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Turbulence spectra in the wind immediately over a water surface

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TURBULENCE SPECTRA IN THE WIND IMMEDIATELY OVER A WATER SURFACE

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TURBULENCE SPECTRA IN THE WIND

IMMEDIATELY OVER A WATER SURFACE

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ABSTRACT

In order to understand more fully the wind generation of water waves, the oceanographer should have a better knowledge of the turbulence structure of the wind field immediately above a water surface.

Measurements of atmospheric turbulence about three inches above the surface of a lake, using a hot-wire anemometer, were made. The analog signals were recorded as DC voltages on a magnetic tape recorder. The analog data were converted to digital form to permit subsequent computation of power spectral densities using a high-speed digital computer.

Average power spectral densities from 0 to 20, 0 to 500, and 0 to 1000 cps, respectively, are presented.

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1. Introduction

The fact that the wind generates and maintains waves on the ocean surface and provides the driving force for many ocean currents has been well known for many years. The exact mechanism by which the wind produces these effects is, however, not well known. Prior to understanding completely the nature of the air-sea interaction, the oceanographer must describe accurately the properties of the wind field immediately over the ocean surface.

Most analytical calculations of the rate of energy transfer from the wind to progressive water waves have used the assumption that the air flow over the water surface is basically laminar. This assumption, which, in effect, neglects atmospheric turbulence, is not realistic if the wave-generation process is to be completely understood.

Measurements of turbulence in the wind field in the first few inches above a water surface would contribute to a better understanding of the interactions between air and sea. The objectives of this research, therefore, have been threefold:

1. To develop and test a data-collection system capable of measuring and recording turbulent fluctuations in the natural wind immediately over a water surface.

2. To make recordings of wind turbulence in the first few inches above a water surface.

3. To compute power spectral densities (PSD's) from the recorded data.

Although the system developed is restricted to use in a relatively shallow fresh-water lake, the results obtained and the experience gained may serve as a foundation for further work in this field at the Naval Postgraduate School (NPGS).

2. Description of Observations

In order to measure and record the turbulent fluctuations in the downstream component of the wind field, it was necessary to devise a data-collection system suited to the task. Following a careful search of the literature pertaining to this problem, and after a survey of equipment available at the NPGS, a basic data-collection system was selected. Figure 1 is a block diagram of the system used in this research.

The instrument used for measuring the turbulence in the wind field was a constant temperature hot-wire anemometer, Security Associates Model 200. This anemometer, which consists of a high gain constant temperature amplifier coupled to an analog computer system, gives an output which is linear in velocity and zero for zero velocity. The accuracy of the analog transfer function is better than 0.5 percent over the operating range (DC-50 kilocycles per second). The hot-wire probes consisted of tungsten wires about 0.0015 inches in diameter and 0.090 inches in length.

The signal from the anemometer was recorded on an FM channel of a magnetic tape recorder, the AMPEX Model CP-100: a 14 channel, solid state, portable instrument. Recordings were made at a tape speed of 3.75 inches per second, giving a frequency bandwidth from 0 to 1250 cycles per second (cps). Before recording, the recorder was calibrated in accordance with the standard procedure outlined in the manufacturer's instruction book. The signal from the anemometer was biased so that the turbulent fluctuations were recorded about zero volts DC. This was necessary to insure that the recorder signal remained within the voltage limits of the analog-to-digital (A/D) converter used in data processing. The biased signal was then amplified (x3) and monitored on an oscilloscope to insure that the correct biasing was maintained.

Before collecting data in the field, the system was tested using fan-generated wind over a wave tank. The test signals were recorded and analyzed. The results of the test runs indicated that the system was functioning properly.

In order to maintain the hot-wire probe at a constant distance above the mean water level and normal to the mean wind field, a special wind vane and probe mount were constructed (Figure 2).

At 1600, 7 April 1967, the equipment was set up at Roberts Lake, Seaside, California. This site was selected because of its relatively unbroken wind field, its close proximity to the Naval Postgraduate School, and the availability of electric power for the equipment. Roberts Lake lies 500 yards inland from the Seaside Beach, which borders Monterey Bay. The lake, which is about 500 yards long and 200 yards wide at the center, is approximately oval shaped, with the long axis running parallel to the beach.

The wind vane, with the hot-wire probe mounted about 3 inches above the mean water level, was set in about 2.5 feet of water at the downwind end of the lake. This position gave an unbroken fetch of approximately 75 yards. The signal was recorded for 30 minutes with the wind vane free to fluctuate in the wind field. During this period, it was noted that the vane had a tendency to oscillate about the direction of the mean wind. Upon completion of the 30 minute recording period, the vane was fixed so that the hot-wire probe was approximately normal to the mean wind direction; the signal was then recorded for an additional 10 minutes.

During the recording period, the average wind speed varied between 6 and 8 knots, with the gusts up to 12 knots. The significant wave height was 1 to 2 inches, the significant wave length 15 to 20 inches, and the significant wave period 1 to 2 seconds. Since no accurate measuring devices were available, these values were subjectively estimated.

3. Method of Analysis

Based upon the results of Pond _et al_. (1966), it was expected that a large percentage of the turbulent kinetic energy would lie in the frequency range from 0 to 5 cps. The analog equipment available at the NPGS was not capable of meaningful analysis in this frequency range. For this reason a digital method of analysis was chosen.

Atmospheric turbulence is believed to approximate a stationary, random process. It is suitable, therefore, to apply the Blackman and Tukey (1958) method of analysis to compute the PSD. This method uses the fact that the PSD can be expressed as the Fourier transform of the autocorrelation function. The method readily lends itself to the computation of the PSD using a high-speed digital computer.

In order to convert the continuous record of analog data, which were in the form of varying DC voltage levels on a magnetic tape, to one of discrete data suitable for digital computation, it was necessary to sample the data at equally spaced time intervals.

This was accomplished by using a CDC 160 Computer coupled to an A/D converter for input and CDC 163 Tape Unit for output. The digitizing program, PROGRAM POWSPEC, is capable of sampling the data at a maximum rate of 5000 discrete sample points per second. This allows computation of the PSD's in the frequency range from 0 to 2500 cps.

The final step in the analysis of the data was the computation of the PSD's, using PROGRAM POWSPEC, a FORTRAN 63 program, in a CDC 1604 Computer. Detailed discussions of the A/D conversion and PSD program are given in Appendices A and B.

4. Results and Conclusions

The record was processed to obtain estimates of the power spectral densities from 0 to 1000 cps, 0 to 500 cps, and 0 to 20 cps, using low-pass filters to filter out undesirable high-frequency noise and to prevent "aliasing" of high-frequency energy into the low-frequency end of the spectrum. The record was processed also from 0 to 1000 cps and 0 to 500 cps without filters for comparison with the filtered data. The power spectra were further categorized according to whether the wind vane was free to oscillate about the mean wind or was held fixed into the mean wind. Due to the unusual design of the hot-wire probe mount, calibration of the anemometer system was impractical. Only the relative contributions of spectral energy from the various frequencies, therefore, were measured.

Five spectral estimates in each category were averaged to obtain an approximation of the power spectrum in that category. At the 80-percent confidence level, an estimate of any single value in the average spectra lies between the percentages of the actual value as tabulated below:

Frequency Range (cps)	Number of Data Points	Number of Lags	Percent of Actual Value
0-20	4000	500	79-123
0-500	4000	125	89-111
0-1000	4000	250	85-115.

The average power spectra are graphically presented in Figures 3 through 9. The values from which these spectra were plotted are included as Tables IV through X in Appendix C.

An examination of the 0 to 1000 cps and 0 to 500 cps spectra (Figures 5 through 9) shows that most of the energy lies in the frequency range from 0 to 50 cps. Energy peaks occurring beyond about 50 cps appear to be randomly distributed with frequency. Some possible causes of these peaks are mechanical vibrations in the wind vane, noise in the electronic equipment in the data-collection and processing systems, and changes in the level of turbulence in the wind field. The addition of filters during data processing produced no meaningful changes in the average spectra.

A high-resolution analysis of the 0 to 20 cps frequency band, using a 20 cps low-pass filter, was made. The average spectra in this frequency band, with the vane free to oscillate and with the vane fixed, are shown in Figures 3 and 4, respectively. Although the total energy computed in the fixed-vane case is greater, the differences between the two spectra are not considered significant.

The significant frequency range of the water waves present during the observations, based on a subjective estimate of the significant wave lengths, was computed using the small-amplitude relation of frequency to wave length ($f = [5.12/L]^{\frac{1}{2}}$). The frequency range of the water waves thus computed was 1.7 to 2.1 cps; this range has been indicated by the vertical dashed lines on

Figures 3 and 4. On each of these two average spectra, an energy peak appears within the frequency range of the water waves. These peaks are attributed to the influence of the water-wave undulance on the turbulence structure of the wind field. It should be noted that, although the probe was only about twice as high above the mean water surface as were the water waves, the undulance of the water waves seems to contribute a relatively small percentage of the total turbulent energy.

PROGRAM POWSPEC estimates the total energy in two different ways: (1) by computing the variance of the 4000 data points and (2) by integrating the power spectrum by application of the trapezoidal rule. The ratio of the two energy values thus obtained gives the fraction of the total energy accounted for in the power spectrum. The value of this ratio is called XFACT in the program. If all of the energy is accounted for in the power spectrum, XFACT will equal unity.

The average XFACT in the 0 to 500 cps and the 0 to 1000 cps power spectra, using a 4 cps frequency interval, was about 0.80, indicating that the power spectral estimates did not account for nearly 20 percent of the energy. Spectra in these frequency ranges were recomputed using a 1 cps frequency interval, and XFACT increased to about 0.90. The shapes of the spectra were unchanged. The power spectral estimates for the 0 to 20 cps spectra, using a 0.1 cps frequency interval, accounted for about 94 percent of the energy. XFACT apparently can be made to approach unity by decreasing the frequency interval. This is probably true because as the number of estimates is increased the trapezoidal rule provides a more accurate approximation of the value of the integral of the power spectrum. The confidence in any single value in the spectrum, however, is decreased when the number of estimates is increased.

In every power spectrum computed a large spectral density value was obtained at zero frequency. In every average spectrum, the maximum spectral density value was obtained at one frequency interval above zero frequency. Precautions are taken in PROGRAM POWSPEC to prevent unrealistic values of power density at or near zero frequency in that the mean of the data is subtracted from each data point before computing the PSD's, as suggested by Blackman and Tukey (1958). The significance of the large spectral density values remaining at the very low end of each spectrum is not fully understood.

5. Recommendations for Future Work

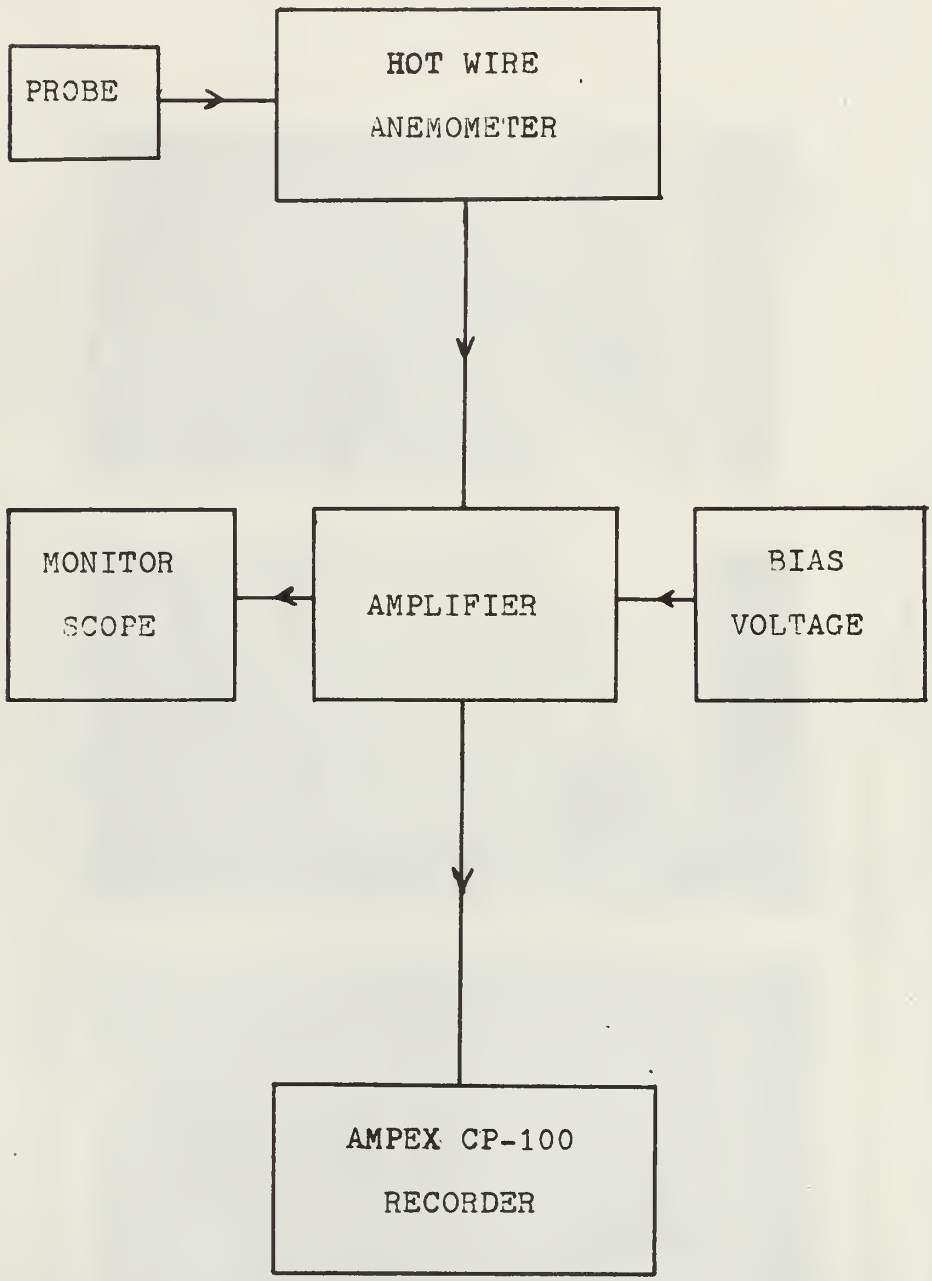
1. A detailed analysis of the very low frequency end of the spectrum should be made to determine more accurately the distribution of energy in this frequency range.

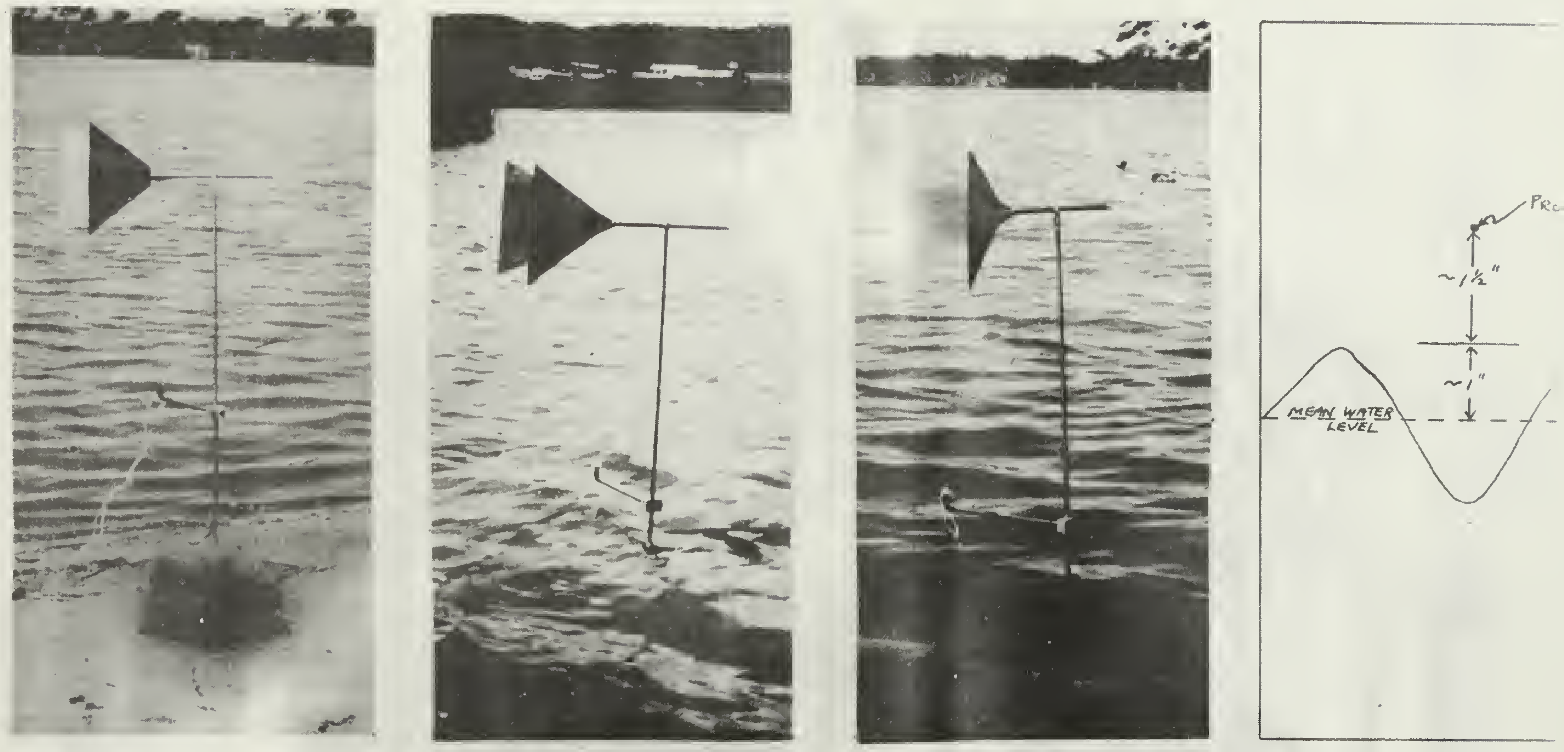
2. A float-mounted probe should be used to measure the turbulence in the wind field at a constant distance above the actual water surface. A comparison between spectra thus obtained and the spectra obtained at a fixed level above the mean water surface should be made.

3. Crossed hot-wire arrays and a multichannel hot-wire anemometer should be used to measure the downstream and transverse components of atmospheric turbulence in order to compute co-spectral densities and Reynolds stresses.

FIGURE-1

BLOCK DIAGRAM OF DATA COLLECTION SYSTEM





Before Installation | In Operation | In Operation | Height of Probe Above Water

FIGURE 2. WIND VANE AND PROBE MOUNT

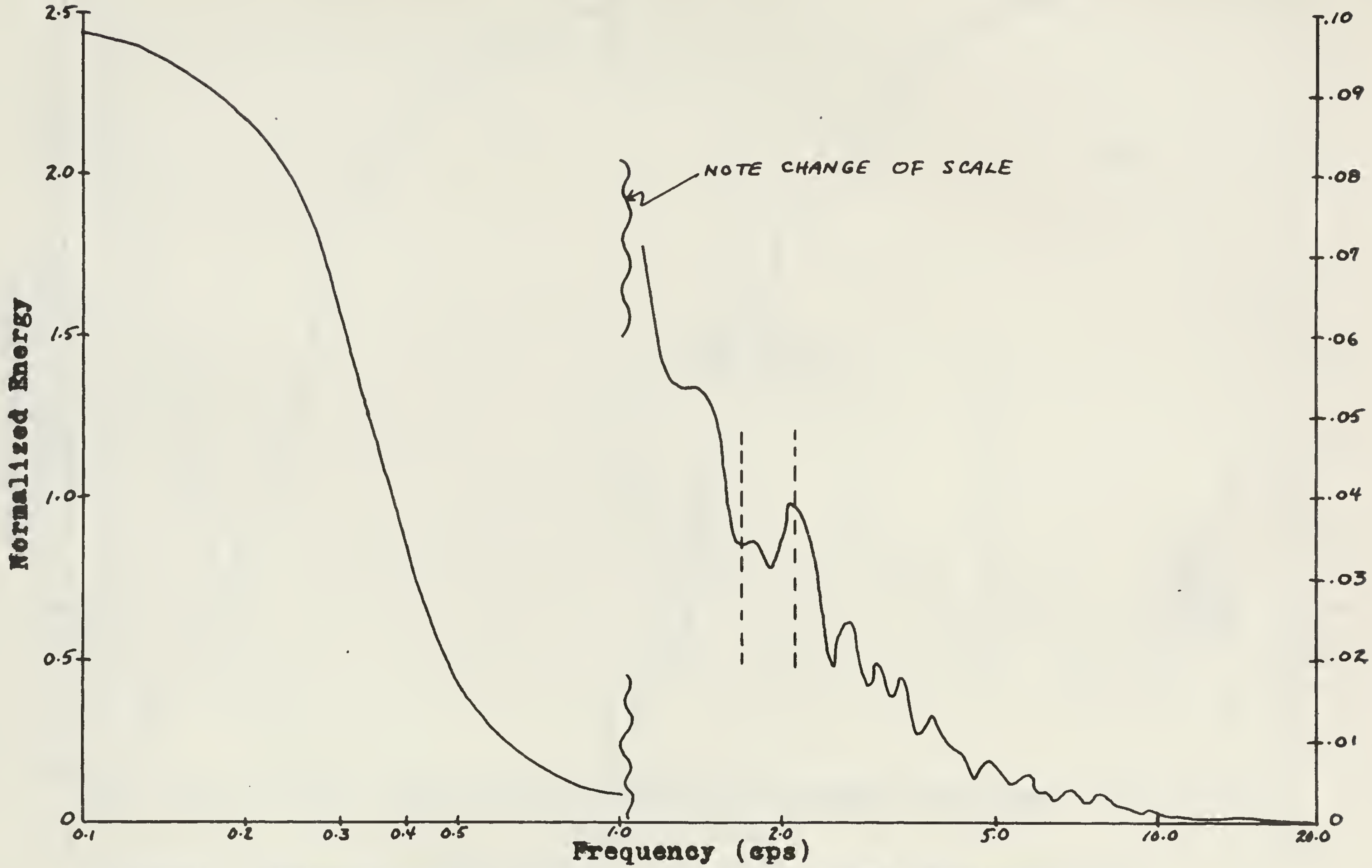


FIGURE 3. AVERAGE POWER SPECTRUM, 0-20 cps, FILTER, VANE FREE

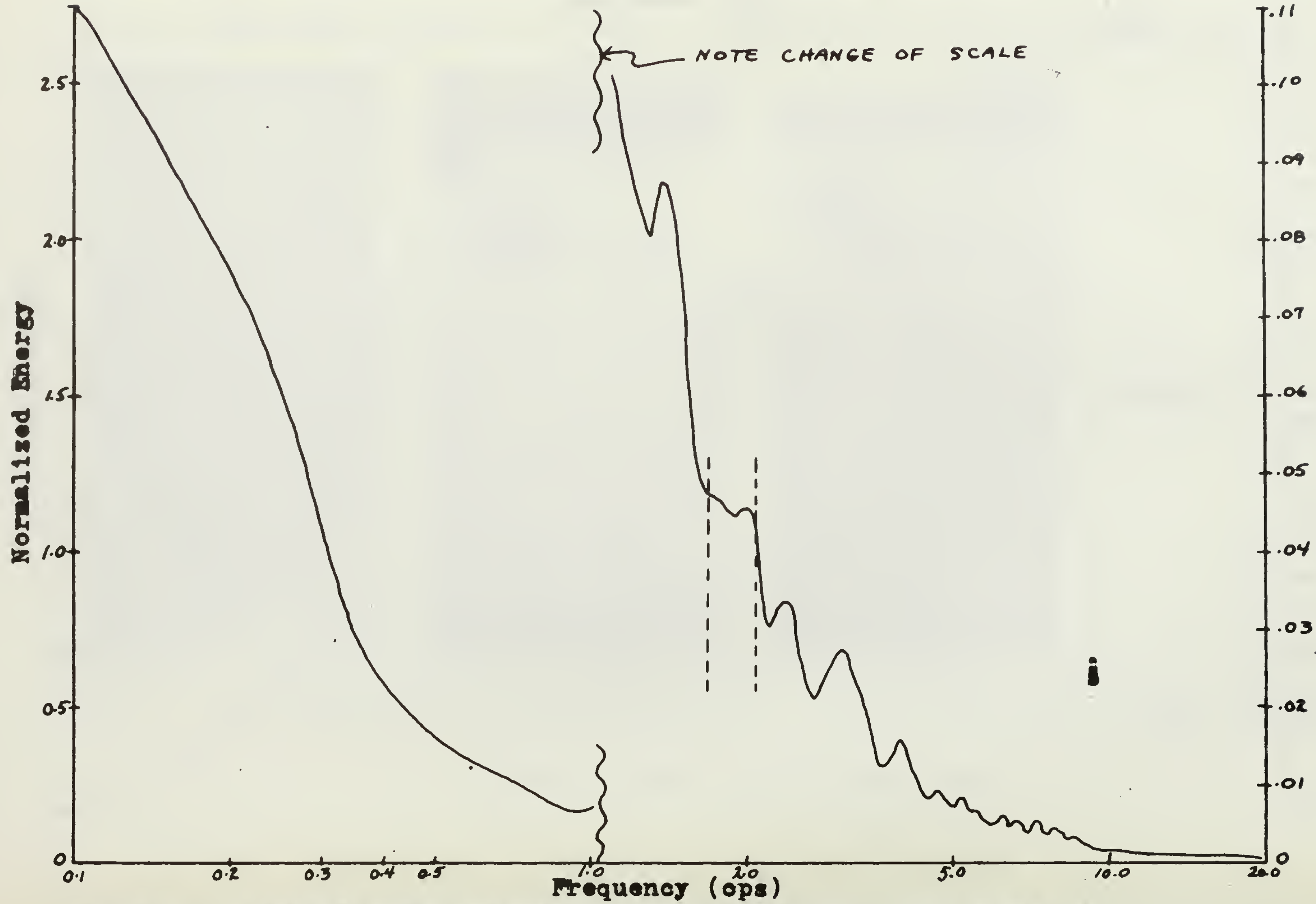


FIGURE 4. AVERAGE POWER SPECTRUM, 0-20 cps, FILTER, VANE FIXED

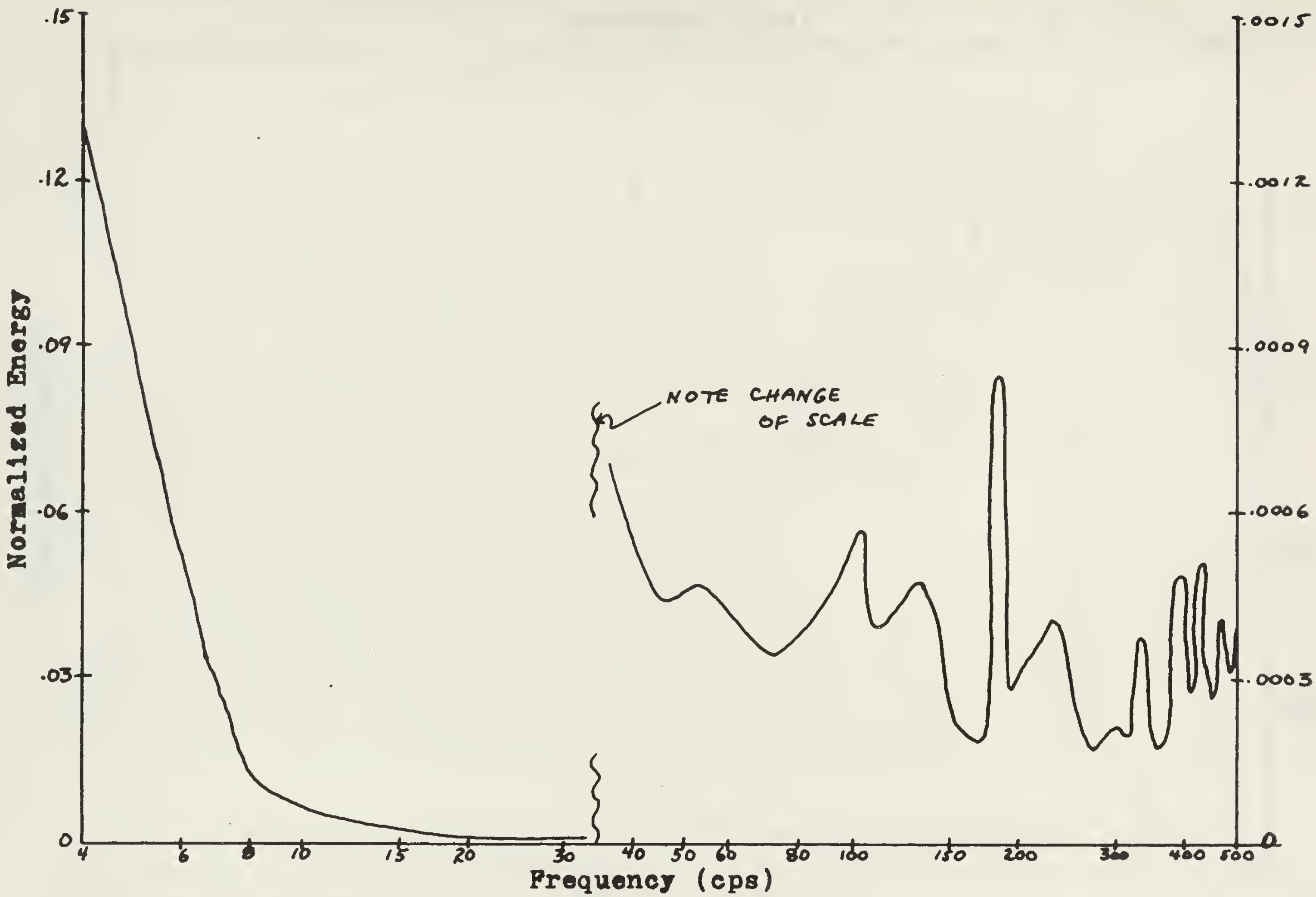


FIGURE 5. AVERAGE POWER SPECTRUM, 0-500 cps, NO FILTER, VANE FREE

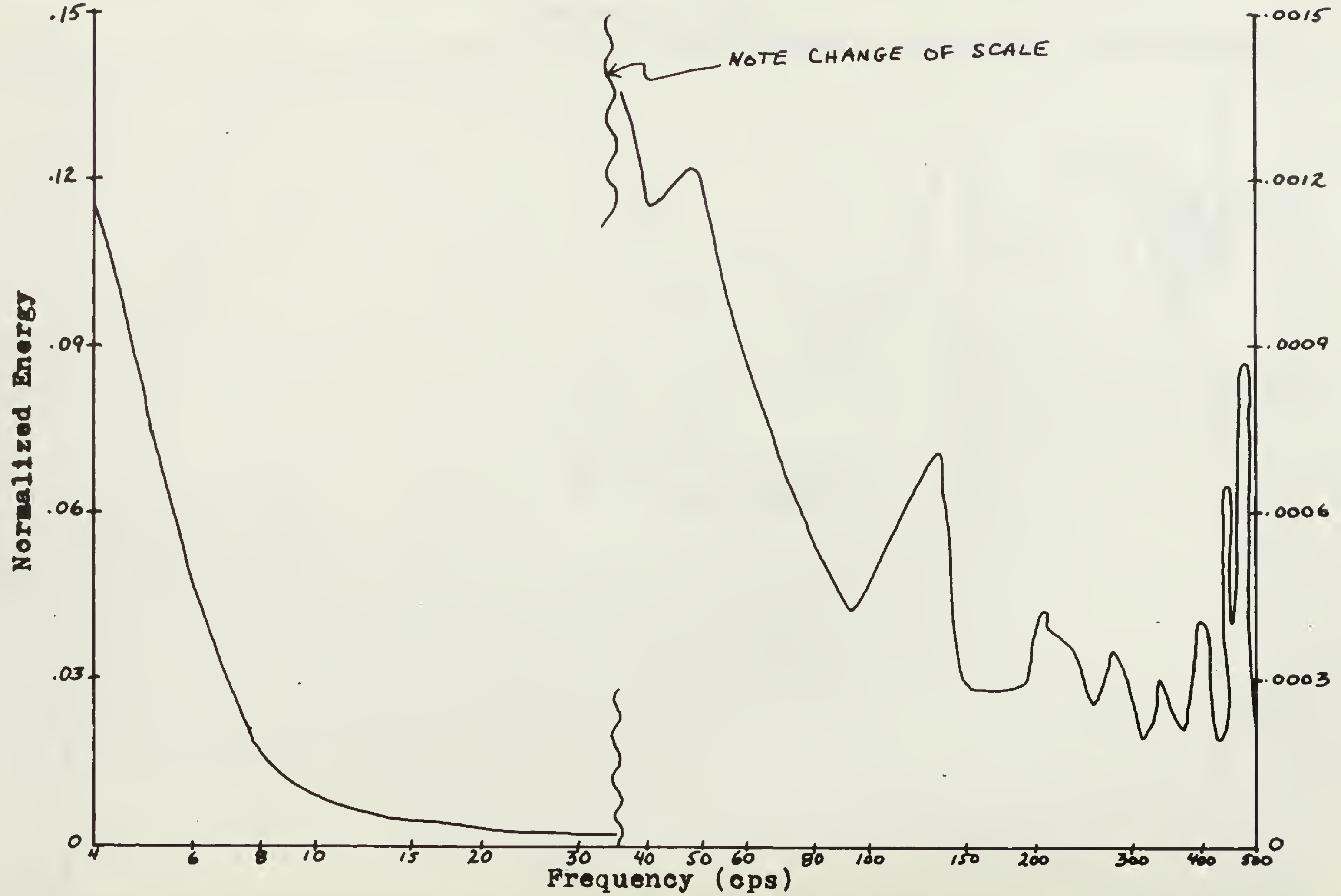


FIGURE 6. AVERAGE POWER SPECTRUM, 0-500 cps, NO FILTER, VANE FIXED

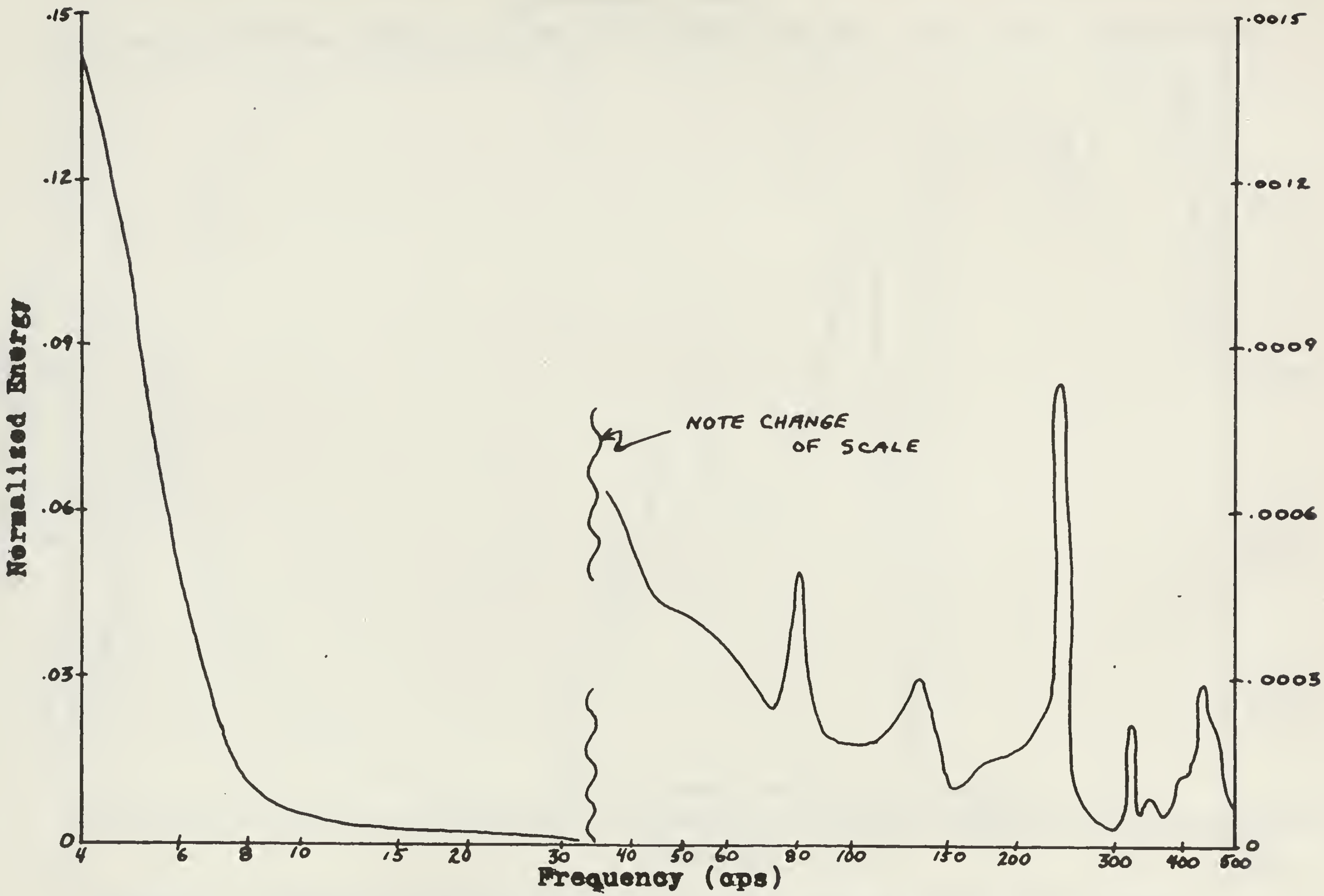


FIGURE 7. AVERAGE POWER SPECTRUM, 0-500 cps, FILTER, VANE FREE

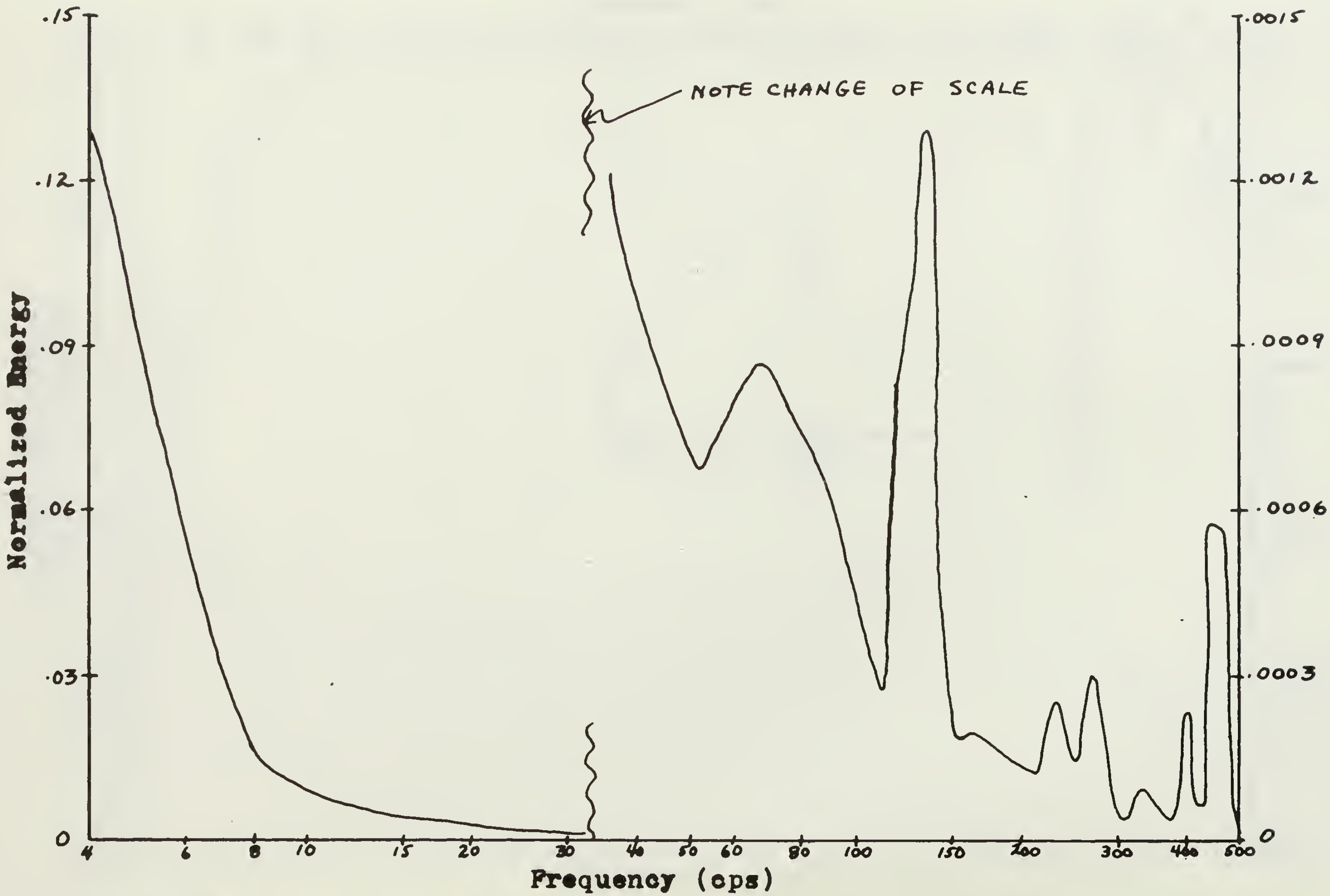


FIGURE 8. AVERAGE POWER SPECTRUM, 0-500 cps, FILTER, VANE FIXED

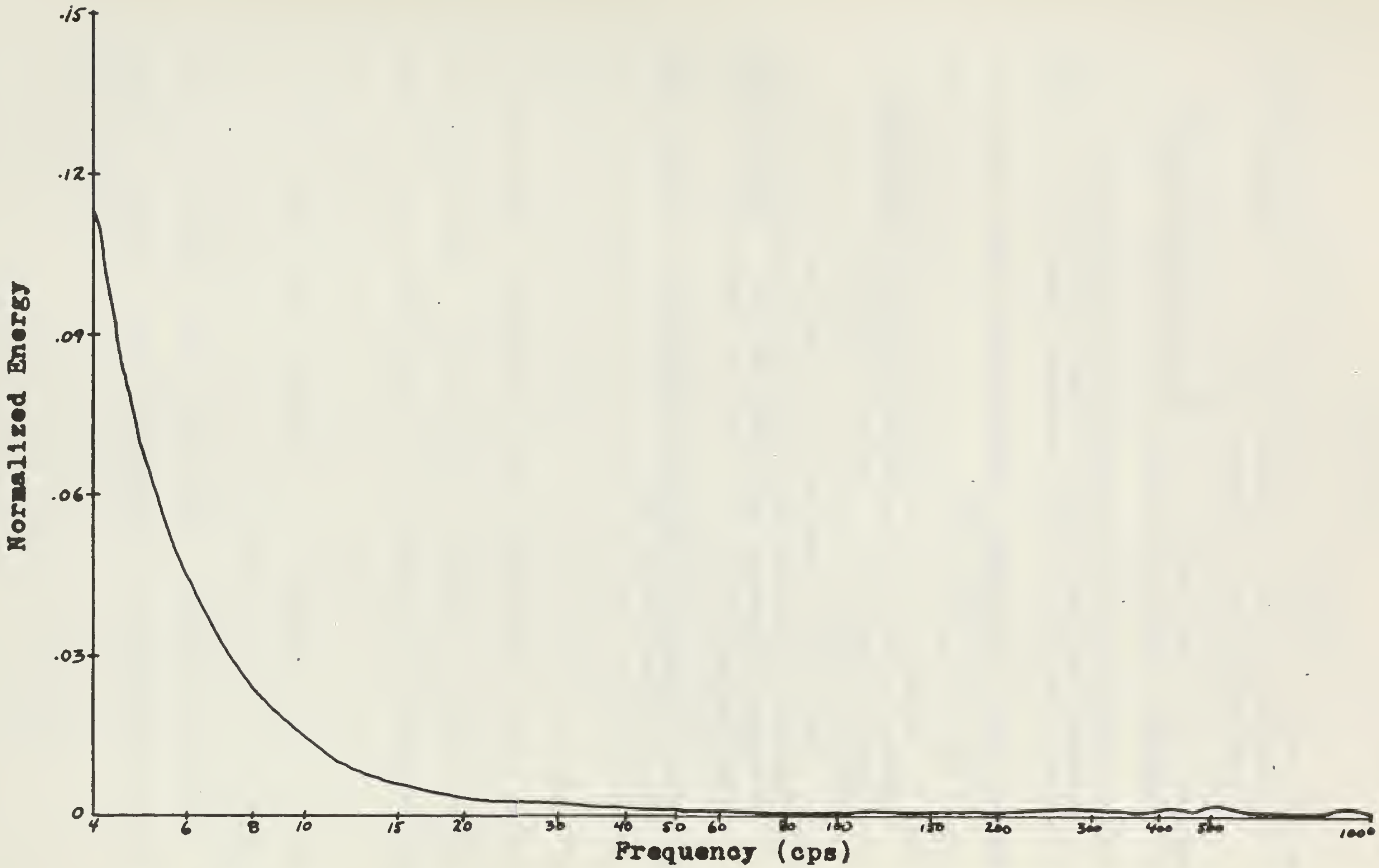


FIGURE 9. AVERAGE POWER SPECTRUM, 0-1000 cps, FILTER, VANE FIXED

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APPENDIX A

ANALOG TO DIGITAL DATA CONVERSION

1. Introduction

The analog data, recorded on magnetic tape as a varying DC voltage, is converted to digital form in order to use a high-speed digital computer for analysis. The output data from the AMPEX CP-100 Recorder is fed through an analog-to-digital (A/D) converter. The digitizing computer, CDC Model 160, alternately activates the A/D converter for data input and the tape unit, CDC Model 163, for data output.

The CDC 160 Computer has a 4096-cell memory. Each cell contains 12 bits. The top 96 cells are used for programming, while the lower 4000 cells are reserved for data storage. A block diagram of the digitizing system is shown in Figure A-1. When the A/D converter is activated and the input instruction executed, the analog input data from the recorder is sampled and a 12-bit number, representing signal amplitude, is sent to the CDC 160 and stored. This process is repeated in rapid succession. Blocks of up to 4000 samples can be stored and the maximum sampling rate is 5000 samples per second.

The normal mode of operation is to initiate each block in a run by a manual gating pulse on the A/D converter. The computer controls the inter-sample delay time. Automatic pulsing, in which the computer controls the gating of each block in a run, is also available.

2. Calibration

Prior to the actual digitizing process, the system must be calibrated using a test program, TEST 160 (Table I). In PROGRAM TEST 160, cells 0000 to 0017 contain a program which accurately sets the -5.0 volt bias voltage required by the A/D converter. If the bias voltage is properly set at -5.0 volts, with no input signal to the A/D converter, the value of the conversion, as indicated in cell 0004, should be 0000 or 7777. Small variations in the bias voltage, which are to be expected during the course of a run, are eliminated by removing the mean of the data during computation of the power spectral density.

Cells 0020 to 0045 in PROGRAM TEST 160 contain a program to set the inter-sample delay time accurately. The input request pulses to the A/D converter are observed on an oscilloscope. The inter-sample delay time can be adjusted to the desired value by manually changing the timer-control word in the program (cell 0042). Figure A-2 is a plot of timer-control word (octal) versus inter-sample delay time.

3. Digitizing the Analog Data

After the calibration procedure is completed, PROGRAM DIGITIZE (Table II) is read into the computer. The following manual entries into PROGRAM DIGITIZE are required:

Cell No.	Contents	Remarks
0066	Timer Control Word	See Figure A-2
0067	Spare Identifier	Any number $\leq 7777_8$
0070	Initial Run Number	Set as 0001
0071	Number of runs desired	
0072	Number of samples/block	$\leq 7640_8 = 4000_{10}$
0073	Number of blocks/run.	

Each block of digitized data is labeled with a 16-digit octal identifying number so that the block can be recalled for computation in the main PSD program. Four quantities are specified in the identifier:

1. Current run number - steps once per run
2. Spare ID - may be set to any number $\leq 7777_8$
3. Current block number in the run
4. Number of blocks per run.

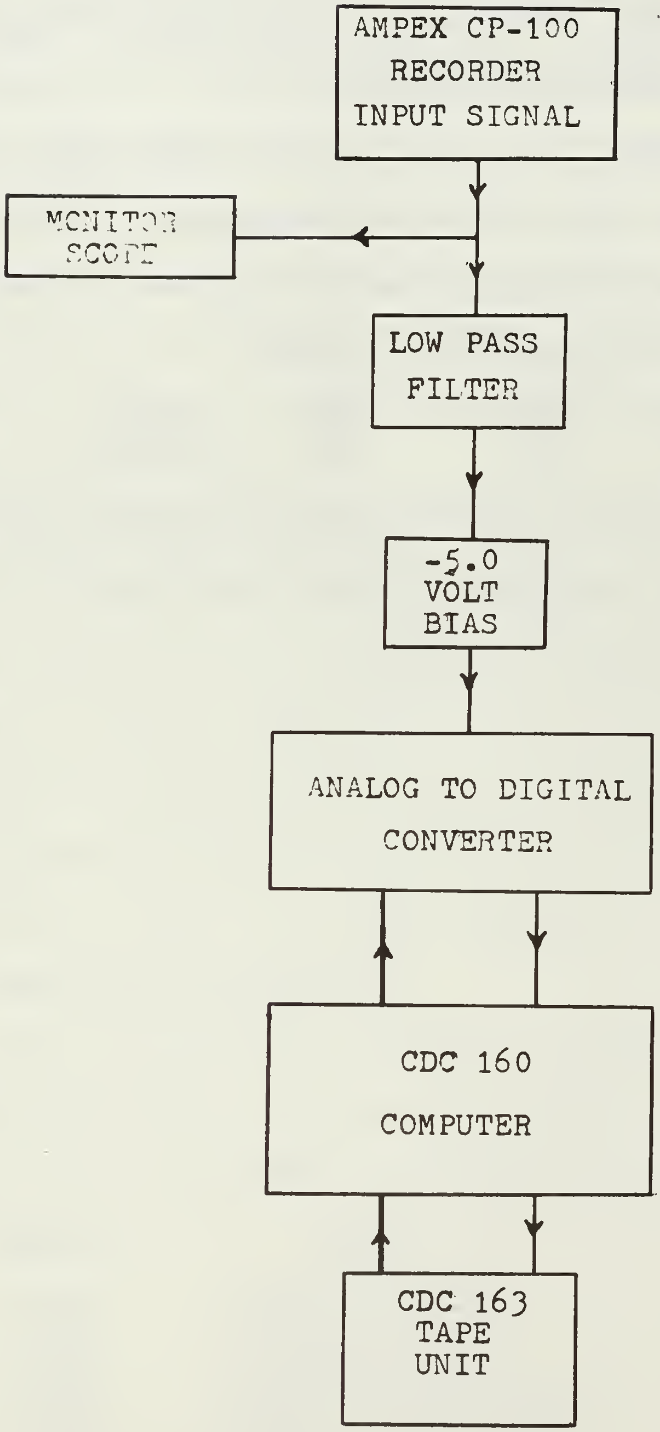
As an example, assume that ten runs, forty blocks per run, with the spare ID set at 0015, are being used. If the fourth and fifth blocks of the sixth run are recalled, the identifiers would appear in the CDC 1604 as follows:

0006	0015	0004	0050
0006	0015	0005	0050.

Exact records of the identifiers must be kept while digitizing, as this is the only means of recalling the data desired for computation in the main program.

FIGURE A-1

ANALOG TO DIGITAL CONVERSION SYSTEM



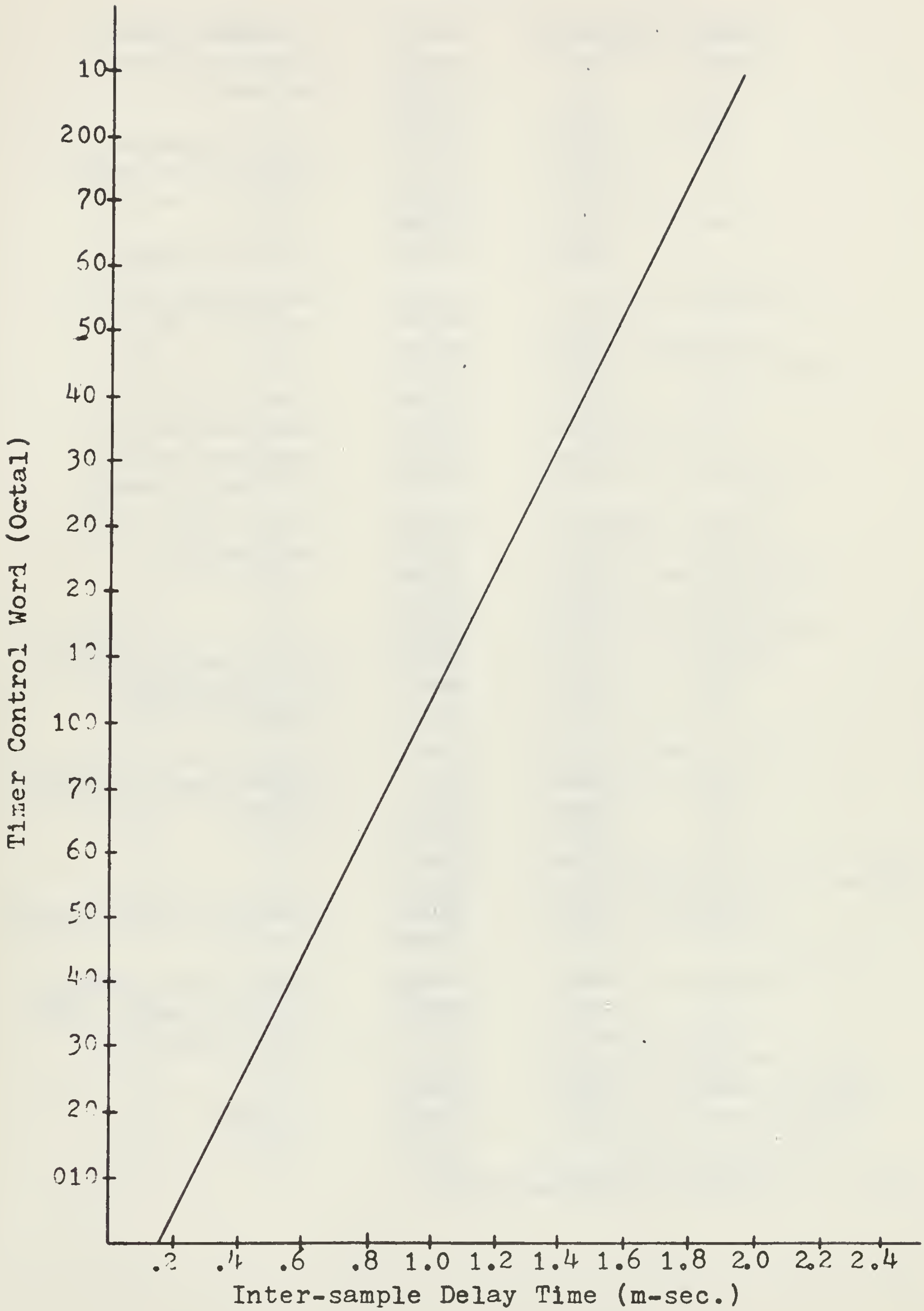


FIGURE A -2. INTER-SAMPLE DELAY TIME VS TIMER CONTROL WORD

TABLE I

PROGRAM TEST 160

Cell	Contents	Code	Explanations
0000	7500	EXF00	Begin Bias-set
1	2410	2410	Set Enable
2	7500	EXF00	
3	1401	1401	Call A/D Channel 1
4	7600	INA	Input to "A" in Reg.
5	4070	STD70	Store "A" in 0070
6	7500	EXF00	
7	2401	2401	Call D/A Channel 1
0010	7303	OUT03	Output Cell 0070 to
11	0072	0072	Cell 0071 INC.
12	6102	NZF02	
13	0070	0070	
14	0400	LDN00	Load zero's.
15	4071	STD71	Store in 0071
16	6414	ZJB14	Jump back to 0000
17	7700	HLT00	HLT. End Bias-set
0020	7500	EXF00	Begin Timer
21	2410	2410	Set Enable
22	7500	EXF00	Call A/D Ch. 1
23	1401	1401	
24	7600	INA	
25	4143	STI43	Store Sample in 0043
26	0300	NOP	No Operation-NOP
27	0300	NOP	These are Time
0030	0300	NOP	Dummies to
31	0300	NOP	Match Program DIGITIZE
32	0300	NOP	Timing
33	0300	NOP	
34	0300	NOP	
35	0300	NOP	
36	2042	LDD42	Load Timer Control Word
37	0701	SBN01	Subtract 1
0040	6501	NXB01	If not zero, go back 1
41	7044	JPI44	If zero, jump to 0022
42	M	M	Timer Control Word
43	0043	0043	
44	0022	0022	
45	7701	HLT01	End Timer

Note: M is manual entry.

TABLE II

PROGRAM DIGITIZE

Cell	Contents	Code	Explanations
0000	0101	PTA	
1	0603	ADN03	
2	7064	JPI64	Jump to INITIAL
3	7500	EXF00	
4	2410	2410	Set Enable
5	7500	EXF00	
6	1401	1401	Call A/D Channel 1
7	7600	INA	INPUT
0010	4176	STI76	Store sample in (0076)
11	2076	LDD76	
12	3465	SBN65	Enough samples yet?
13	6134	NZF34	If not, go to cell 0047
14	7500	EXF00	
15	2400	2400	Clear Enable
16	2074	LDD74	Load Current Run No.
17	4160	STI60	Store in cell 0133
0020	2067	LDD67	Load Spare ID.
21	4161	STI61	Store in cell 0134
22	2075	LDD75	Load Current Block No.
23	4162	STI62	Store in cell 0135
24	2073	LDD73	Load No. of Blocks/Run
25	4163	STI63	Store in cell 0136
26	7500	EXF00	
27	2111	2111	Call 163 M.T.U.
0030	7303	OUT03	Output from
31	0000	C	computed L.W.A.
32	6102	NZF02	to
33	0133	0133	0133
34	2246	LDF46	Set A-0137
35	4076	STD76	Reset running storage address
36	2075	LDD75	Enough Blocks yet?
37	3473	SBD73	
0040	6155	NZF55	If not, go to cell 0115
41	0401	LDN01	
42	4075	STD75	Reset block no.
43	5455	AOD55	Update total block count
44	3454	SBD54	Check if capacity exceeded
45	6153	NZF53	If not, go to cell 0120
46	6061	ZJF61	If not, go to cell 0127
47	5476	AOD76	Begin intersample delay loop

TABLE II (continued)

Cell	Contents	Code	Explanations
0050	2066	LDD66	Load intersample delay word
51	0701	SBN01	If not zero, go back 1
52	6501	NZB01	If zero, go to cell 0005
53	7056	JPI56	0760-M.T.U. block capacity
54	0760	0760	Total No. Blocks written
55	0000	C	Address
56	0005	0005	Address
57	0003	0003	
0060	0133	0133	Address of Current Run No. ID
61	0134	0134	Address of Spare ID of ID
62	0135	0135	Address of Cur. Block No. ID
63	0136	0136	Address of Tot. Blocks ID
64	0100	0100	Address of INITIAL
65	C	C	Address of last word of data
66	M	M	Intersample delay word
67	M	M	Spare ID anything
0070	M	M	Initial Run No. Set 1
71	M	M	No. runs desired
72	M	M	No. samples/block 7640_8
73	M	M	No. blocks/run
74	C	C	Current run no.
75	C	C	Current Block Number
76	C	C	Running Storage Address
77	C	C	JUMP CONTROL
0100	4077	STD77	BEGIN INITIAL
101	2200	LDC00	
102	0137	0137	Set "A" -0137
103	4076	STD76	Initialize running storage address
104	3072	ADD72	Compute last address
105	4031	STD31	Store in 0031
106	0701	SBN01	
107	4065	STD65	Store in 0065
0110	2070	LDD70	
11	4074	STD74	Initialize Run No.
12	0401	LDN01	
13	4075	STD75	Initialize Block No.
14	7077	JPI77	END INITIAL
15	5475	AOD75	Update Current Block No.
16	5455	AOD55	Update Current Block Count
17	7057	JPI57	Go to 0003

TABLE II (continued)

Cell	Contents	Code	Explanations
0120	2074	LDD74	Have enough runs
21	3471	SBD71	been done yet?
22	6103	NZF03	If no, go to 0125
23	2074	LDD74	If yes, display last run no.
24	7701	HLT01	Halt 01
25	5474	AOD74	Update current run no.
26	7057	JPI57	Go to 0003
27	7500	EXF00	Call E.O.F.
0130	1111	1111	Write an EOF Mark
31	2055	LDD55	Load block count
32	7702	HLT02	Halt 02
33	C	C	RUN #ID
34	C	C	SPARE #ID
35	C	C	BLOCK #ID
36	C	C	BLOCKS/RUN ID.
0137	D	D	Data Storage
↓	D	D	
7776	D	D	Data Storage

Note:

C is PROGRAM COMPUTED ENTRY

M is MANUAL ENTRY

D is DATA STORAGE

APPENDIX B

PROGRAM FOR COMPUTING POWER SPECTRAL DENSITIES

1. Introduction

After the digitizing is completed, the magnetic tape contains binary numbers, the form of which is suitable for the computation of power spectral density (PSD) by a high-speed digital computer. PROGRAM POWSPEC, a FORTRAN 63 program which uses the Tukey method with a hanning lag window for smoothing, is used to compute the PSD (Table III). This program is available at the Naval Postgraduate School.

2. Data Recall

The data in digital form are recalled in PROGRAM POWSPEC by calling SUBROUTINE DATA, which uses two subroutines, FINDIT and UNPACK. SUBROUTINE FINDIT locates the data on the tape and SUBROUTINE UNPACK unpacks the block of numbers into the memory of the CDC 1604. The data to be recalled is designated by its 16-digit octal identifying number.

3. Main Program

The unpacked data is in the memory of the CDC 1604 in integer format. PROGRAM POWSPEC converts the data to floating point format, divides each data point by -409.6 (which reconverts the data point to the voltage which it represents), and removes the mean of the data. The program then computes the mean square and the autocorrelation for each lag. By means of a Fourier cosine transform the power spectrum is computed from the autocorrelations. The PSD with respect to frequency is then normalized with respect to the energy at zero frequency. The program prints out the autocorrelations and the PSD's versus the frequencies, and plots a normalized frequency spectrum.

4. Data Cards

In order to compute the frequency spectrum certain data cards are required by the main program. These cards are as follows:

1. Data Control Card

   a) ITAPE - indicates whether data is read in from tape or cards. ITAPE = 0 for tape data and 1 for card data.

   b) IDELTA - indicates that every IDELTA data point is to be used in the computation of the frequency spectrum. If every data point is to be used, IDELTA = 1.

   c) DELTAT - the inter-sample delay time used when digitizing data.

   d) ISTART - indicates which data point is the starting point for the computation. If the computations begin with the first data point, ISTART = 1.

   e) IMAX - the maximum number of data points to be used for computation. If data is read in from tape, using the CDC 160 digitizing process, IMAX $\leq$4000.

   f) M - the number of estimates to be used in computing the frequency spectrum.

2. Graph Control Card

a) ABS - the number of units per inch for the abscissa. This number is rounded to one significant figure by the program.

b) ORD - the number of units per inch for the ordinate. This number is rounded to one significant figure by the program.

c) IWD - width of graph in inches ($1 \le IWD \le 9$).

d) IHI - height of the graph in inches ($1 \le IHI \le 15$).

3. Other Data Cards

a) NUMHDR - the number of blocks to be computed.

b) Block Identifier - a 16-digit octal number assigned during the digitizing process.

c) Graph Identifier - an eight character alphanumeric graph identifier.

5. <u>General Comments</u>

The maximum frequency (f_{max}) to which the frequency spectrum may be computed is controlled by the selection of DELTAT (ΔT). This must be determined before digitizing. The following equation applies:

$$f_{max} = 1/[2\Delta T].$$

The number of intervals between zero frequency and the maximum frequency is determined by M, the number of estimates, in accordance with the following equation:

$$\Delta f = 1/[2\Delta TM].$$

TABLE III

PROGRAM POWSPEC

```
-COOP,BOX S,SLAYPHEL,I/1/0/49/S/1S/2S/E/45=54/5=50/6=51,15,20000.
-FTN,L,E.
      PROGRAM POWSPEC
C     TUKEY METHOD FOR ESTIMATING POWER SPECTRAL DENSITIES
      DIMENSION P(4000),A(600),X(600),FREQ(600),TAU(600),Q(3000)
      DIMENSION KDATA(4000,2),IDENT(200)
      DIMENSION ITITLE(12)
      DIMENSION DATE(160),SKIP(160)
      COMMON KDATA
      EQUIVALENCE(KDATA,P)
C     FIRST STEP IS DATA CONTROL CARD--DATA READ IN BY TAPE OR CARD
C     FIND IF DATA IS ON TAPE--ITAPE=0 FOR TAPE,=1 FOR CARD DATA
      WRITE(6,103)
    1 READ (5,101) ITAPE,IDELTA,DELTAT,ISTART,IMAX,M
      READ (5,116) ABS,ORD,IWD,IHI
      WRITE(6,104)
      WRITE(6,101) ITAPE,IDELTA,DELTAT,ISTART,IMAX,M
      IQ=ISTART-1
      IADJ=IMAX-IQ
    2 IF(ITAPE-1)6,5,5
C     START DATA CARD READ IN--USE THIS BRANCH FOR TEST PURPOSES
C     IF CARD DATA,REMOVE STATEMENT 11 AND REPLACE WITH A CONTINUE
    5 READ(5,102) (P(I),I=1,IMAX)
      WRITE(6,105)
      WRITE(6,106) (P(I),I=1,100)
      GO TO 30
C     START TAPE DATA READ IN--USE THIS BRANCH FOR PRODUCTION
C     NUMHDR=NO. OF HEADINGS
    6 READ 110,NUMHDR
      DO 7 N=1,NUMHDR
```

TABLE III (continued)

```
    7 READ 111,IDENT(N)
      WRITE(6,114)
      WRITE(6,111)(IDENT(N),N=1,NUMHDR)
C     MAIN DO LOOP ON ENTIRE PROGRAM
      DO 500 N=1,NUMHDR
      IDENT=IDENT(N)
      KLIST=1
      MAX=IMAX
      CALL DATA (IDENT,MAX,KLIST,KFLAG)
      IF(KFLAG)8,9,8
    8 WRITE(6,112)
      WRITE(6,113) N,IDENT
      GO TO 500
    9 DO 11 J=1,IMAX
      I=1
   10 P(J)=KDATA(J,I)
   11 P(J)=P(J)/(-409.6)
      WRITE(6,105)
      WRITE(6,106) (P(I),I=1,100)
      GO TO 30
C     NORMALIZE INPUT DATA TO WIPE OUT D C TERM ON AVERAGE BASIS
   30 ASUM=0.0
   31 DO 32 I=1,IADJ,IDELTA
      ASUM=ASUM+P(I)
   32 CONTINUE
C     AZ IS NUMBER OF DATA SAMPLES BEING COMPUTED
      AZ=FLOATF((IADJ-1)/(IDELTA))+1.0
      ASUM=(ASUM)/(AZ)
   33 DO 34 I=1,IADJ,IDELTA
      P(I)=P(I)-ASUM
```

TABLE III (continued)

```
   34 CONTINUE
      ASIS=0.0
      DO 35 I=1,160
      DATE(I)=P(I)
      SKIP(I)=ASIS
      ASIS=ASIS+1.0
   35 CONTINUE
C     FIND MEAN SQUARE AZERO  I.E.AUTOCORRELATION AT TAU=ZERO
   40 ASUM=0.0
   41 DO 42 I=1,IADJ,IDELTA
      ASUM=ASUM+P(I)**2
   42 CONTINUE
      AZERO=ASUM/AZ
C     FIND AUTOCORRELATIONS A(L) FOR L=1,M
   43 DO 46 L=1,M
      ASUM=0.0
      BSUM=0.0
      CSUM=0.0
      MZ=(L*IDELTA+1)
   44 DO 45 I=MZ,IADJ,IDELTA
      IZ=I-(L*IDELTA)
      ASUM=ASUM+P(IZ)*P(I)
      BSUM=BSUM+P(IZ)
      CSUM=CSUM+P(I)
   45 CONTINUE
      AZ=(1.0)/FLOATF(((IADJ-1)/(IDELTA))+1-L)
      A(L)=(AZ)*(ASUM)-(AZ**2)*BSUM*CSUM
   46 CONTINUE
C     FIND XZERO---POWER SPECTRAL DENSITY AT FREQ=ZERO
   50 ASUM=0.0
```

TABLE III (continued)

```
      MZ=M-1
      FM=FLOATF(M)
      CS1=COSF(3.14159/FM)
      SN1=SINF(3.14159/FM)
      CSL=CS1
      SNL=SN1
   51 DO 52 L=1,MZ
C     AZ=HANNING FACTOR
C     FIND COSINE SUM FROM TRIG. IDENTITIES
      AZ=1.0+CSL
      ASUM=ASUM+AZ*A(L)
      CSL1=CSL*CS1-SNL*SN1
      SNL1=SNL*CS1+CSL*SN1
      CSL=CSL1
      SNL=SNL1
   52 CONTINUE
      DZ= .5/FM
      XZERO=DZ*(ASUM+AZERO)
C     FIND X(K)---POWER SPECTRUM AT K=1,M
      CSK=CS1
      SNK=SN1
   53 DO 59 K=1,M
      ASUM=0.0
      CSKL=CSK
      SNKL=SNK
      CSL=CS1
      SNL=SN1
   54 DO 55 L=1,MZ
      AZ=(1.0+CSL)*CSKL
      ASUM=ASUM+AZ*A(L)
```

TABLE III (continued)

```
      CSL1=CSL*CS1-SNL*SN1
      SNL1=SNL*CS1+CSL*SN1
      CSL=CSL1
      SNL=SNL1
      CSKL1=CSKL*CSK-SNKL*SNK
      SNKL1=SNKL*CSK+CSKL*SNK
      CSKL=CSKL1
      SNKL=SNKL1
   55 CONTINUE
      IF(K-M)56,57,57
   56 DZ=1.0
      GO TO 58
   57 DZ= .5
      GO TO 58
   58 DZ=DZ/FM
      X(K)=DZ*(ASUM+AZERO)
      CSK1=CSK*CS1-SNK*SN1
      SNK1=SNK*CS1+CSK*SN1
      CSK=CSK1
      SNK=SNK1
   59 CONTINUE
C     SHIFT INDICES--ZERO FREQ WILL START AT K=1 AFTER SHIFT
C     USE STORAGE SPACE OF P(I) DATA DURING SHIFT OPERATION
C     NORMALIZE AUTOCORRELATION
C     NORMALIZE AUTOCORRELATION W.R.T. AZERO
   60 DO 61 I=1,M
      P(I 1)=X(I)
      P(I 1001)=A(I)
   61 CONTINUE
      X(1)=XZERO
```

TABLE III (continued)

```
      A(1)=1.0
      MZ=M+1
   62 DO 63 I=2,MZ
      X(I)=P(I)
      A(I)=P(I+1000)/(AZERO)
   63 CONTINUE
C     APPLY TRAPEZOIDAL RULE TO FIND ENERGY CONTAINED IN POWER SPECTRUM
C     FOR RANGE OF K=1,M+1---DEFINE ENERGY AS XENGY
C     NOTE X(K) IS ENERGY W.R.T. UNIT CHANGE OF INDEX K
      ASUM=0.0
   65 DO 66 K=2,M
      ASUM=ASUM+X(K)
   66 CONTINUE
      XENGY=0.5*(X(1)+2.*ASUM+X(M+1))
C     FIND FRACTION OF TOTAL ENERGY IN CALCULATED FREQ. RANGE
      XFACT=XENGY/AZERO
C     OBTAIN SPECTRAL DENSITY W.R.T. FREQ(CPS)--NORMALIZE W.R.T. XENGY
      FREQ(1)=0.0
      TAU(1)=0.0
      MZ=M+1
   67 DO 68 K=1,MZ
      AZ=2.0*(DELTAT)*FM
      X(K)=(AZ)*X(K)/XENGY
      FREQ(K+1)=FREQ(K)+(1.0)/(AZ)
      TAU(K+1)=TAU(K)+DELTAT
   68 CONTINUE
C     POWER SPECTRUM WRITE OUT INSTRUCTIONS
   70 WRITE (6,103)
      WRITE(6,107) XFACT,AZERO
      WRITE(6,108)
```

TABLE III (continued)

```
      WRITE(6,109)(TAU(K),A(K),FREQ(K),X(K),K=1,MZ)
      LABEL=4H
      ITITLE(1)=8HSLAYMAN
      ITITLE(2)=8HAND PHEL
      ITITLE(3)=8HPS POWER
      ITITLE(4)=8H SPECTRA
      ITITLE(5)=8HL DENSIT
      ITITLE(6)=8HIES
      ITITLE(7)=8HWIND TUR
      ITITLE(8)=8HBULENCE
      ITITLE(9)=8HMEASUREM
      ITITLE(10)=8HENTS OVE
      ITITLE(11)=8HR WATER-
      READ (5,115) ITITLE(12)
      CALLDRAW(M,FREQ,X,0,0,LABEL,ITITLE,ABS,ORD,0,0,2,2,IWD,IHI,1,LAST)
  500 CONTINUE
  101 FORMAT (2I2,F8.5,2I6,I4)
  102 FORMAT (12F6.4)
  103 FORMAT (99H1 T U K E Y  S P E C T R U M  E S T I M A T E S,
     1POWER SPECTRAL DENSITY AND AUTO-CORR. CALCS.     //)
  104 FORMAT (20H  DATA CONTROL CARD  //)
  105 FORMAT (30H0 DATA RECORD--(P(I)=1,100)      //)
  106 FORMAT (10F8.3)
  107 FORMAT (8H XFACT= F8.5,8H  A(0)= F12.5  //)
  108 FORMAT (42H TAU(SEC)  AN(TAU)    FREQ(CPS)  XN(FREQ)   //)
  109 FORMAT(F9.3,F10.5,F12.3,F10.5)
  110 FORMAT (3X,I4)
  111 FORMAT (3X,O16)
  112 FORMAT (31H1  ERROR IN SR DATA AT HEADING )
  113 FORMAT (40X,I3,7X,O16)
```

TABLE III (continued)

```
  114 FORMAT (22H  IDENT(N),N=1,NUMHDR  //)
  115 FORMAT (A8)
  116 FORMAT (2F10.4,2I3)
      END

      SUBROUTINE DATA(IDENT,MAX,KLIST,KFLAG)
      DIMENSION IBLOCK(1001),KDATA(4000,2)
      COMMON KDATA, IBLOCK
C     KDATA IS THE OUTPUT LIST AND IS REFERENCED BY KLIST
C     SUBROUTINE DATA CALLS ON SR UNPACK AND SR FINDIT
C     AFTER UNPACK THERE EXISTS ONE 1604 WORD/160 WORD
C     ASSIGNMENT NOS USED IN DATA,822,823,824,825,828,829
  824 FORMAT(48H1 ERROR OCCURRED IN FINDIT SUBROUTINE AT HEADER )
  825 FORMAT(50X,O16)
  828 FORMAT(33H0 I HAVE UNPACKED DATA HEADED BY ,O16      )
 830  FORMAT(1X,I4,3X,O16)
      CALL FINDIT(IDENT,MAX,IFLAG)
      IF(IFLAG) 822,823,822
  822 PRINT 824 $ PRINT 825,IDENT $KFLAG=1$ GO TO 829
  823 JMAX=MAX/4+1
      CALL UNPACK (IBLOCK,JMAX,KLIST,KDATA(1,KLIST))
      KFLAG = 0 $ PRINT 828 , IDENT
      DO 826 M=1,4
  826 PRINT 830,M,KDATA(M,KLIST)
      J = MAX - 3
      DO 827 M = J, MAX
  827 PRINT 830,M,KDATA(M,KLIST)
  829 CONTINUE
      END
```

TABLE III (continued)

```
      SUBROUTINE FINDIT(IDENT,MAX,IFLAG)
      DIMENSION KDATA(4000,2),IBLOCK(1001)
      COMMON KDATA,IBLOCK
  814 FORMAT(53H1 A PARITY ERROR WAS DETECTED BUT RUN WAS NOT STOPPED)
  815 FORMAT(45H PARITY ERROR OCCURRED AT HEADER AS FOLLOWS)
  816 FORMAT (33X,O16)
  818 FORMAT (32H1 I HAVE LOCATED DATA HEADED BY     , O16       )
  820 FORMAT(38H UNABLE TO LOCATE HEADING AS FOLLOWS)
      MAX1=MAX/4 + 1 $ ASSIGN 811 TO JUMP
  805 BUFFER IN (1,1)(IBLOCK(1),IBLOCK(MAX1))
  806 IF(UNIT,1) 806,807,808,810
  807 IF(IDENT-IBLOCK(1)) 805,813,805
  808 GO TO JUMP,(811,812)
  811 REWIND 1$ ASSIGN 812 TO JUMP $ GO TO 805
  810 IPAR=1$ GO TO 807
  812 REWIND 1$ GO TO 819
  809 PRINT 814$ PRINT 815$ PRINT 816,IDENT$ GO TO 817
  813 IF(IPAR)809,817,809
  817 IFLAG=0 $ PRINT 818,IDENT$ GO TO 821
  819 PRINT 820
      PRINT 816,IDENT
      IFLAG=1
  821 CONTINUE
      END
```

TABLE III (continued)

```
          IDENT      UNPACK         ARGS IBLOCK,JMAX,KLIST,KDATA
          ENTRY      UNPACK         SUBR UNPACK CALLED BY SR DATA
UNPACK    SLJ        **
          SIU    1   EXIT
          LIU    1   UNPACK          JMAX=MAX/4+1, MOST=JMAX-1
          LDA    1   0              GETS ADDR OF CALLING ARGS
          SAL        U1              U1 IS JMAX ADDR
          ARS        24             IBLOCK PACKED IN DATA 1001 WDS
          INA        -1
U1        SAU        AADRS          ADRS OF IBLOCK IN AADRS
          LDA        **              FILLED IN BY 3 INSRUCTIONS BACK
          SAU        BADRS          STORE JMAX IN LOOP COUNT
          LDA    1   1               GO GET ADRS OF NEXT ARG
          SAU        J4              STORE ADRS OF KDATA(1,KLIST)
          INA        1              ADVANCE ADRS
          SAL        J3              STORE ADRS OF KDATA(2,KLIST)
          INA        1
          SAU        J2              DITTO FOR KDATA(3,KLIST)
          INA        1
          SAL        J1              DITTO FOR KDATA(4,KLIST)
          INI    1   2              SET CORRECT EXIT ADRS
          SIU    1   EXIT+1          STORE IN EXIT INST
          SIL    2   EXIT           SAVE INDEX 2
          ENI    1   2               FIRST DATA WORD IN IBLOCK
          ENI    2   0              FIRST WORD IN KDATA IS DATA
AADRS     LDA    1   **              IBLOCK(J)
          LRS        12             SHIFT 4TH WORD INTO A REG
J1        QRS        36              RIGHT JUST,SIGN EXTEND
          STQ    2   **             STORE IN KDATA (I+4,KLIST)
          LRS        12              SHIFT 3RD WORD INTO Q
```

TABLE III (continued)

```
          QRS        36                RIGHT JUST ,SIGN EXTEND
J2        STQ    2   **                 STORE IN KDATA(I+3,KLIST)
          LRS        12                SHIFT 2ND WORD INTO A REG
J3        QRS        36                  RIGHT JUST, SIGN EXTEND
          STQ    2   **                STORE IN KDATA(I+2,KLIST)
J4        STA    2   **                 1ST WORD NOW RT.JUST +SIGN EXT
          INI    2   4                 I=I+4
BADRS     ISK    1   **                 ISK ON JMAX
          SLJ        AADRS             J=J+1 REPEAT LOOP
EXIT      ENI    1   **                 RESTORE INDEX 1
          ENI    2   **                RESTORE INDEX 2
          SLJ        **                  JUMP OUT
          END                          SUBROUTINE UNPACK
          END
          FINIS
-EXECUTE.
```

APPENDIX C

TABLES OF COMPUTED AVERAGE SPECTRAL DENSITIES

Five power spectra were averaged for each average power spectrum shown in Figures 3 through 9. The average values of power spectral density versus frequency from which the average spectra were drawn are listed in Tables IV through X.

TABLE IV

AVERAGE POWER SPECTRAL DENSITIES
0-20 cps, FILTER, VANE FREE

Frequency (cps)	Energy	Frequency (cps)	Energy
0.0	1.02972	4.5	.00628
0.1	2.40273	4.6	.00524
0.2	2.17715	4.7	.00656
0.3	1.56216	4.8	.00739
0.4	.86354	4.9	.00734
0.5	.41093	5.0	.00758
0.6	.24272	5.2	.00507
0.7	.19241	5.4	.00462
0.8	.14300	5.6	.00503
0.9	.12687	5.8	.00565
1.0	.09937	6.0	.00358
1.1	.07135	6.2	.00352
1.2	.05696	6.4	.00255
1.3	.04846	6.6	.00329
1.4	.04885	6.8	.00366
1.5	.04625	7.0	.00357
1.6	.03681	7.2	.00288
1.7	.03397	7.4	.00228
1.8	.03451	7.6	.00248
1.9	.03137	7.8	.00312
2.0	.03408	8.0	.00238
2.1	.03898	8.2	.00247
2.2	.03691	8.4	.00175
2.3	.03157	8.6	.00161
2.4	.02312	8.8	.00130
2.5	.01920	9.0	.00117
2.6	.02404	9.2	.00126
2.7	.02467	9.4	.00096
2.8	.01899	9.6	.00111
2.9	.01789	9.8	.00100
3.0	.01956	10.0	.00070
3.1	.01738	11.0	.00084
3.2	.01548	12.0	.00038
3.3	.01781	13.0	.00045
3.4	.01733	14.0	.00040
3.5	.01250	15.0	.00024
3.6	.01008	16.0	.00017
3.7	.01171	17.0	.00011
3.8	.01288	18.0	.00010
3.9	.01162	20.0	.00006
4.0	.01053		
4.1	.00980		
4.2	.00891		
4.3	.00885		
4.4	.00849		

Average XFACT = .95139
Average A(0) = .25695

TABLE V

AVERAGE POWER SPECTRAL DENSITIES
0-20 cps, FILTER, VANE FIXED

Frequency (cps)	Energy	Frequency(cps)	Energy
0.0	1.58421	4.5	.00827
0.1	2.74913	4.6	.00884
0.2	1.87637	4.7	.00917
0.3	1.06050	4.8	.00836
0.4	.56193	4.9	.00744
0.5	.39477	5.0	.00696
0.6	.34068	5.2	.00834
0.7	.26455	5.4	.00651
0.8	.21270	5.6	.00665
0.9	.15058	5.8	.00471
1.0	.10860	6.0	.00497
1.1	.10138	6.2	.00661
1.2	.08719	6.4	.00438
1.3	.08060	6.6	.00516
1.4	.08737	6.8	.00494
1.5	.07508	7.0	.00383
1.6	.05162	7.2	.00534
1.7	.04714	7.4	.00431
1.8	.04651	7.6	.00357
1.9	.04443	7.8	.00452
2.0	.04520	8.0	.00395
2.1	.03793	8.2	.00333
2.2	.03017	8.4	.00285
2.3	.03243	8.6	.00314
2.4	.03381	8.8	.00209
2.5	.02888	9.0	.00221
2.6	.02345	9.2	.00174
2.7	.02105	9.4	.00186
2.8	.02309	9.6	.00195
2.9	.02518	9.8	.00166
3.0	.02680	10.0	.00135
3.1	.02716	11.0	.00141
3.2	.02415	12.0	.00091
3.3	.02163	13.0	.00058
3.4	.01860	14.0	.00038
3.5	.01473	15.0	.00036
3.6	.01297	16.0	.00022
3.7	.01286	17.0	.00018
3.8	.01403	18.0	.00019
3.9	.01516	20.0	.00007
4.0	.01443		
4.1	.01306		
4.2	.01136		
4.3	.00940		
4.4	.00853		

Average XFACT = .92798
Average A(0) = .27124

TABLE VI

AVERAGE POWER SPECTRAL DENSITIES
0-500 cps, NO FILTER, VANE FREE

Frequency (cps)	Energy	Frequency (cps)	Energy
0	.12076	188	.00056
4	.12954	192	00027
8	.01088	212	.00034
12	.00348	232	.00041
16	.00227	252	.00024
20	.00159	272	.00017
24	.00120	292	.00020
28	.00098	312	.00020
32	.00085	332	.00038
36	.00069	352	.00017
40	.00054	372	.00019
44	.00045	392	.00047
48	.00045	412	.00028
52	.00047	420	00038
72	.00034	424	.00050
92	.00045	428	.00053
104	.00057	432	.00046
112	.00040	452	.00026
132	.00047	472	.00042
152	.00021	492	00031
172	.00018	496	.00040
180	.00048	500	.00023
184	.00084		

Average XFACT = .80523
Average A(0) = .24117

TABLE VII

AVERAGE POWER SPECTRAL DENSITIES
0-500 cps, NO FILTER, VANE FIXED

Frequency (cps)	Energy	Frequency (cps)	Energy
0	.11824	140	.00065
4	.12909	152	.00017
8	.01402	172	.00019
12	.00562	192	.00013
16	.00394	212	.00012
20	.00261	232	.00025
24	.00193	252	.00014
28	.00159	272	.00030
32	.00145	292	.00010
36	.00121	312	.00004
40	.00098	332	.00009
44	.00086	352	00005
48	.00076	372	.00003
52	.00068	392	.00009
64	.00083	404	.00022
68	.00086	408	.00014
72	.00058	412	.00007
92	.00061	432	.00007
100	.00044	448	.00057
104	.00039	452	.00057
112	.00027	472	.00055
132	.00113	492	.00007
136	.00129	500	.00002

Average XFACT = .80876
Average A(0) = .28710

TABLE VIII

AVERAGE POWER SPECTRAL DENSITIES
0-500 cps, FILTER, VANE FREE

Frequency (cps)	Energy	Frequency (cps)	Energy
0	.13247	212	.00021
4	.14017	232	.00028
8	.01024	236	.00064
12	.00390	240	.00084
16	.00220	244	.00048
20	.00154	248	.00013
24	.00118	252	.00009
28	.00088	272	.00005
32	.00073	292	.00003
36	.00063	312	.00005
40	.00055	320	.00022
44	.00045	332	.00006
48	.00043	352	.00008
52	.00041	372	.00006
72	.00025	392	.00012
80	.00049	412	.00013
84	.00031	432	.00021
92	.00018	436	.00029
112	.00018	440	.00026
132	.00030	452	.00013
152	.00012	472	.00020
172	.00015	492	.00016
192	.00017	500	.00008

Average XFACT = .79104
Average A(0) = .25916

TABLE IX

AVERAGE POWER SPECTRAL DENSITIES
0-500 cps, FILTER, VANE FIXED

Frequency (cps)	Energy	Frequency (cps)	Energy
0	.10440	232	.00036
4	.11572	252	.00027
8	.01525	272	.00037
12	.00688	292	.00029
16	.00474	312	.00020
20	.00296	316	.00022
24	.00210	332	.00030
28	.00190	352	.00026
32	.00172	372	.00023
36	.00136	392	.00040
40	.00116	396	.00043
44	.00119	400	.00041
48	.00123	412	.00029
52	.00106	432	.00018
72	.00063	436	.00035
92	.00043	440	.00065
112	.00059	444	.00066
132	.00071	452	.00040
152	.00028	472	.00075
172	.00029	476	.00088
192	.00030	480	.00046
204	.00042	492	.00012
208	.00038	500	.00007
212	.00039		

Average XFACT = .82849
Average A(0) = .27232

TABLE X

AVERAGE POWER SPECTRAL DENSITIES
0-1000 cps, FILTER, VANE FIXED

Frequency (cps)	Energy	Frequency (cps)	Energy
0	.09235	292	.00005
4	.11094	312	.00007
8	.02349	332	.00006
12	.00879	352	.00007
16	.00638	372	.00005
20	.00488	392	.00006
24	.00298	412	.00011
28	.00203	432	.00003
32	.00166	452	.00006
36	.00159	472	.00005
40	.00146	492	.00007
44	.00135	512	.00027
48	.00120	552	.00001
52	.00111	592	.00001
72	.00087	632	.00002
92	.00048	672	.00003
112	.00068	712	.00003
132	.00053	752	.00010
152	.00035	792	.00016
172	.00022	832	.00010
192	.00014	872	.00017
212	.00013	912	.00017
232	.00028	952	.00008
252	.00008	992	.00012
272	.00007	1000	.00006

Average XFACT = .84719
Average A(0) = .15414

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13. ABSTRACT

In order to understand more fully the wind generation of water waves, the oceanographer should have a better knowledge of the turbulence structure of the wind field immediately above a water surface.

Measurements of atmospheric turbulence about three inches above the surface of a lake, using a hot-wire anemometer, were made. The analog signals were recorded as DC voltages on a magnetic tape recorder. The analog data were converted to digital form to permit subsequent computation of power spectral densities using a high-speed digital computer.

Average power spectral densities from 0 to 20, 0 to 500, and 0 to 1000 cps, respectively, are presented.

14. KEY WORDS	LINK A		LINK B		LINK C	
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