND LEVEL $(d_b)_C$
Lookout	74	95
C.O. Qtr.	70	87
Bridge	68	88
Boat Deck	78	94
Fan Tail	82	102
Berthing Aft	76	93
Berthing	76	90
Ship's Office	71	92
Head	68	84
Hyd. Compt.	74.5	84
Fwd. Locker	66	90
Fwd. Hold	66	82
CPO Berthing	68	86
Mess Deck	69	94
Galley	83*	94*
*Note: 93A & 102C with Gaylord Hood "ON."		
Mach. Shop	96	100
Eng. Rm.	104	106
Control Rm.	85	72

Table C-5R

USCGC RED WOOD

BUOY TENDING DATA 2' seas (Est.)

RELATIVE SEA DIR.	DATA TYPE AVG	ROLL ANGLE (DEG)	ROLL RATE (DEG/SEC)	PITCH ANGLE (DEG)	PITCH RATE (DEG/SEC)	HEAVE (G's)	SURGE (G's)	SWAY (G's)
HEAD SEAS	HIGH	7.649	10.133	1.128	4.680	below .05		
	1/10	6.906	9.584	1.055	3.045			
	1/3	5.889	7.492	0.848	2.435			
	RMS	4.187	4.963	0.628	1.761			
	MEAN	3.834	3.954	0.589	1.562			