AD-A058 711 NAVAL RESEARCH LAB WASHINGTON D C F/G 8/3

REMOTELY SENSED WAVE SPECTRA FROM JOINT NORTH SEA EXPERIMENTS I--ETC(U)

AUG 78 D T CHEN NASA-P45823G

UNCLASSIFIED NRL-MR-3808 NL

| OF |

AD
A058711

END

DATE
FILMED
11-78

DDC

NRL Memorandum Report 3808

Remotely Sensed Wave Spectra From Joint North Sea Experiments II

DAVIDSON T. CHEN

Advanced Space Sensing Application Branch
Space Science Division

August 1978

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 3808 ✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 REMOTELY SENSED WAVE SPECTRA FROM JOINT NORTH SEA EXPERIMENT [redacted] S II.		5. TYPE OF REPORT & PERIOD COVERED 9 Final Report,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Davidson T. Chen		8. CONTRACT OR GRANT NUMBER(s) 15 NASA [redacted] P45823G
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D. C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem G01-05C
11. CONTROLLING OFFICE NAME AND ADDRESS NASA Wallops Flight Center Wallops Island, Virginia 22337		12. REPORT DATE 11 August 1978
		13. NUMBER OF PAGES 43
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 44p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

14 NRL-MR-3808

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Remote sensing
One-dimensional wave spectra
Wave height distributions
Laser profilometer
JONSWAP II
Wave-current interactions

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The amount of available remotely sensed wave data, obtained by a Helium-Neon laser profilometer in Joint North Sea Experiment II (JONSWAP II), has been quite limited because the signal emitted from the laser profilometer, to say the least, was very noisy throughout the whole airborne experiment. Fortunately, among the very few flights whose data was relatively less noisy, steady offshore wind conditions were found to exist for the single flight on September 19, 1973. Wave spectra calculated from wave data obtained by this particular flight are presented in this report. Due to

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 950 LB

20. Abstract (Continued)

the lack of strong current gradients in the experiment area, the feasibility of inferring currents by using the technique proposed by Huang, et al. (1972) could not be appropriately investigated. However, this particular technique has been included in this report as an Appendix for reference purposes.

CONTENTS

REMOTELY SENSED WAVE SPECTRA FROM JOINT NORTH SEA EXPERIMENTS II

I. INTRODUCTION

The Joint North Sea Wave Project II (JONSWAP II) was a cooperative effort by a number of scientists from Germany, Holland, Denmark, England, Canada and the United States. One of the experimental objectives was to obtain remote sensing data, from an instrumented aircraft simultaneously with the ground-truth data from an array of surface instruments for addressing important questions regarding the interpretation of remotely sensed data.

Scientists from the Naval Research Laboratory and NASA Wallops Flight Center utilized NASA's instrumented C-54 aircraft for observation in JONSWAP II, as one of the remote sensing teams. A typical remote sensing instrument carried aboard the aircraft was the laser profilometer. This airborne laser profilometer profiled the ocean surface as the aircraft flew with constant velocity and at the altitude of 91.5 or 152.4 meters above the ocean. Wave spectra calculated from wave data obtained on September 19, 1973, are presented in this report. The data were relatively less noisy and steady offshore wind conditions were observed on that particular day.

Due to the lack of strong current gradients in the experiment area, the original goal of demonstrating the feasibility of inferring currents by using the technique proposed by Huang, et al. (1972) could not be properly

Note: Manuscript submitted June 15, 1978.

investigated. Nevertheless, the technique has been worked out and included in this report as an Appendix.

II. EXPERIMENTS

The placements of in-situ ground-truth instruments of JONSWAP II are presented in Figure 1. The instruments at Stations 4 and 8 are shown, particularly, for their arrangements. Airborne measurements were made in the general area from Station 4 to Station 11 during the period of September 17 to September 27. Of which, only September 18 and September 19 had the condition of steady offshore wind in which the analysis is interested because of its assumptions, the data taken on these two days is, thus, selected for the study.

The flight patterns of these two days are shown in Figures 2 and 3. According to Dr. Walsh (private communication), of NASA Wallops Flight Center, the NASA airplane was flying at the altitude of 152.4 meters on September 18 and at the altitude of 91.5 meters on September 19. The small circles on the flight paths in Figures 2 and 3 indicate the locations at which data from Inertial Navigation System was taken. The symbol "P" indicates that photographs were taken with 70 mm Hasselbold cameras (80 mm lens) out the left side of the aircraft at the depression angles of 45 degrees.

On September 18 over Station 8 the wind was recorded as steady for 14 hours at 13.5 M/sec in the direction of 121 deg. from the north. While on September 19 over the same station the wind was in the direction of 147 deg. from the north and remained steady for 12 hours at 12.5 M/sec. The detailed information on these two flights as well as the available in-situ measurements is listed in Table 1. The dotted lines indicate that the information was not recorded

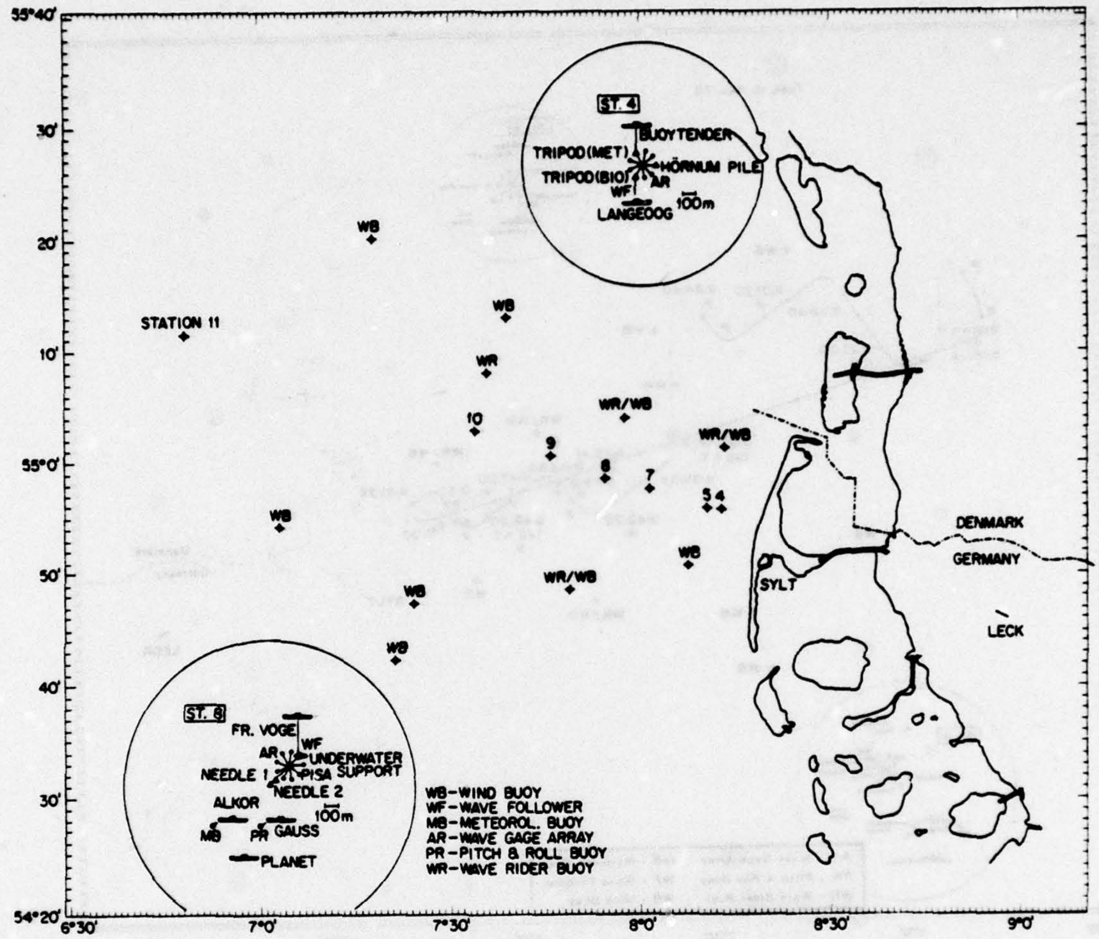


Fig. 1 - Jonswap II

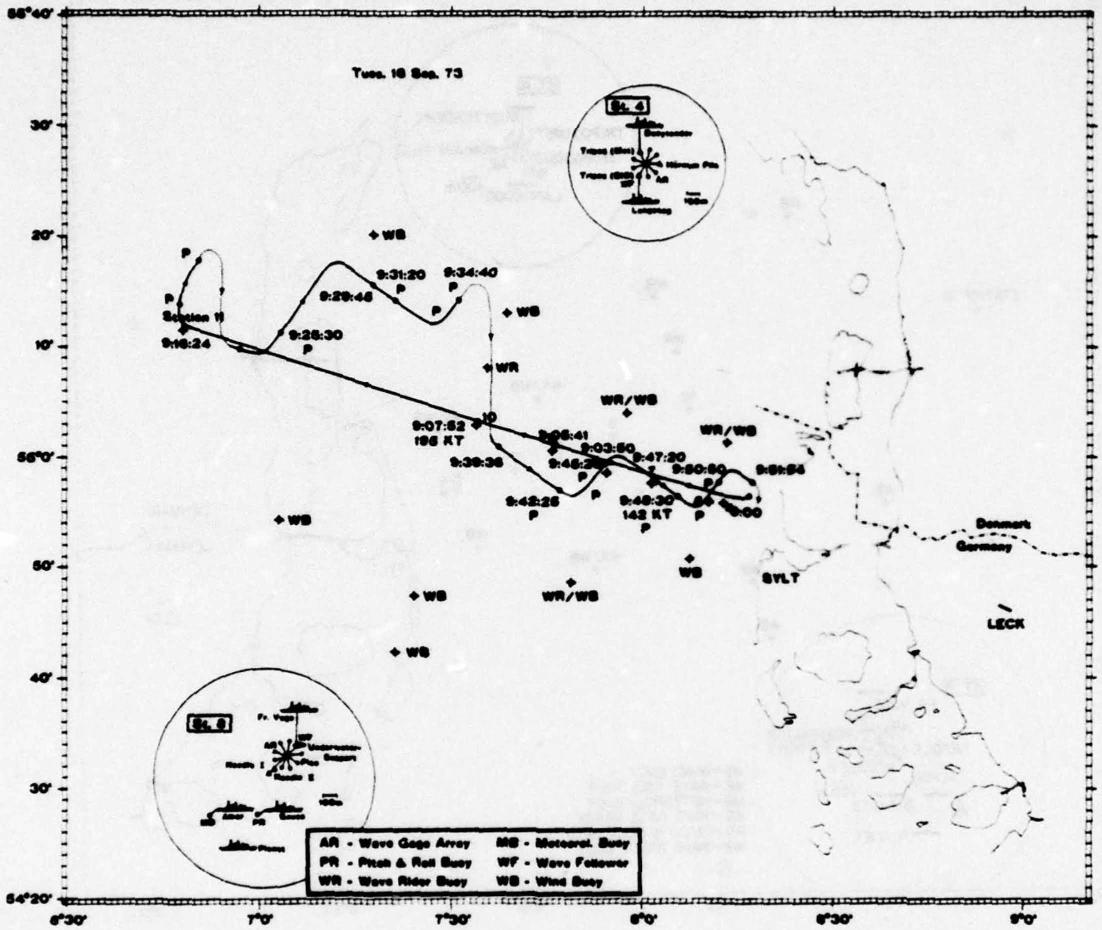


Fig. 2 - Flight pattern at the altitude of 152.4 M on September 18, 1973

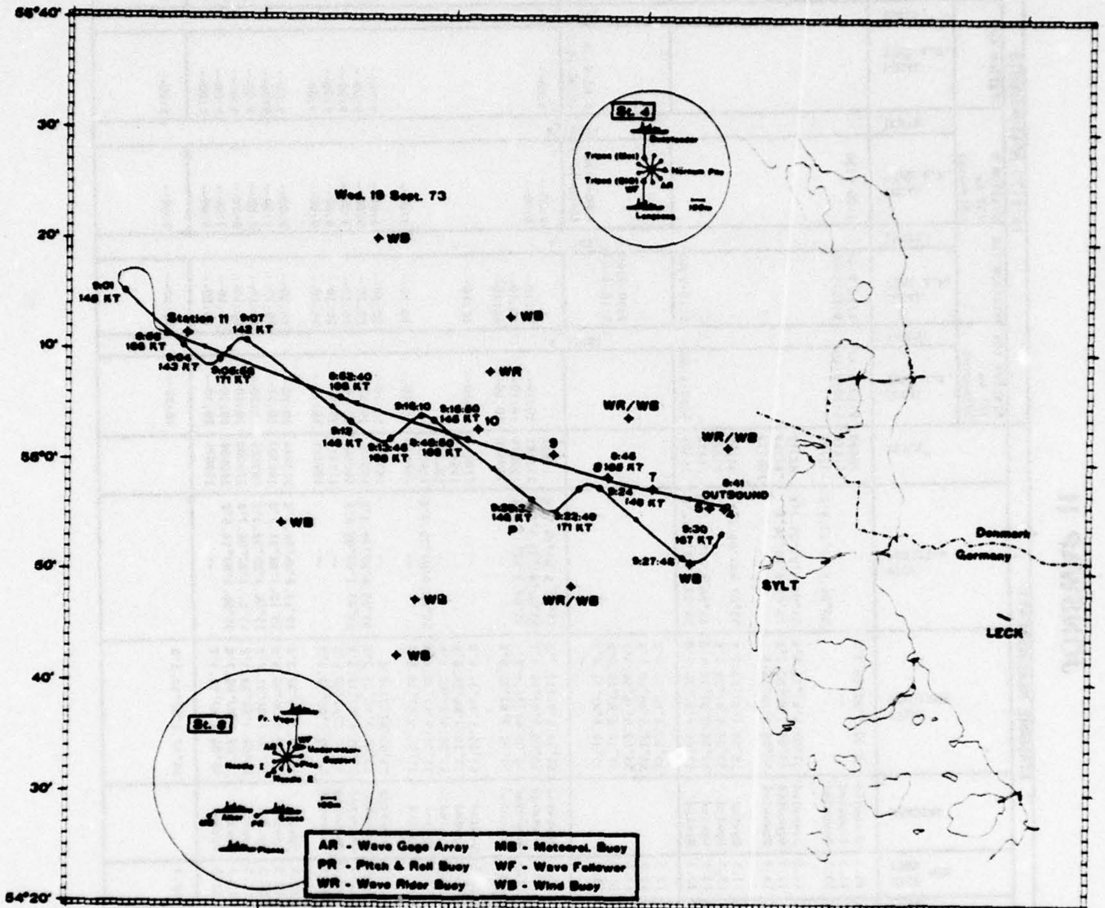


Fig. 3 - Flight pattern at the altitude of 91.5 M on September 19, 1973

Table 1 - Airborne and In-Situ instruments

JONSWAP II

AIRBORNE MEASUREMENTS												IN-SITU MEASUREMENTS									
												STATION 10W (65 km offshore)		STATION 10E		STATION 9 (37 km offshore)		STATION 8N		STATION 8S	
DATE	INSTR.	LOCAL TIME A.M.	TAPE NO.	FILE NO.	ALTITUDE m	GROUND SPEED kt.	WIND COND. m/s	HEADING	START POSITION	STOP POSITION	FETCH m	LOCAL TIME A.M.	INSTR.	LOCAL TIME A.M.	INSTR.	LOCAL TIME A.M.	INSTR.	LOCAL TIME A.M.	INSTR.	LOCAL TIME A.M.	INSTR.
Tuesday, Sept. 18, 1973 9:00 AM-10:30 AM	Laser & Nanosecond Radar	9:01:30-9:03	1	3	152.4	189	13.5	Downwind	55°02.5'N7°40.1'E	--	50498	9:10-9:40	A_1 (IOS)	9:10-9:40	A_2 (IOS)	7:00-9:30	W_6 (DHI)		W_5 (DHI)		W_4 (DHI)
		9:03-9:04:30	1	4	152.4	189	13.5	Downwind	--	--	61116	9:10-9:40		9:10-9:40							
		9:04:30-9:06	1	5	152.4	189	13.5	Downwind	--	55°06.8'N7°13.9'E	71734										
		10:06-10:07:30	2	0	609.6	204	13.5	Downwind	55°07.4'N7°14.5'E	55°08.7'N7°05.2'E	82352										
		10:07:30-10:09	2	1	609.6	204	13.5	Downwind	55°08.7'N7°05.2'E	55°09.8'N6°56'E	97292										
		10:09-10:10:30	2	2	609.6	202	13.5	Downwind	55°09.8'N6°56'E	--	106552										
		10:36-10:37:30	3	0	3352.8	180	13.5	Upwind	55°09.1'N7°00.2'E	55°07.6N7°09.1'E	91736										
		10:37:30-10:39	3	1	3352.8	180	13.5	Upwind	55°07.6'N7°09.1'E	--	77537										
		10:40-10:41:30	3	2	3352.8	181	13.5	Upwind	55°06.0'N7°18.4'E	55°04.7'N7°26.7'E	66178										
		10:41:30-10:43	3	3	3352.8	182	13.5	Upwind	55°04.7'N7°26.7'E	55°03.3'N7°35.2'E	56301	9:10-9:40		9:10-9:40							
	Stillwell Photography	-- (1)			152.4		13.5		55°13.8'N6°47.0'E												
		-- (2)			152.4		13.5		55°17.5'N6°49.7'E												
		9:23:00 (3)			152.4		13.5		55°09.6'N6°56.5'E					9:10-9:40							
		9:31:20 (4)			152.4		13.5		55°14.6'N7°20.6'E					9:10-9:40							
		-- (5)			152.4		13.5		55°14.8'N7°31.4'E							7:00-9:30 10:00-10:30		7:00-9:30 10:00-10:30		9:00-9:30	
Wednesday, Sept. 19, 1973 8:40 AM-10:20 AM	Laser & Nanosecond Radar	8:44-8:45:30	1	2	91.5	186	12.5	Downwind	54°59.8'N7°52.7'E	55°00.9'N7°44.1'E	71858					9:00--		9:00--		9:00	
		8:45:30-8:47	1	3	91.5	186	12.5	Downwind	55°00.9'N7°44.1'E	55°02'N7°35.6'E	152481	10:10--		10:10--		9:00--					
		8:47-8:48:30	1	4	91.5	185	12.5	Downwind	55°02'N7°35.6'E	55°02.7'N7°31.8'E	155074	10:10--		10:10--							
		8:48:30-8:50	1	5	91.5	187	12.5	Downwind	55°02.7'N7°31.8'E	--	157420	10:10--		10:10--							
		9:01-9:02:30	2	0	91.5	145	12.5	Upwind	55°15.1'N6°37.4'E	--	218042	10:10--		10:10--							
		9:06-9:07:30	2	1	91.5	142	12.5	Upwind	55°10.3'N6°58.6'E	--	175940										
		9:08-9:09:30	2	2	91.5	145	12.5	Upwind	55°07.9'N7°04.2'E	--	164705										
		9:15-9:16:30	2	3	91.5	145	12.5	Upwind	55°02.9'N7°30.4'E	55°00.4'N7°35.9'E	154333										
		9:16:30-9:18	2	4	91.5	142	12.5	Upwind	55°00.4'N7°35.9'E	--	148530	10:10--		10:10--		9:00--					
		10:02-10:03:30	3	0	3505.2	193	12.5	Downwind	55°03'N7°33.9'E	--	157543	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:03:30-10:05	3	1	3505.2	191	12.5	Downwind	55°04.3'N7°25.2'E	55°05.6'N7°16.3'E	153716	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:05-10:06:30	3	2	3505.2	190	12.5	Downwind	55°05.6'N7°16.3'E	55°07.1'N7°07.6'E	160507	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:06:30-10:08	3	3	3505.2	193	12.5	Downwind	55°07.1'N7°07.6'E	--	172113	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:10-10:11:30	3	4	3505.2	190	12.5	Downwind	55°09.3'N6°55.3'E	--	189521	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:30-10:31:30	4	0	762	161	12.5	Upwind	55°13.5'N6°37.3'E	55°12.2'N6°44.5'E	213844	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:31:30-10:33	4	1	762	162	12.5	Upwind	55°12.2'N6°44.5'E	55°10.7'N6°51.7'E	194707	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:33-10:34:30	4	2	762	165	12.5	Upwind	55°10.7'N6°51.7'E	55°09.3'N6°59.3'E	183225	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:34:30-10:36	4	3	762	169	12.5	Upwind	55°09.3'N6°59.3'E	55°07.7'N7°06.7'E	172483	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:36-10:37:30	4	4	762	167	12.5	Upwind	55°07.7'N7°06.7'E	55°06.3'N7°14.5'E	162606	10:10--		10:10--		9:00--		9:00--		9:00--	
		10:37:30-10:39	4	5	762	169	12.5	Upwind	55°06.3'N7°14.5'E	--	155074	10:10--		10:10--		9:00--		9:00--		9:00--	
	Stillwell Photography	9:20:30(1)			91.5	146	12.5		54°57.4'N7°42.5'E			10:10--		10:10--		9:00--		9:00--		9:00--	

but can be estimated. The heading of the airplane is presented in a general sense of upwind and downwind, however, this information is used precisely in the calculation as what has been recorded. Three tapes were recorded on September 18 and four tapes were recorded the next day. Excluding calibrations, the files with data of real measurements are listed also in the table. Each file takes 91 seconds of digitized data at a frequency of 90 Hz. The in-situ instruments listed in the table provide wave information. The Institute of Oceanographic Sciences at Wormley, Great Britain, operated the Telemetering Accelerometer Buoys A_1 and A_2 at Stations 10W and 10E, respectively. The Wave Rider Buoys, W_4, W_5, and W_6 were operated by the Deutsches Hydrographic Institute at Hamburg, Federal Republic of Germany. Very unfortunately, due to circumstances beyond control at the time of the flights, all of these in-situ instruments provide a very limited quantity of data. As a consequence, no ground-truth information on waves at Stations 10 and 11 is available for the purpose of comparison.

III. RESULTS

The Spectra-Physics Geodolite 3A Laser Profilometer used in this experiment happened to produce very noisy data for these two flights. There are also clear indications from the data that this laser profilometer lost its lock on the phase shifting mechanism quite frequently. Among all the available data for these two days, data from File 4 of Tape 1 and Files 1, 2, and 3 of Tape 2, taken on September 19, is barely acceptable in quality. After careful examination these four files were chosen for further analyses.

Each file of data contains 8192 digitized numerical values at the time interval of one-ninetieth of a second. A high pass filter was used to filter out the effects of aircraft motions on the measurements. The numerical filter applied was the so-called "Martin Filter" (Martin, 1957). It is a symmetric, non-recursive filter which features a sine termination to the gain function and a correction which insures unity at a cutoff frequency of zero. The sine termination is introduced to avoid large oscillations in the gain function due to a sharp cutoff. The cutoff frequency used in the filter corresponded to a cutoff period of 10 seconds in this particular application.

Due to the limited storage capacity of the CDC 1604 computer this amount of data was segmented at a time length of 5.69 seconds each. This length in time is considered adequate for obtaining the ocean wave spectrum. Fifteen spectra were then ensemble averaged. The effects due to Doppler shift were removed by assuming that waves were travelling in the direction of the wind.

Figures 4, 5, 6, and 7 are the wave spectra calculated from File 4 of Tape 1, and Files 1, 2, and 3 of Tape 2, respectively. In addition, Figures 8, 9, 10, and 11 are the wave height distribution functions obtained from the files in the same sequence. The vertical coordinates of Figures 4, 5, 6 and 7 are in logarithmic scale and in the unit of M^2/Hz. The horizontal coordinates of these figures are also in logarithmic scale, but in the unit of Hz. Figures 4 through 7 show wind speeds in M/sec and fetches in M as well as Figures 8 through 11. The significant wave heights (SWH's) in M as defined by Neumann and Pierson (1966) are also shown in Figures 4 through 7. The abscissas, of Figure 8 to 11, represent wave amplitudes and are nondimensionalized by being divided with variances of the corresponding wave spectra.

The laser noise levels vary from 0.048 M to 0.094 M while the laser noise limits are greater than 3.47, 4.26,

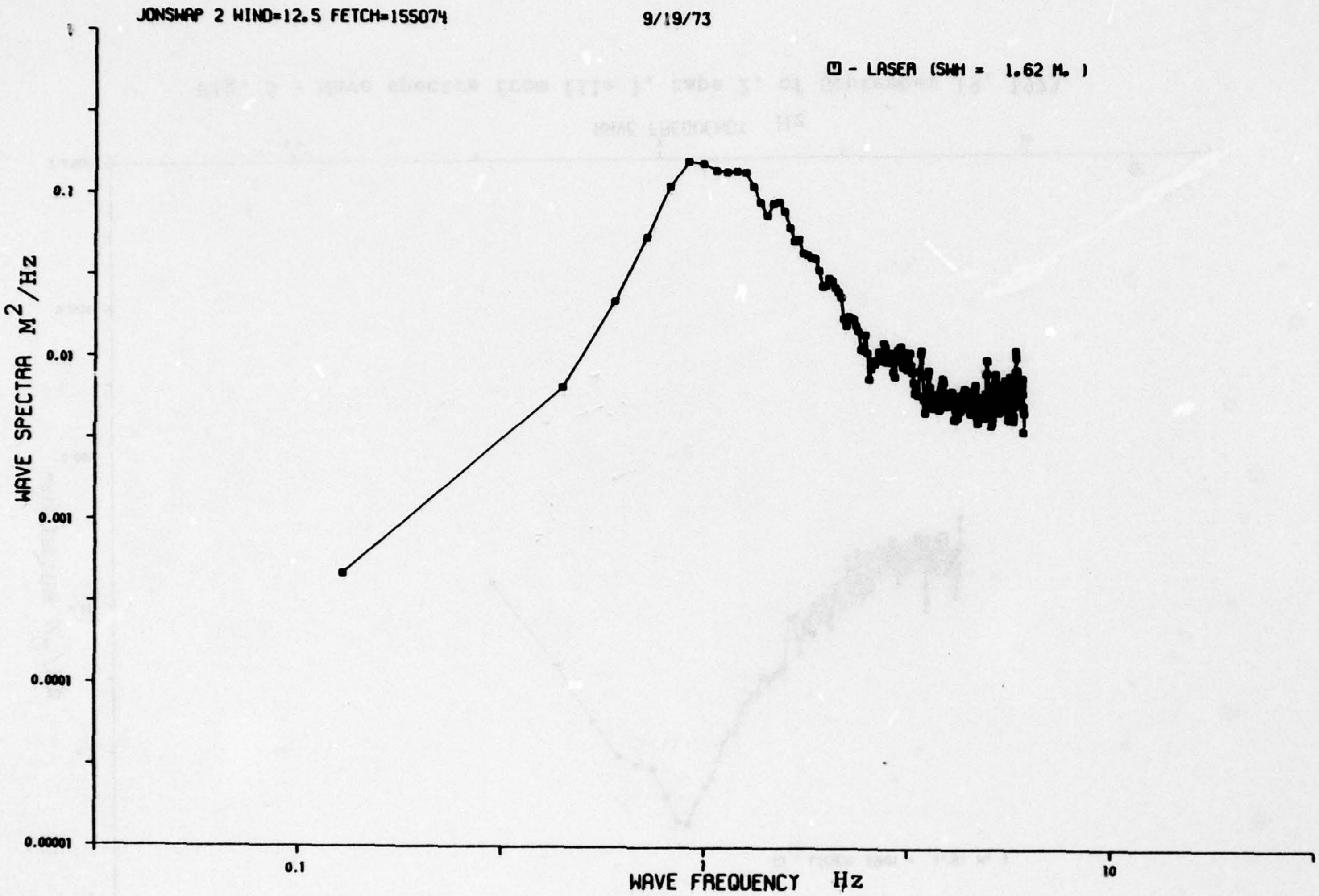


Fig. 4 - Wave spectra from file 4, tape 1, of September 19, 1973

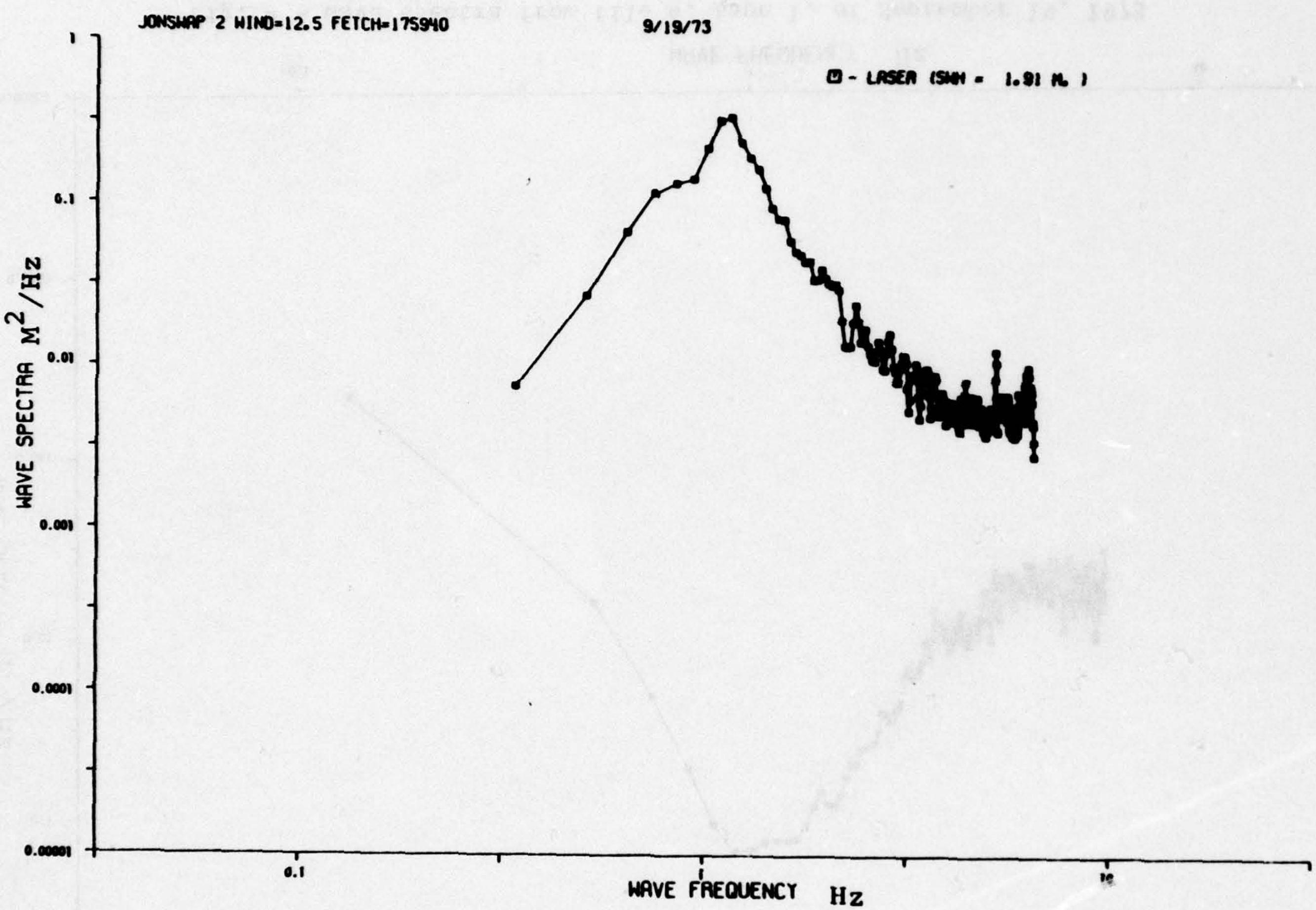


Fig. 5 - Wave spectra from file 1, tape 2, of September 19, 1973

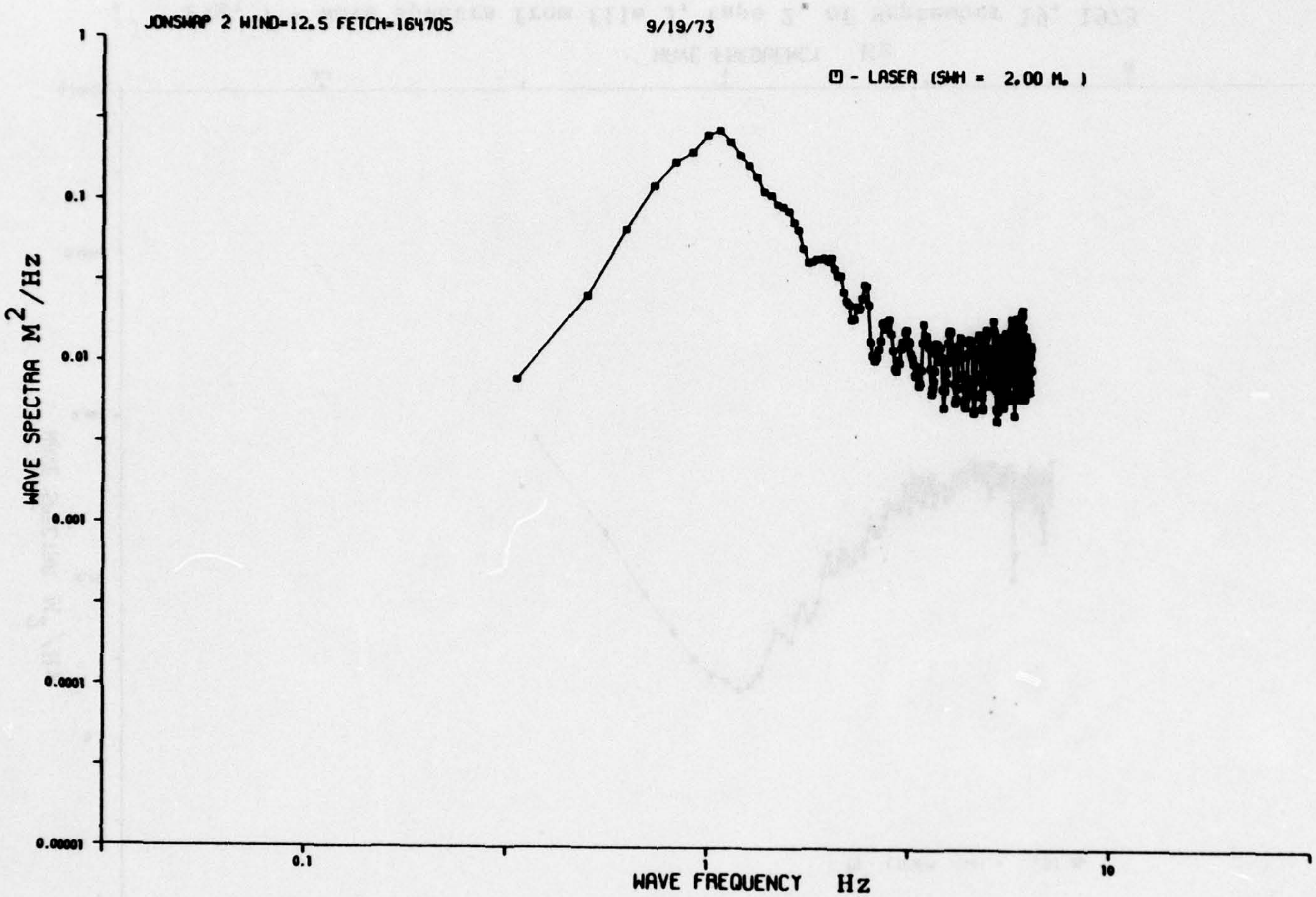


Fig. 6 - Wave spectra from file 2, tape 2, of September 19, 1973

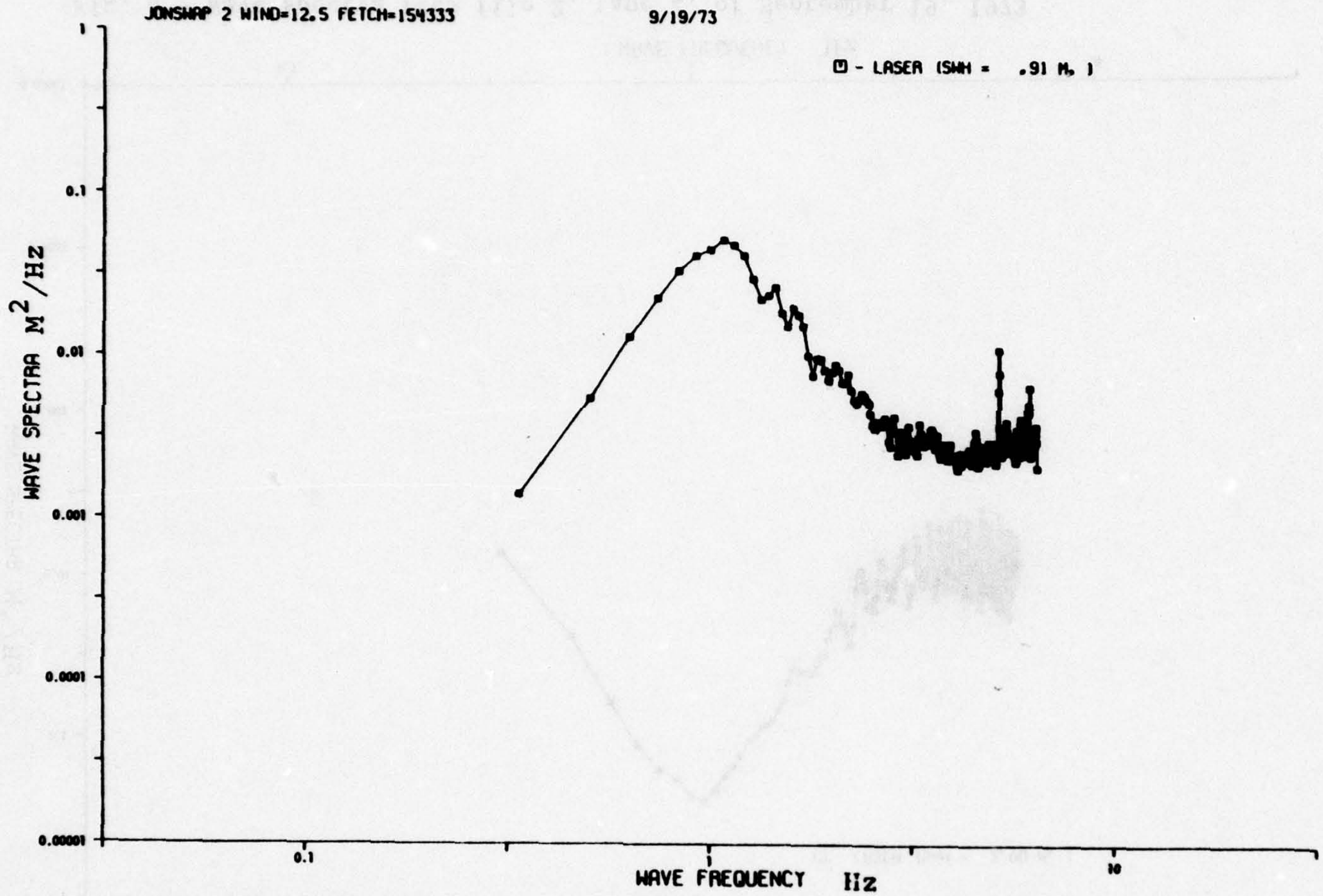
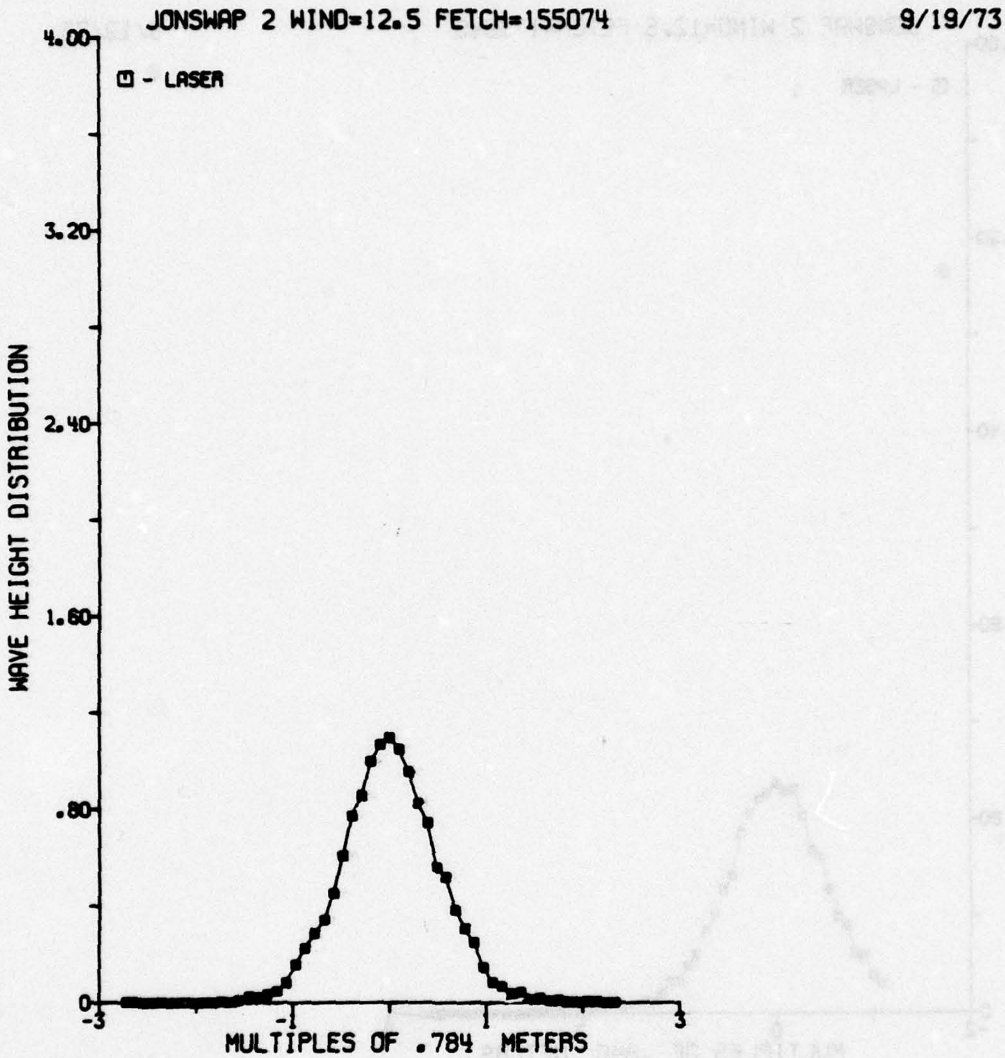
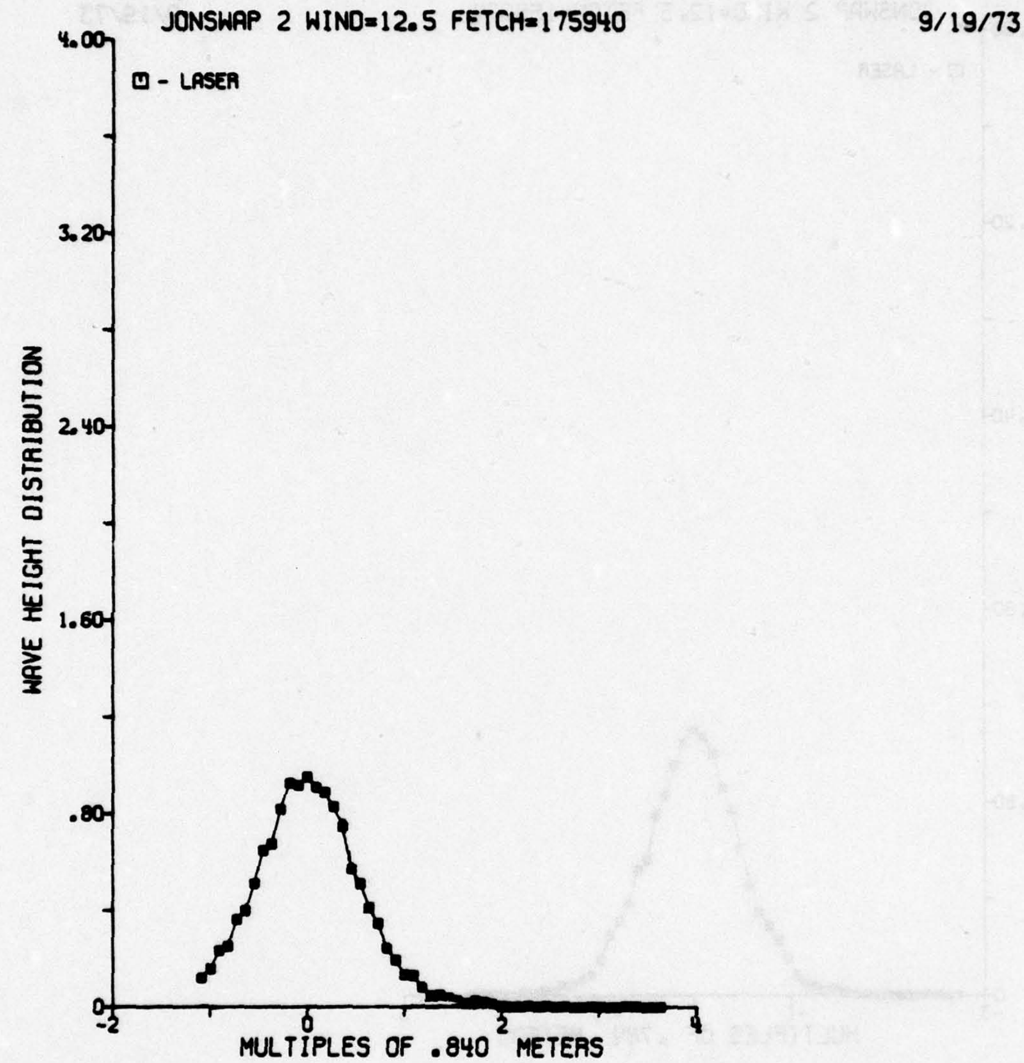


Fig. 7 - Wave spectra from file 3, tape 2, of September 19, 1973



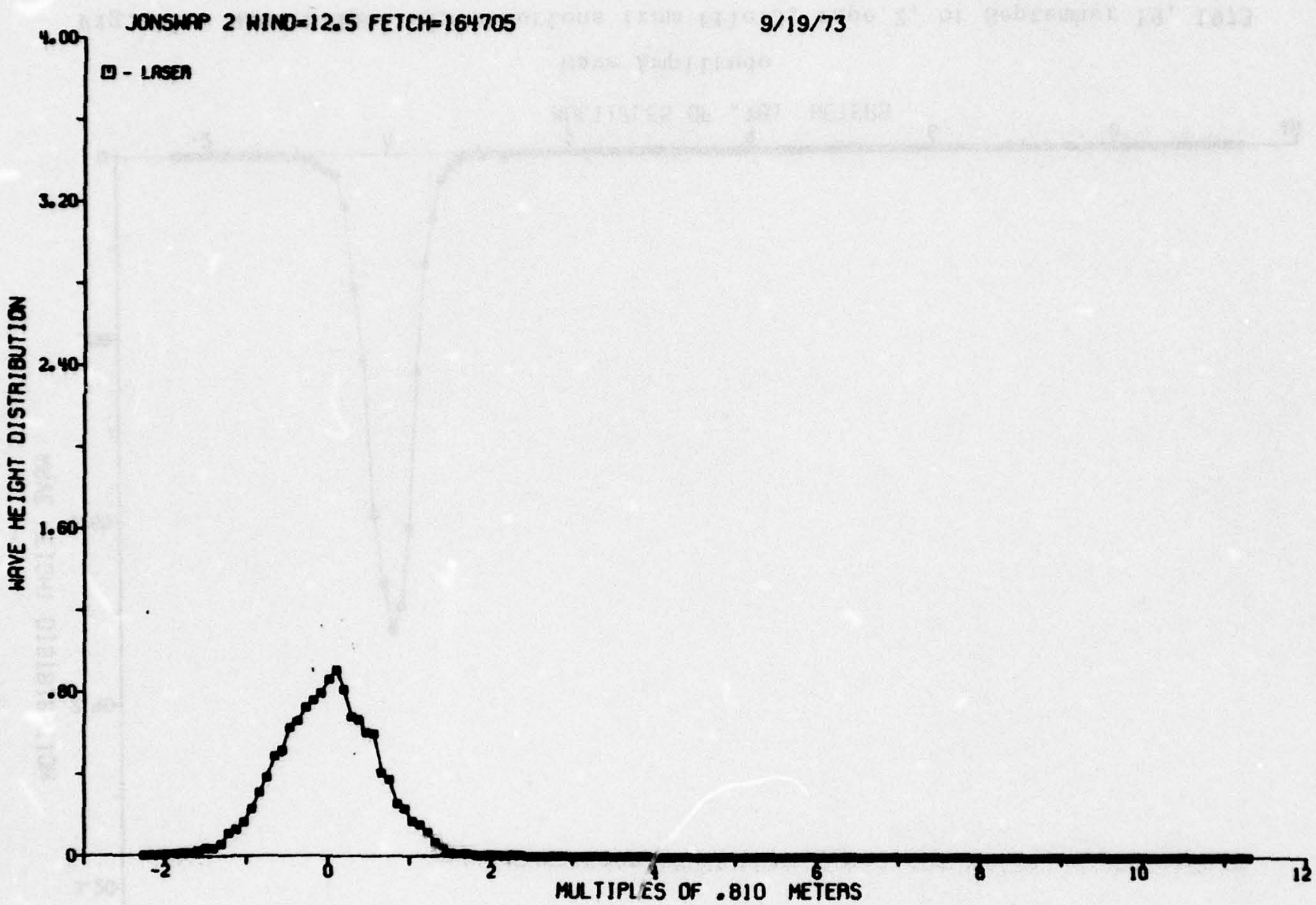
Wave Amplitude

Fig. 8 - Wave height distributions from file 4, tape 1, of September 19, 1973



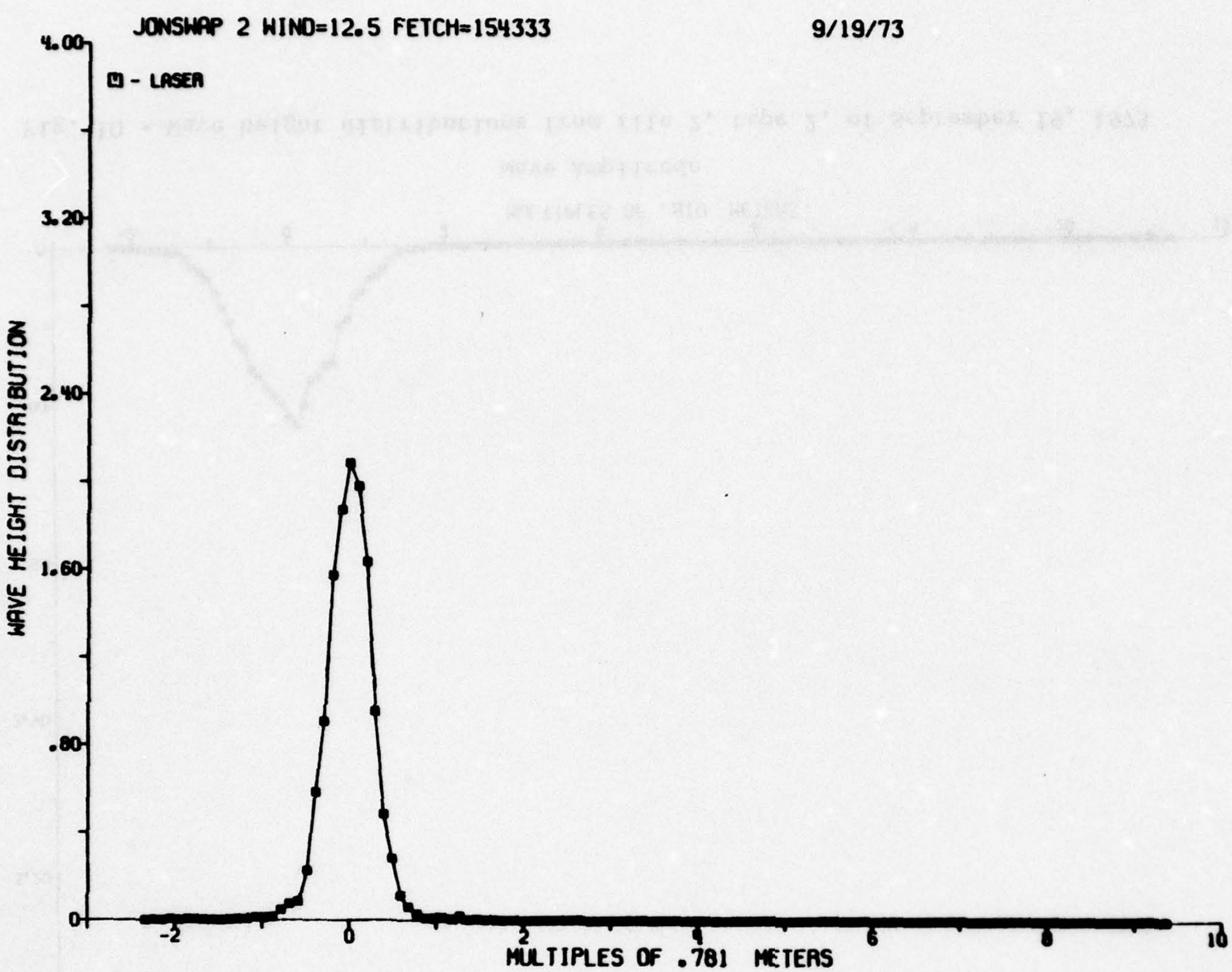
Wave Amplitude

Fig. 9 - Wave height distributions from file 1, tape 2, of September 19, 1973



Wave Amplitude

Fig. 10 - Wave height distributions from file 2, tape 2, of September 19, 1973



Wave Amplitude

Fig. 11 - Wave height distributions from file 3, tape 2, of September 19, 1973

3.36, and 4.02 Hz shown by Figures 4, 5, 6, and 7, respectively. These are unusually high noise levels at low ranges of frequencies which are the indications of highly noisy and undesireable laser signals. The spectral estimates which appear to be lower than laser noise levels in values at the low frequency are caused by the high pass filter.

The slopes at the high wave frequency ends of the wave spectra show a range of values from -3.25 to -4.71 in Figures 4 to 7. Some mechanisms other than the wave-breaking mechanism suggested by Phillips (1958) and Kitaigorodskii (1961) must have been in control of the physical processes as well at these high wave frequency ends. For otherwise the slope at the high wave frequency end should show a value of 5 if the wave-breaking mechanism were the only one which controls the growth of these waves. However, due to the lack of strong current gradients in the area as indicated by the in-situ measurements there might be some mechanisms other than wave-current interaction which were responsible for the variations of slope values at the high wave frequency ends from the expected value of $^{-}5$.

Nevertheless, the wave height distributions shown in Figures 8 to 11 display the characteristics of Gaussian distribution. The values shown beyond 2.1 M, 2.03 M, and 1.95 M in Figures 9, 10, and 11, respectively are due to the drops of bits in the recording tapes which are not the results of the real physical processes in the ocean.

The remotely sensed significant wave heights (SWH's), which are also shown in Figures 4 to 7 and are defined as four times the variances of the wave spectra (Neumann and Pierson, 1966), agree well with those from visual estimates (Walsh, private communications).

IV. CONCLUSION

As stated by Hasselmann, et al. (1973) for waves generated by offshore wind at the site of JONSWAP II, the assumption of deep water is valid only for wind speeds below 25 M/sec and the assumption of homogeneous wave field in the direction parallel to the shoreline is valid only when the angle between the shoreline and wind direction is less than 30 degrees. Both these assumptions are valid for the wind conditions on September 19, upon which the theoretical analyses were based.

However, due to the lack of strong current gradients in the area where the experiment was performed, no appropriate investigation can be done on the feasibility of inferring currents by employing the technique proposed by Huang, et al. (1972). Nevertheless, this proposed technique has been worked out in detail and is included in this report as Appendix A. An area, with known strong shear current, such as the western boundary of the Gulf Stream is desireable to be established as the test site for inferring currents by employing this particular technique.

The remotely sensed significant wave heights (SWHs) agree well with what would be expected for SWHs at those particular areas in the North Sea at the time of the experiments.

ACKNOWLEDGEMENTS

The author would like to give special thanks to Mr. J. T. McGoogan and Mr. H. R. Stanley of NASA Wallops Flight Center, Wallops Island, Virginia for encouragement in this study. Messrs. E. A. Uliana, D. L. Hammond, and K. J. Craig of the Naval Research Laboratory recorded the laser profilometer data, and their efforts and help are highly appreciated. Dr. E. J. Walsh provided Figures 1-3 of this report. His generosity deserves special appreciation. Thanks are also due to Mrs. Carolyn Eden and Miss Marie Spangler for their typing and editing and to Mrs. Jean Ware for her drawing.

The author would also like to thank NASA Wallops Flight Center for their financial support under the SR&T Program Contract No. P45823G to the Naval Research Laboratory.

REFERENCES

Chen, D. T., The Directional Fetch-Limited Spectra for Wind-Generated Waves, Ph.D. Thesis, North Carolina State University, 1972.

Hasselmann, K., Barnett, T. P., Bouws, E., Carlson, H., Cartwright, D. E., Enke, K., Ewing, J. A., Gienapp, H., Hasselmann, D. E., Kruseman, P., Meerburg, A., Muller, P., Olbers, D. J., Richter, K., Sell, W., and Walden, H., Measurements of Wind-Wave Growth and Swell Decay During the Joint North Sea Wave Project, Deutsches Hydrographisches Institut, Hamburg, 1973.

Huang, N. E., Chen, D. T., Tung, C. C., and Smith, J. R., Interactions Between Steady Non-Uniform Currents and Gravity Waves with Applications for Current Measurements, J. Physical Oceanography, Vol. 2, No. 4, pages 420-431, 1972.

Huang, N. E., Ocean Dynamics Studies, NASA CR137467, page 180, Wallops Island, Virginia 23337, 1974.

Kitaigorodskii, S. A., Applications of the Theory of Similarity to the Analysis of Wind-Generated Motion as a Stochastic Process, Bull. (Izv) Acad. Sci. USSR, Geophys. Ser. No. 1, 105-117, 1961.

Martin, M. A., Frequency Domain Applications in Data Processing, General Electric Co. Document No. 575D340, 128 p., 1957.

Neumann, G., and Pierson, W.J., Jr. Principles of Physical Oceanography, Prentice-Hall, Inc., Englewood Cliffs, N.J. 1966.

Phillips, O. M., The Equiblibrium Range in the Spectrum of Wind-Generated Ocean Waves, J. Fluid Mech., Vol. 4, pages 426-434, 1958.

Walsh, E. J., Private Communication, Directorate of Applied Science, NASA Wallops Flight Center, Wallops Island, Virginia 23337.

APPENDIX A

NUMERICAL EVALUATION OF THE INTERACTIONS BETWEEN STEADY NON-UNIFORM CURRENTS AND FETCH-LIMITED WIND-GENERATED GRAVITY WAVES

A1. THEORY

a. Theoretical Background

Let n be the total wave frequency, g be the gravitational acceleration, U be the current speed, and the function

$$R(n) = (1 + 4Un/g)^{1/2} \quad . \tag{1}$$

Huang, et al. (1972) have shown that, under the influence of a steady non-uniform current, the wave frequency spectrum, $\phi(n)$, for random gravity waves in deep water and under steady wind conditions is given by

$$\phi(n) = \frac{4\phi_o(n)}{[1 + R(n)]\ [R(n) + (R(n))^2]} \tag{2}$$

where $\phi_o(n)$ is the wave frequency spectrum without the influence of the current. Because of the special locality of JONSWAP II, $\phi_o(n)$ is chosen to be the fetch-limited wave frequency spectrum for wind-generated waves as proposed by Hasselmann, et al. (1973). More detailed information on this wave spectrum will be presented later in this section.

From Equation (2), the standard deviation, σ, of wave amplitude, η, measured from mean sea level, can be evaluated as

$$\sigma^2 = \int_o^{n_c} \phi(n)dn \tag{3}$$

in which n_c is the cutoff wave frequency of the wave frequency spectrum taken as that of a wave with wave length of 30 cm. Thus, from Equations (2) and (3), the influence of a steady non-uniform current on the standard deviation, σ, is known.

Subsequently, as done by Huang (1974), it is possible to evaluate the probability density function, $p(\eta)$, of wave amplitude, η, of the form

$$p(\eta) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{1}{2}\frac{\eta^2}{\sigma^2}\right) , \tag{4}$$

for different currents and wind speeds.

b. Wave Frequency Spectrum

Hasselmann, et al. (1973) have proposed a one-dimensional fetch-limited wave frequency spectrum for wind-generated waves from the results of their studies in JONSWAP I which were conducted at the same site as that of JONSWAP II. This wave frequency spectrum, $\phi_o(n)$, has the form of

$$\phi_o(n) = \frac{Kg^2}{n^5} \exp\left[-1.25\,(n_m/n)^4\right] G(n) \tag{5}$$

where n_m is the wave frequency at the peak of the spectrum, K is a parameter, and G(n) is a shape function which is defined as

$$G(n) = \gamma^{\exp\left[-(n - n_m)^2/2\xi^2 n_m^2\right]} \tag{6}$$

These four parameters, n_m, K, γ and ξ in Equations (5) and (6) are determined by the technique of simultaneously optimizing all four parameters. They are evaluated as

$$n_m = 21.99\,(g/W)\,(gF/W^2)^{-0.33} , \tag{7}$$

$$K = 0.4775\,(gF/W^2)^{-0.22} , \tag{8}$$

$$\gamma = 3.3 \quad , \tag{9}$$

and

$$\xi = \begin{cases} 0.07 & \text{for } n \text{ in } (o,\ n_m) \\ 0.09 & \text{for } n \text{ in } (n_m,\ \infty) \end{cases} \tag{10}$$

where F is the fetch in meters and W is the wind speed, in m/sec, measured at 10 meters above the mean sea level. The value of n_m given by Equation (7) is very close to the value calculated for n_m by Chen (1972).

Let β be the equilibrium coefficient as defined by Phillips (1958), then, from Equations (5), (6), (7), (8) and (9)

$$\beta = 0.4775 \left(\frac{gF}{W^2}\right)^{-0.22} \cdot 3.3^{\exp\left\{ - \left[\frac{nW}{g} \left(\frac{gF}{W^2}\right)^{0.33} - 21.99 \right] / 967.22\xi^2 \right\}} \tag{11}$$

One can notice, from Equation (11), that β is not only a function of the dimensionless fetch parameter gF/W^2 but also it is a function of the dimensionless wave frequency parameter nW/g. For fixed values of W and F, as the value of n increases the value of β approaches a limit which can be expressed as

$$\beta_{n \to \infty} = 0.4775\ (gF/W^2)^{-0.22} \tag{11}$$

A2. NUMERICAL RESULTS

Theoretically, wave spectra and wave height distribution functions for wave interacting with various steady non-uniform currents can be evaluated for the locations at which the four files were taken on September 19. With the use of Equations (2) and (5), wave spectra can be evaluated by considering wave spectra in the form of Equation (5) as the wave spectra of waves without the influence of currents. By the same token wave height distribution functions can be evaluated by using Equations (4) and (5). Figures A-1, A-2, A-3 and A-4 show the theoretical wave spectra of waves interacting with currents at the locations where File 4 of Tape 1, and Files 1, 2, and 3 of Tape 2 were taken, respectively. The vertical coordinates are presented in logarithmic scale and in the unit of m^2/Hz and the horizontal coordinates are presented, also, in logarithmic scale and in the unit of Hz. As shown on the top of these figures, the currents' speeds for the curves from the top down are -2, -1.5, -1, -0.5, 0, 0.5, 1, 2, 3, and 5 m/sec in an increasing order. Figures A-5, A-6, A-7, and A-8 are the theoretical wave height distribution functions of waves interacting with currents at the locations where File 4 of Tape 1, and Files 1, 2, and 3 of Tape 2 were taken. The current speeds for the curves from the top down along the vertical axes are -2, -1.5, -1, -0.5, 0, 0.5, 1, 2, 3, and 5 m/sec. The computer program used to compute for Figures A-1 to A-8 is included in this report as Appendix B.

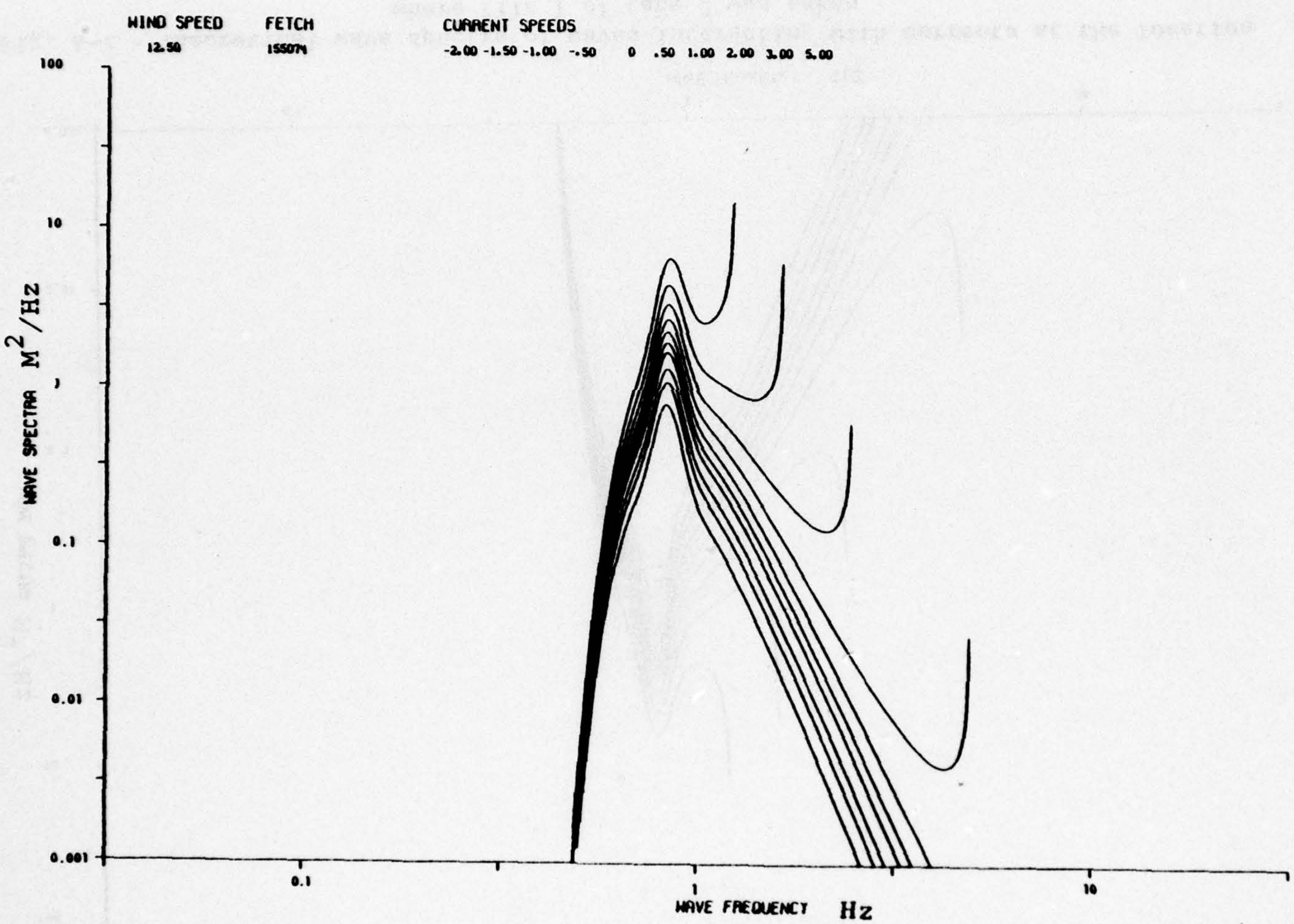


Fig. A-1 - Theoretical wave spectra of waves interacting with currents at the location where file 4 of tape 1 was taken

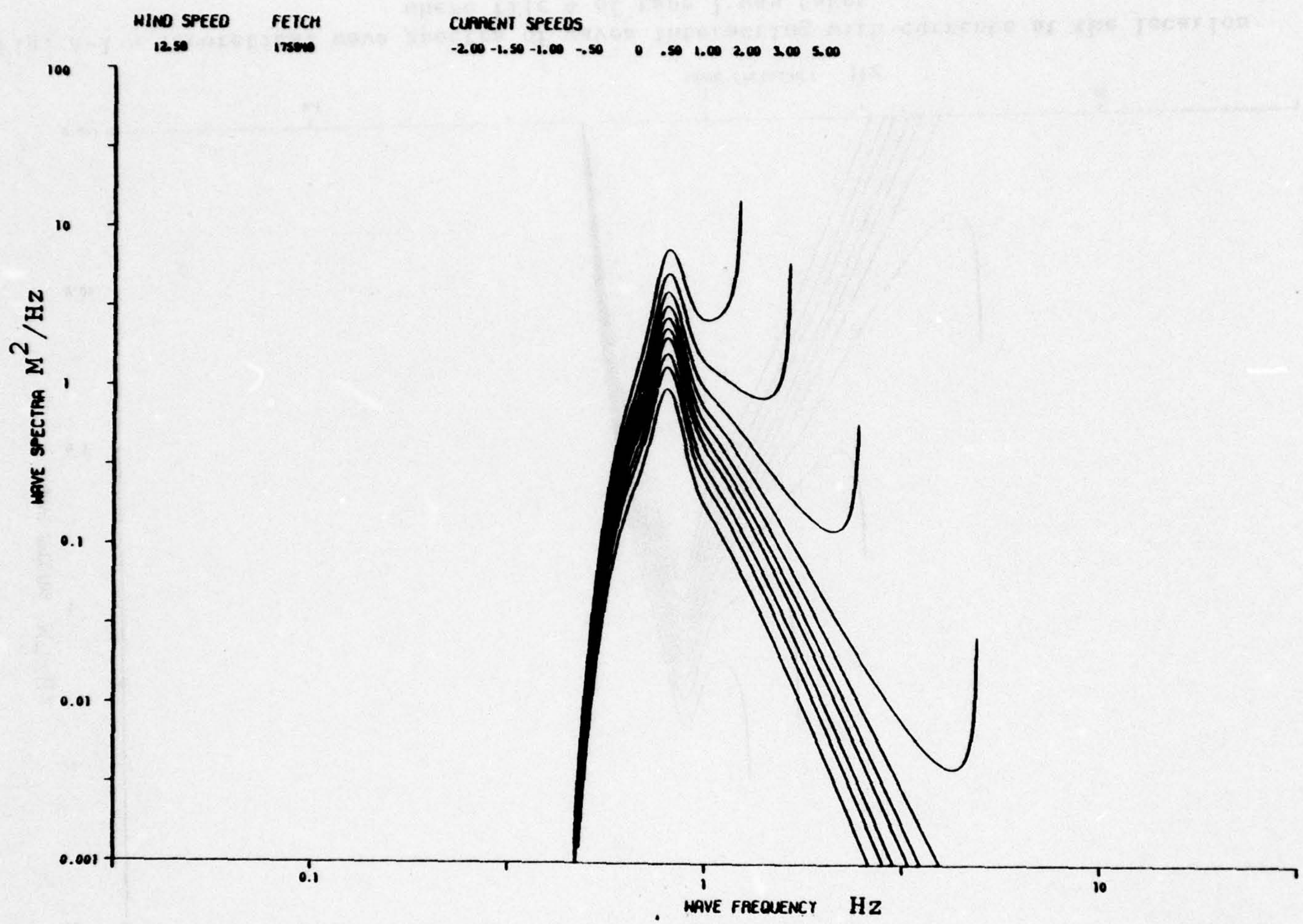


Fig. A-2 - Theoretical wave spectra of waves interacting with currents at the location where file 1 of tape 2 was taken

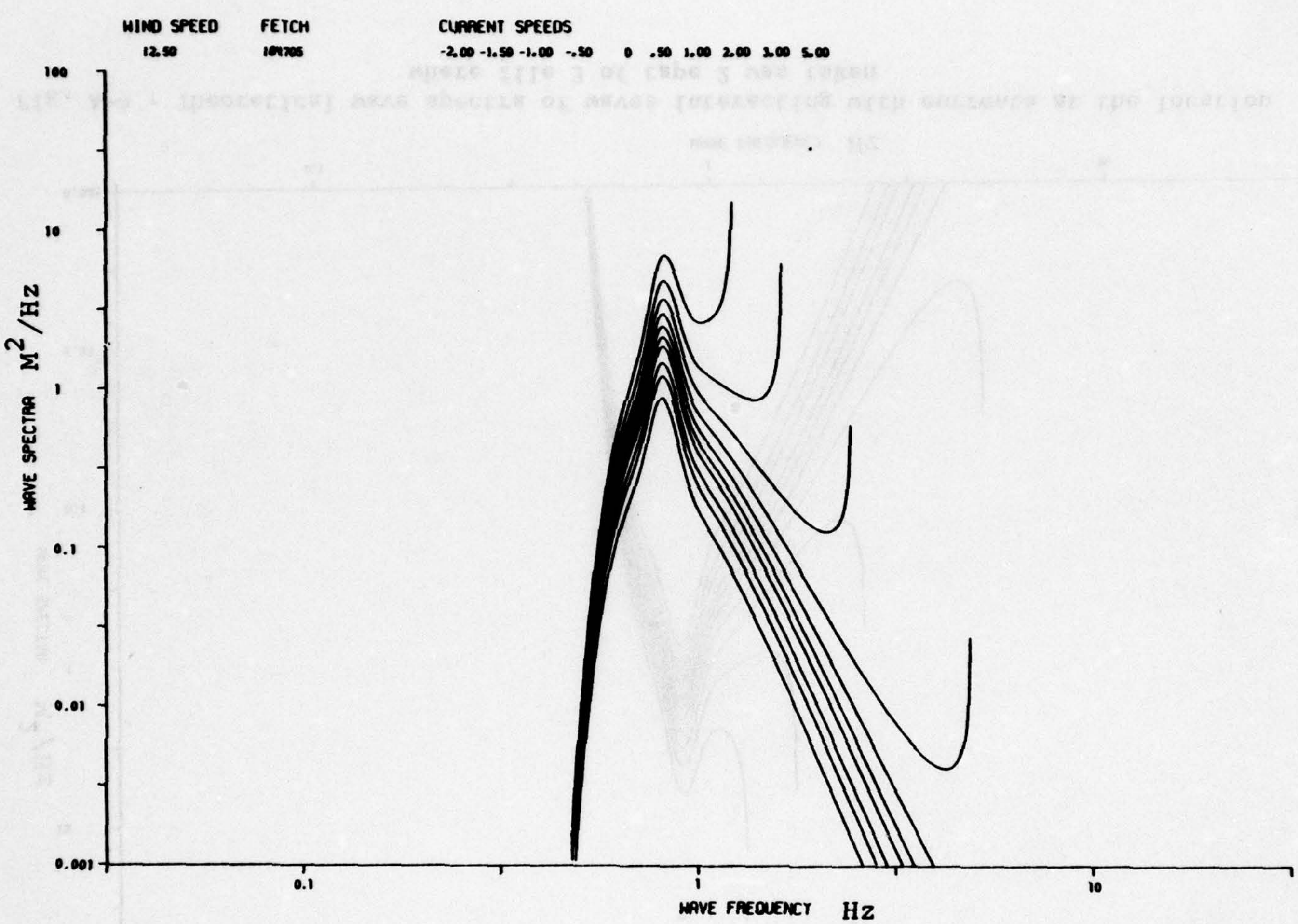


Fig. A-3 - Theoretical wave spectra of waves interacting with currents at the location where file 2 of tape 2 was taken

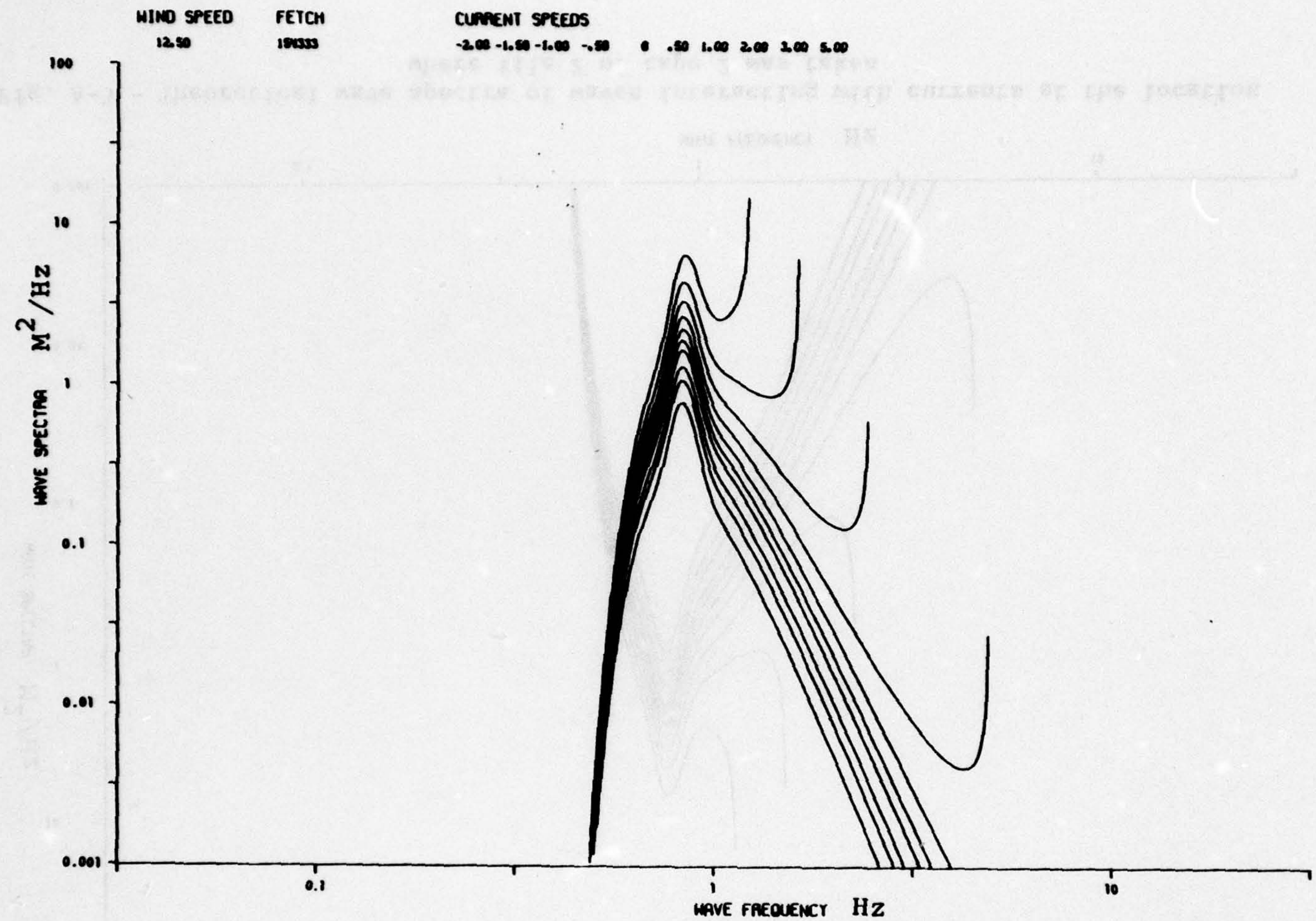
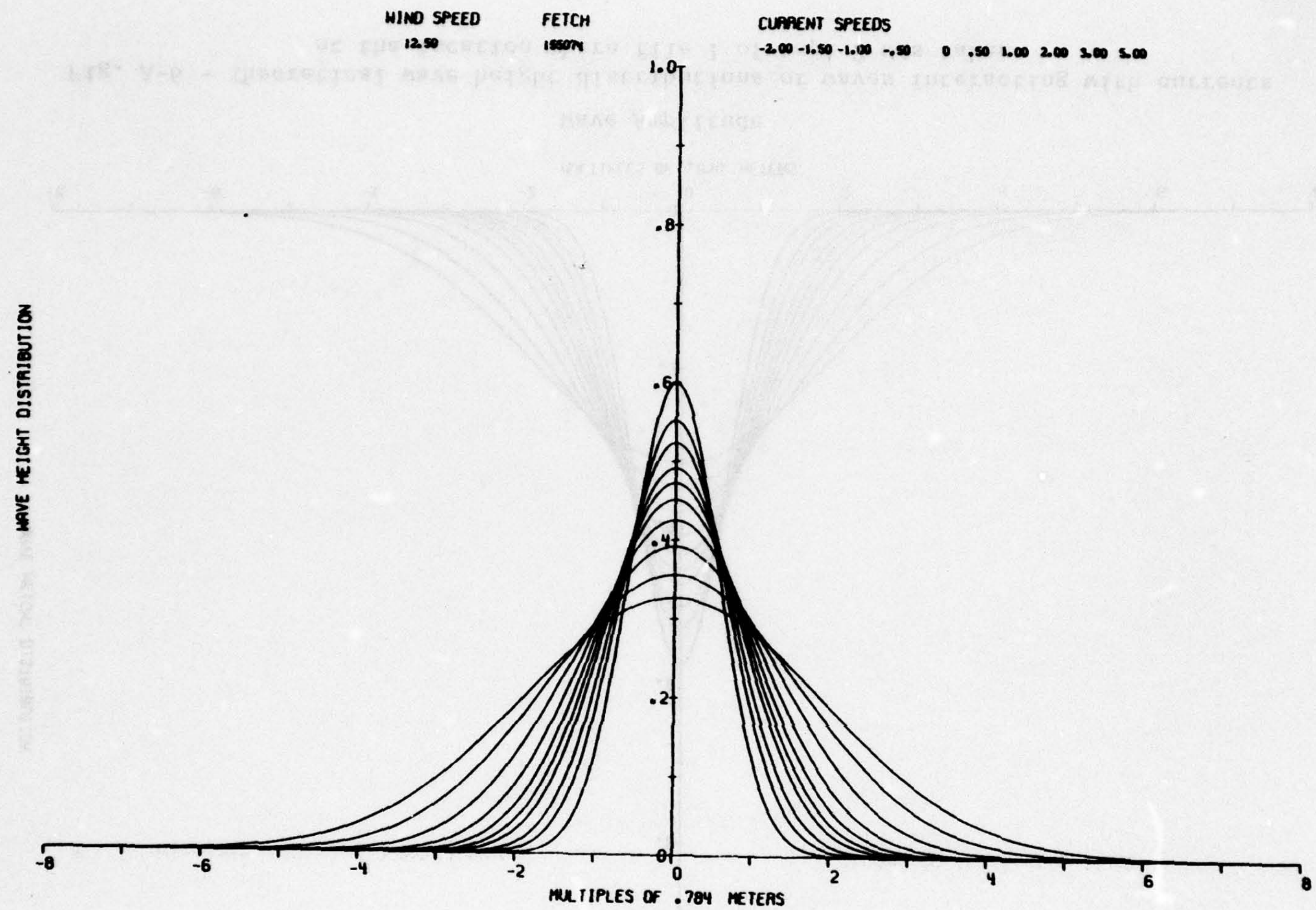
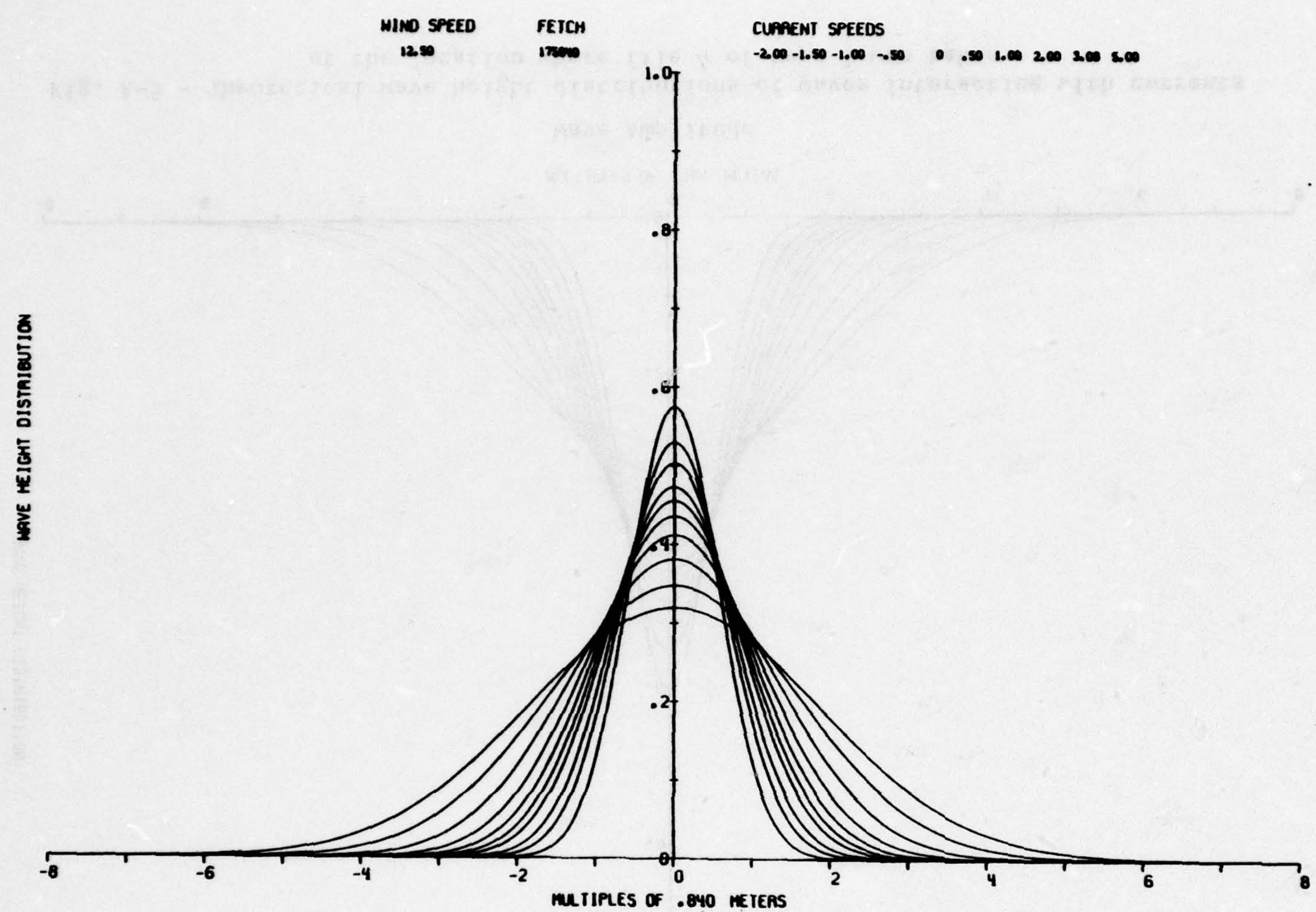


Fig. A-4 - Theoretical wave spectra of waves interacting with currents at the location where file 3 of tape 2 was taken



Wave Amplitude

Fig. A-5 - Theoretical wave height distributions of waves interacting with currents at the location where file 4 of tape 1 was taken



Wave Amplitude

Fig. A-6 - Theoretical wave height distributions of waves interacting with currents at the location where file 1 of tape 2 was taken

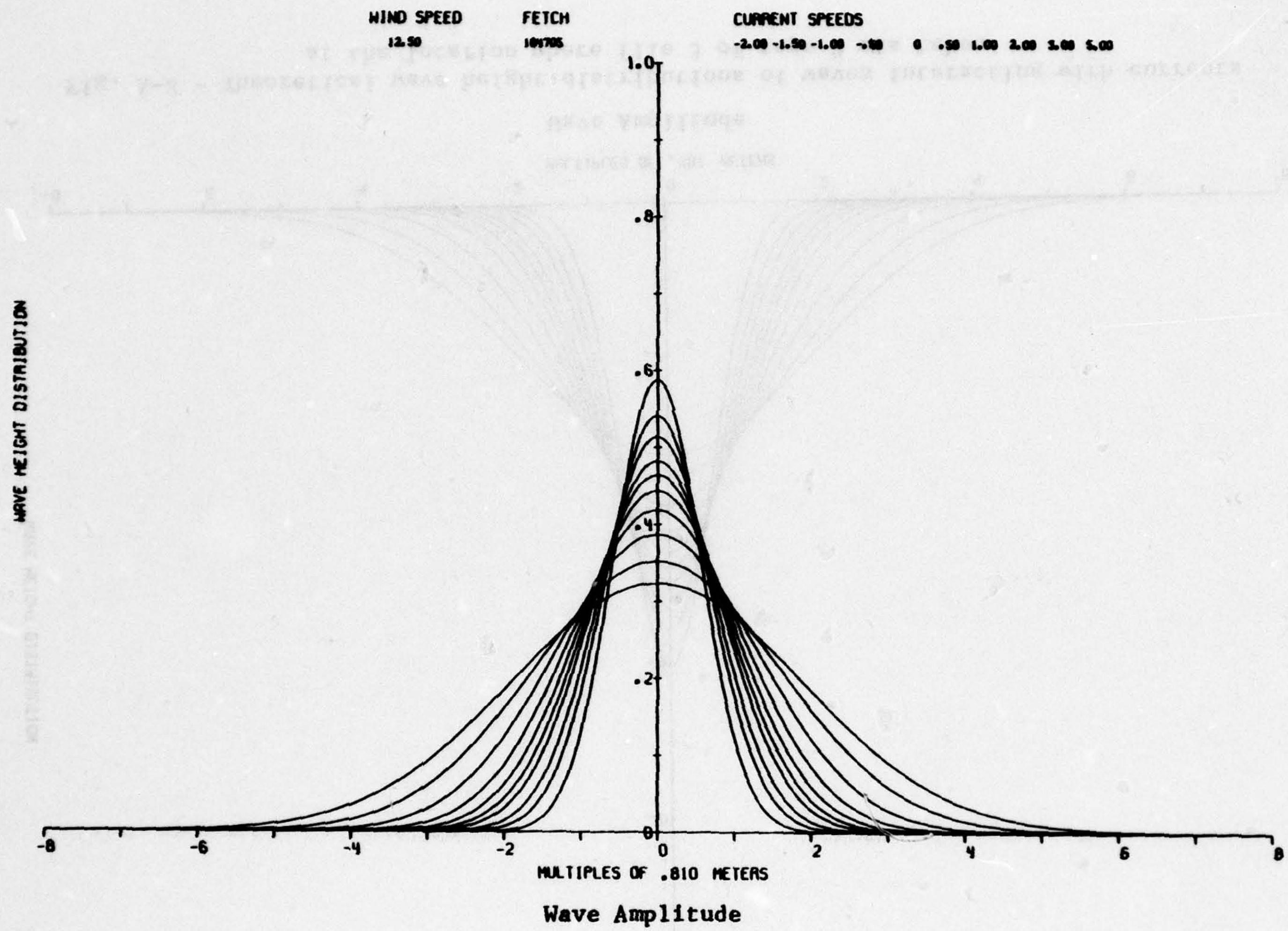


Fig. A-7 - Theoretical wave height distributions of waves interacting with currents at the location where file 2 of tape 2 was taken

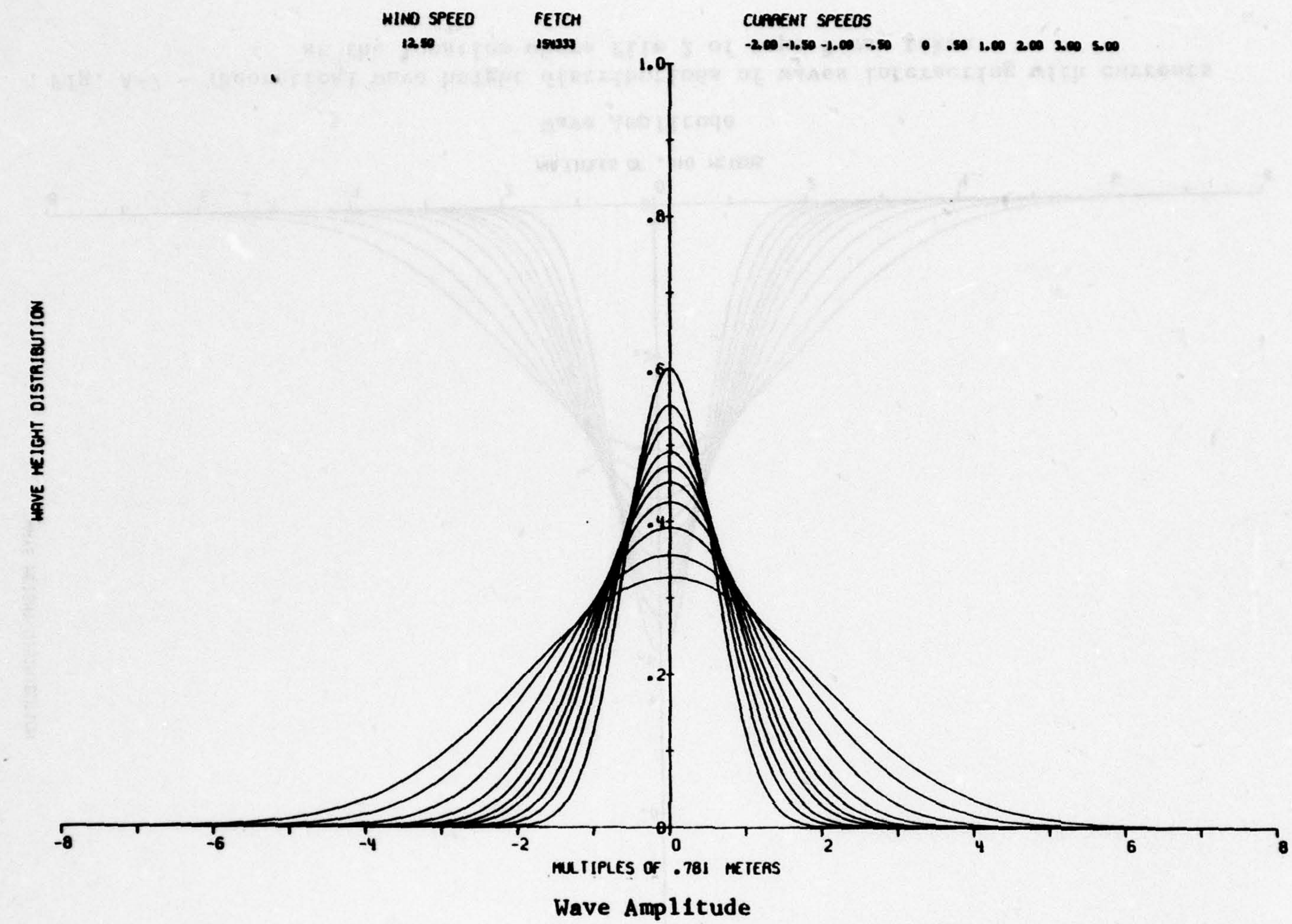


Fig. A-8 - Theoretical wave height distributions of waves interacting with currents at the location where file 3 of tape 2 was taken

APPENDIX B

COMPUTER PROGRAM

```
      PROGRAM HECK
      BETA   = EQUILIBRIUM COEFFICIENT
      CUTF   = CUT-OFF WAVE FREQUENCY
      DELTAN= INCREMENT FOR WAVE FREQUENCY
      DFP    = DIMENSIONLESS FETCH PARAMETER
      F(I,J)= J TH FETCH VALUE FOR I TH WIND SPEED
      FREQ   = TOTAL WAVE FREQUENCY
      FREQM  = PEAK WAVE FREQUENCY FOR FIXED WIND SPEED AND
               FETCH
      GA     = GRAVITATIONAL ACCELERATION
      NF(I)  = NUMBER OF FETCHES FOR EACH WIND SPEED
      NLPHIC(L)= LIMIT OF THE NUMBER OF INTEGER INCREMENTS
               FOR PHIC(L,K)
      NU     = NUMBER OF CURRENTS
      NW     = NUMBER OF WIND SPEEDS
      NWF    = NUMBER OF WAVE FREQUENCIES
      PHIC(L,K)= WAVE FREQUENCY SPECTRUM WITH THE INFLUENCE
               OF CURRENT, L TH CURRENT AND K TH WAVE
               FREQUENCY
      PX(I)  = X-ARRAY FOR PLOT
      PY(I)  = Y-ARRAY FOR PLOT
      SIGMA(L)= STANDARD DEVIATION FOR WAVE ELEVATION FOR L
               TH CURRENT
      SIGMA(NUE)= STANDARD DEVIATION FOR WAVE ELEVATION FOR
               NO CURRENT
      SIGNOT= STARTING VALUE FOR PX ARRAY
      TITLE(I)= DESCRIPTION OF THE DATA CARDS
      U(I)   = CURRENTS
      W(I)      = WIND SPEEDS
      X(I)   = X-COORDINATE OF THE SYMBOLS FOR CURRENTS
      Y(I)   = Y-COORDINATE OF THE SYMBOLS FOR CURRENTS
      COMMON     W(11),NF(20),F(11,20),U(13),PHIC(13,1500),
     1NLPHIC(13),SIGMA(13),X(13),Y(13),PX(321),PY(321),
     2TITLE(18),PLX(321),PLY(321),PLZ( 254),XS(13),YS(13)
      INTRINSIC CONSTANTS
      PAUSE 1
      GA=9.8
      GA2=GA**2
      GAMA=3.3
      ETAA=0.07**2
      ETAB=0.09**2
      PAI=3.14159
      TWOPAI = 2.*PAI
      DELTAN=0.01
      DELTDF = 0.05
      CUTF=14.3
      NWF=CUTF/DELTAN
      TLOG=LOGF(10.)
      FMAX = 15.
      FMAY = 10.
      FDMAX = 16.
      FMID = FMAX/2.
      FDMID = FDMAX/2.
      FMIDY = FMAY/2.
      XSLEFT = -1.5
      XSRIGHT = 1.5
      YSTOP = 2.
      YSBOTTOM = -3.
      YSANUR = YSBOTTOM*TLOG
      ANUR = EXPF(YSANUR)
      XSCALF = (XSRIGHT-XSLEFT)/FMAX
      YSCALF = (YSTOP-YSBOTTOM)/FMAY
      XDLEFT = -8.
      XDRIGHT = 8.
      YDTOP = 1.
      XDCALE = (XDRIGHT-XDLEFT)/FDMAX
      YDCALE = YDTOP/FMAY
      CALL PLOTS(PLZ, 254,3)
      CALL PLOT(1.,2.5,-3)
      XSNOT=3.75
      DO 10 I=1,13
      XSNOT=XSNOT+0.5
      XS(I)=XSNOT
      YS(I) = FMAY+0.2
   10 CONTINUE
      XNOT=0.5
      DO 30 I=1,13
      XNOT=XNOT+0.5
      X(I)=XNOT
      Y(I) = FMAY+0.2
   30 CONTINUE
      READ-IN INFORMATION
      PRINT 500
      READ   506, (TITLE(I),I=1,18)
      READ   501, NW,(W(I),I=1,NW)
      READ   506, (TITLE(I),I=1,18)
      READ 502,(NF(I),I=1,NW)
      READ 506,(TITLE(I),I=1,18)
      DO 50    I = 1,NW
      NFN = NF(I)
      READ 507,    (F(I,J),J=1,NFN)
   50 CONTINUE
      DO 60    I = 1,NW
      PRINT 503,    W(I)
      NFN = NF(I)
      PRINT 508,    (F(I,J),J=1,NFN)
   60 CONTINUE
      READ   506, (TITLE(I),I=1,18)
      READ   501, NU,(U(I),I=1,NU)
      PRINT 504
      NUE=NU+1
      U(NUE)=0.00
      LOOP 450 - FOR DIFFERENT VALUES OF WIND SPEED
      DO 450 I = 1,NW
      W2=W(I)*W(I)
      FREQM1=21.99*GA/W(I)
      LOOP 440 - FOR DIFFERENT VALUES OF FETCH
      NFV=NF(I)
      DO 440 J = 1,NFV
      DFP=GA*F(I,J)/W2
      FREQM2=DFP**0.33
      FREQM=FREQM1/FREQM2
      FREQMS=FREQM**2
      BETA1=DFP**0.22
```

```
      BETA2=0.4775/BETA1
      LOOP 109 - FOR DIFFERENT VALUES OF TOTAL WAVE FREQUENCY.
              CUT-OFF WAVE FREQUENCY IS 14.30 RADIANS/SEC
      FREQ=0.
      CALCULATE WAVE FREQUENCY SPECTRUM WITHOUT THE
             INFLUENCE OF CURRENT
      BETA3=2.*FREQMS
      BETA4=BETA3*ETAA
      BETA5=BETA3*ETAB
      DO 109 K = 1,NWF
      FREQ=FREQ+DELTAN
      BETA6=FREQ-FREQM
      BETA7=BETA6**2
      IF (BETA6) 100,100,101
  100 BETA8=BETA7/BETA4
      GO TO 102
  101 BETA8=BETA7/BETA5
  102 IF (BETA8-100.) 104,104,103
  103 BETA10=0.
      GO TO 105
  104 BETA9=-BETA8
      BETA10=EXPF(BETA9)
  105 BETA11=GAMA**BETA10
      BETA=BETA2*BETA11
      PHI1=BETA*GA2
      PHI2=FREQ**5
      PHI3=FREQM/FREQ
      PHI4=PHI3**4
      PHI5=1.25*PHI4
      IF (PHI5-100.) 107,107,106
  106 PHI=0.
      GO TO 108
  107 PHI6=-PHI5
      PHI7=EXPF(PHI6)
      PHI=PHI1*PHI7/PHI2
  108 PHIC(NUE,K)=PHI/TWOPAI
  109 CONTINUE
      CALCULATE WAVE FREQUENCY SPECTRA WITH THE INFLUENCE OF
             CURRENT
      LOOP 130 - FOR DIFFERENT VALUES OF CURRENT
      DO 130 L = 1,NU
      FREQ=0.
      DO 120 K = 1,NWF
      FREQ=FREQ+DELTAN
      PHIC1=4.*U(L)*FREQ/GA+1.
      IF (PHIC1) 110,110,111
  110 NLPHIC(L)=K
      PHIC(L,K)=0.
      GO TO 130
  111 PHIC2=SQRTF(PHIC1)
      PHIC3=(1.+PHIC2)*(PHIC2+PHIC1)
      PHIC(L,K)=4.*PHIC(NUE,K)/PHIC3
      NLPHIC(L)=K
  120 CONTINUE
  130 CONTINUE
      NLPHIC(NUE)=NWF
      LOOP 140 - FOR PRINTING WAVE SPECTRA WITH DIFFERENT
             CURRENT
      DO 140 L=1,NUE
      PRINT 509,  W(I),F(I,J),U(L)
      NWWF=NLPHIC(L)
      PRINT 510,  (PHIC(L,K),K=1,NWWF)
  140 CONTINUE

      PLOTS OF THE WAVE FREQUENCY SPECTRA

      DESCRIPTIONS OF THE PLOTS
      CALL PLOT(0.,15.0,-3)
      XLABLE = XSLEFT
      XA = 0.
      NXLABLE = 7
      AXLABLE = NXLABLE-1
      DXLABLE = FMAX/AXLABLE
      DO 150 IP = 1,NXLABLE
      CALL NUMBER(XA-0.25,-0.3,0.14,XLABLE,0.,4HF4.1)
      XA = XA+DXLABLE
      XLABLE=XLABLE+(XSRIGHT-XSLEFT)/AXLABLE
  150 CONTINUE
      CALL PLOT(FMAX,0.,3)
      CALL PLOT(0.,0.,2)
      XTICK = 0.
      YTICK1 = 0.
      YTICK2 = -0.1
      DO 160 IP = 1,NXLABLE
      CALL PLOT(XTICK,YTICK2,3)
      CALL PLOT(XTICK,YTICK1,2)
      XTICK=XTICK+DXLABLE
  160 CONTINUE
      CALL SYMBOL(FMID-0.7,-0.6,0.14,
     119HLOG(WAVE FREQUENCY),0.0,19)
      YLABLE = YSBOTTOM
      T = 0.
      NYLABLE = 6
      AYLABLE = NYLABLE-1
      DYLABLE = FMAY/AYLABLE
      DO 170 IP = 1,NYLABLE
      CALL NUMBER(-0.7,T-0.07,0.14,YLABLE,0.,4HF5.2)
      T = T+DYLABLE
      YLABLE=YLABLE+(YSTOP-YSBOTTOM)/AYLABLE
  170 CONTINUE
      CALL PLOT(0.,FMAY,3)
      CALL PLOT(0.,0.,2)
      XTICK1 = 0.
      XTICK2 = -0.1
      YTICK=0.
      AYLABLE1 = 2.*AYLABLE
      NAYLABLE = AYLABLE1 + 1
      DAYLABLE = FMAY/AYLABLE1
      DO 180 IP = 1,NAYLABLE
      CALL PLOT(XTICK2,YTICK,3)
      CALL PLOT(XTICK1,YTICK,2)
      YTICK=YTICK+DAYLABLE
  180 CONTINUE
      CALL SYMBOL(-0.90,FMIDY-1.,0.14,
```

```
    118HLOG(WAVE SPECTRA) ,90.0.18)
    CALL SYMBOL(0.25.FMAY+0.5.0.14.10HWIND SPEED.0.0.10)
    CALL SYMBOL(2.0.FMAY+0.5.0.14.5HFETCH.0.0.5)
    CALL SYMBOL(4.25.FMAY+0.5.0.14.14HCURRENT SPEEDS.
   10.,14)
    CALL NUMBER(0.4.FMAY+0.2.0.10.W(I).0.0.4HF6.2)
    FETCH=F(I.J)
    CALL NUMBER(1.75.FMAY+0.2.0.10.FETCH.0.0.4HF9.0)
    ICOUNT = 0
    XPU = XS(1)
    YPU = YS(1)
    UPU = U(1)
    AUPU = ABSF(UPU)
    TUPU = UPU+AUPU
    CALL NUMBER(XPU.YPU.0.10.UPU.0.0.4HF5.2)
    IF (TUPU) 190.190.230
190 DO 200 IP = 2.NUE
    ICOUNT = ICOUNT+1
    XPU=XS(IP)
    YPU=YS(IP)
    UPU=U(IP)
    AUPU = ABSF(UPU)
    TUPU = UPU+AUPU
    IF (TUPU) 195.195.210
195 CALL NUMBER(XPU.YPU.0.10.UPU.0.0.4HF5.2)
200 CONTINUE
    GO TO 255
210 UPU = U(NUE)
    CALL NUMBER(XPU.YPU.0.10.UPU.0..4HF5.2)
    DO 220 IC = IP.NU
    ICP = IC+1
    XPU = XS(ICP)
    YPU = YS(ICP)
    UPU = U(IC)
220 CALL NUMBER(XPU.YPU.0.10.UPU.0.0.4HF5.2)
    GO TO 255
230 DO 240 IP = 2.NUE
    XPU = XS(IP)
    YPU = YS(IP)
    UPU = U(IP)
    AUPU = ABSF(UPU)
    TUPU = UPU+AUPU
    IF (TUPU) 250.250.235
235 CALL NUMBER(XPU.YPU.0.10.UPU.0.0.4HF5.2)
240 CONTINUE
    GO TO 255
250 UPU = U(NUE)
    CALL NUMBER(XPU.YPU.0.10.UPU.0.0.4HF5.2)
    DO 251 IC = IP.NU
    ICP = IC+1
    XPU = XS(ICP)
    YPU = YS(ICP)
    UPU = U(IC)
251 CALL NUMBER(XPU.YPU.0.10.UPU.0.0.4HF5.2)
    GENERATE FUNCTIONS AND PLOT
    LOOP 290 - FOR DIFFERENT CURRENT
255 DO 290 M = 1.NUE
    NPWF=NLPHIC(M)
    LOOP 260 - FOR SCALING AND STARTING POINT
    FREQ=0.
    INDIC=0
    DO 260 MM = 1.NPWF
    INDIC=INDIC+1
    FREQ=FREQ+DELTAN
    XPL1=LOGF(FREQ)/TLOG-XSLEFT
    XPL = XPL1/XSCALE
    YPL1=PHIC(M.MM)
    CHECK=YPL1-ANUR
    IF (CHECK) 260.260.270
260 CONTINUE
270 YPL2=LOGF(YPL1)/TLOG-YSBOTTOM
    YPL = YPL2/YSCALE
    CALL PLOT(XPL.YPL.3)
    LOOP 280 - FOR SCALING AND PLOTTING
    INDIC1=INDIC+1
    DO 280 MM = INDIC1.NPWF
    FREQ=FREQ+DELTAN
    XPL1=LOGF(FREQ)/TLOG-XSLEFT
    XPL = XPL1/XSCALE
    YPL1=PHIC(M.MM)
    CHECK=YPL1-ANUR
    IF (CHECK) 290.290.275
275 YPL2=LOGF(YPL1)/TLOG-YSBOTTOM
    YPL = YPL2/YSCALE
    CALL PLOT(XPL.YPL.2)
280 CONTINUE
290 CONTINUE
    CALL PLOT(-XOLEFT.-15..-3)
    INTEGRATION OF THE WAVE FREQUENCY SPECTRA FOR THE
            STANDARD DEVIATION SIGMA FOR WAVE ELEVATION
    LOOP 310 - FOR DIFFERENT VALUES OF CURRENT
    DO 310 M = 1.NUE
    MMK=NLPHIC(M)
    MML=MMK+1
    PHIC(M.MML)=0.
    LOOP 300 - INTEGRATION FOR FIXED VALUE OF CURRENT
    SUM=0.
    DO 300 MM = 2.MMK.2
    MM1=MM-1
    MM2=MM
    MM3=MM+1
    SUMIND=PHIC(M.MM1)+4.*PHIC(M.MM2)+PHIC(M.MM3)
    SUM=SUM+SUMIND
300 CONTINUE
    SIGMA1=SUM*DELTAN/3.
    SIGMA(M)=SQRTF(SIGMA1)
    PRINT 505,   W(I).F(I.J).U(M).SIGMA(M)
310 CONTINUE
    PLOTS OF THE WAVE HEIGHT DISTRIBUTION FUNCTIONS
    DESCRIPTIONS OF THE PLOTS
```

```
      XLABLE = XDLEFT
      XA = -FDMID
      NDXLABLE = 9
      ADXLABLE = NDXLABLE-1
      DDXLABLE = FDMAX/ADXLABLE
      DO 320 IP = 1,NDXLABLE
      CALL NUMBER(XA-0.2,-0.3,0.14,XLABLE,0.,4HF3.0)
      XA = XA+DDXLABLE
      XLABLE=XLABLE+(XDRIGHT-XDLEFT)/ADXLABLE
  320 CONTINUE
      CALL PLOT( FDMID,0.0,3)
      CALL PLOT(-FDMID,0.0,2)
      XTICK = -FDMID
      YTICK1 = 0.
      YTICK2 = -0.1
      AXLABLE1 = 2.*ADXLABLE
      NDXLABLE = AXLABLE1+1
      DDXLABLE = FDMAX/AXLABLE1
      DO 330 IP = 1,NDXLABLE
      CALL PLOT(XTICK,YTICK2,3)
      CALL PLOT(XTICK,YTICK1,2)
      XTICK=XTICK+DDXLABLE
  330 CONTINUE
      CALL SYMBOL(-1.53,-0.60,0.14,
     125HMULTIPLES OF         METERS,0.0,25)
      CALL NUMBER(0.08,-0.6,0.14,SIGMA(NUE),0.0,4HF5.3)
      YLABLE=0.
      T = 0.
      NDYLABLE = 6
      ADYLABLE = NDYLABLE-1
      DO 340 IP = 1,NDYLABLE
      CALL NUMBER(-0.4,T-0.07,0.14,YLABLE,0.,4HF3.1)
      YLABLE=YLABLE+YDTOP/ADYLABLE
      T = T+FMAY/ADYLABLE
  340 CONTINUE
      CALL PLOT(0.0,FMAY,3)
      CALL PLOT(0.,0.,2)
      XTICK1=0.05
      XTICK2=-0.05
      YTICK=1.
      TDYLABLE = 2.*ADYLABLE
      NDYLABLE = TDYLABLE
      DO 350 IP = 1,NDYLABLE
      CALL PLOT(XTICK2,YTICK,3)
      CALL PLOT(XTICK1,YTICK,2)
      YTICK=YTICK+FMAY/TDYLABLE
  350 CONTINUE
      CALL SYMBOL(-FDMID-0.25,FMIDY-1.0,0.14,
     124HWAVE HEIGHT DISTRIBUTION,90.0,24)
      CALL SYMBOL(-3.75,FMAY+0.5,0.14,10HWIND SPEED,0.0,10)
      CALL SYMBOL(-1.75,FMAY+0.5,0.14,5HFETCH,0.0,5)
      CALL SYMBOL(1.0,FMAY+0.5,0.14,14HCURRENT SPEEDS,0.,14)
      CALL NUMBER(-3.6,FMAY+0.2,0.10,W(1),0.0,4HF6.2)
      CALL NUMBER(-2.0,FMAY+0.2,0.10,FETCH,0.0,4HF9.0)
      DO 355 IP = 1,ICOUNT
      XPU = X(IP)
      YPU = Y(IP)
      UPU = U(IP)
  355 CALL NUMBER(XPU,YPU,0.10,UPU,0.0,4HF5.2)
      XPU = X(IP)
      YPU = Y(IP)
      UPU = U(NUE)
      CALL NUMBER(XPU,YPU,0.10,UPU,0.0,4HF5.2)
      DO 360 IC = IP,NU
      ICP = IC+1
      XPU = X(ICP)
      YPU = Y(ICP)
      UPU = U(IC)
  360 CALL NUMBER(XPU,YPU,0.10,UPU,0.0,4HF5.2)
      GENERATE FUNCTIONS AND PLOT
      DO 430 M = 1,NUE
      SIGNOT = XDLEFT-DELTDF
      TMMDF = (XDRIGHT-XDLEFT)/DELTDF+1.
      IMM = TMMDF
      DO 400 MM = 1,IMM
      SIGNOT=SIGNOT+DELTDF
      PX(MM)=SIGNOT
      PY1=SIGNOT*SIGMA(NUE)
      PY2=PY1**2
      PY3=SIGMA(M)**2
      PY4=0.5*PY2/PY3
      IF (PY4-100.) 380,380,370
  370 PY6=0.
      GO TO 390
  380 PY5=-PY4
      PY6=EXPF(PY5)
  390 PY7=TWOPAI*SIGMA(M)
      PY8=SQRTF(PY7)
      PY(MM)=PY6/PY8
  400 CONTINUE
      LOOP 410 - SCALE ARRAYS FOR PLOT
      DO 410 MM = 1,IMM
      PLX(MM)=PX(MM)/XDCALE
      PLY(MM)=PY(MM)/YDCALE
  410 CONTINUE
      CALL PLOT(PLX(1),PLY(1),3)
      DO 420 IP = 2,IMM
      CALL PLOT(PLX(IP),PLY(IP),2)
  420 CONTINUE
  430 CONTINUE
      CALL PLOT(XDRIGHT+6.0,0.0,-3)
  440 CONTINUE
  450 CONTINUE
      CALL STOPPLOT
      FORMAT STATEMENTS
  500 FORMAT(1H1,39HCURRENT MEASUREMENT INFERRED FROM REMOT,
     190HELY SENSED WAVE HEIGHT DISTRIBUTIONS FROM JONSWAP ,
     21H2/2X,12H***INPUTS***)
  501 FORMAT(I2,4X,11F6.0)
  502 FORMAT(11(I2,4X))
  503 FORMAT(1X,10HWIND SPEED,2X,7HFETCHFS/ 3X,F6.2)
  504 FORMAT(2X,13H***OUTPUTS***)
  505 FORMAT(1X,11HWIND SPEED=,F6.2,2X,6HFETCH=,F7.0,2X,
     114HCURRENT SPEED=,F6.2,2X,19HSTANDARD DEVIATION=,
```

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

```
   2F14.7)
506 FORMAT(18A4)
507 FORMAT (6F12.0)
508 FORMAT (12X,10(F7.0,2X)/12X,10(F7.0,2X))
509 FORMAT(1X,11HWIND SPEED=,F6.2,2X,6HFETCH=,F7.0,2X,
   114HCURRENT SPEED=,F6.2/2X,13HWAVE SPECTRUM)
510 FORMAT(2X,7(F14.7,2X))
    STOP
    END
```