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PRELIMINARY RESULTS OF ANEMOMETER COMPARISON TESTS

By Dennis W. Camp
Aero-Astrodynamics Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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ABSTRACT

Mean wind speed and wind speed variance obtained by use of anemometers were compared. The preliminary results of this comparison, which was made using statistical, spectral, and relative techniques, show that any of the anemometers will give a good estimation of wind speed. Although the differences in the wind data obtained by the anemometers are pointed out, no attempt was made to specify a "best anemometer," if one exists.

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ENVIRONMENTAL APPLICATIONS BRANCH
AEROSPACE ENVIRONMENT DIVISION
AERO-ASTRODYNAMICS LABORATORY

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PRELIMINARY RESULTS OF ANEMOMETER COMPARISON TESTS

SUMMARY

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Mean wind speed and wind speed variance obtained by use of anemometers were compared. The preliminary results of this comparison, which was made using statistical, spectral, and relative techniques, show that any of the anemometers will give a good estimation of wind speed. Although the differences in the wind data obtained by the anemometers are pointed out, no attempt was made to specify a "best anemometer," if one exists.

I. INTRODUCTION

When wind speed and particularly gust measurements are made, questions concerning the anemometer response are almost certain to arise. Some of these questions are likely to be concerned with the ability of the anemometer to measure the mean and variance of the wind speed. If the mean wind speed is all that is desired, then most anemometers presently being used would be satisfactory. However, if it is desired that the wind speed variations be measured, then the response characteristics of the anemometers must be considered in more detail. Some insight into these questions can be obtained by a comparison of anemometers. The actual response of the anemometers was not investigated in this study.

Both the mean and variance of the wind speed are of concern in the preflight preparation and launch of space vehicles. These parameters are used to calculate space vehicle responses to winds before launch, and to evaluate atmospheric diffusion conditions associated with the use of toxic fuels.

NOTE: The term "mean wind" as used in this report refers to a five-minute arithmetic average of data points having an interval of 0.5 seconds.

II. DISCUSSION OF ANEMOMETERS AND MEASURED WIND DATA

When the comparison tests were first conceived, it was thought that the program would involve approximately eleven anemometers. These anemometers were of four types: hot wire, rotating cup, propeller, and drag sphere. For various reasons, the hot-wire and drag sphere types of anemometers were deleted from the preliminary comparison. The anemometers used in the preliminary tests were as follows:

Cup-Type

(1) Beckman & Whitley Series 50 (Plastic 3 cup),

(2) Beckman & Whitley Series 100, and

(3) Climet Model Cl-14.

Propeller-Type

(1) Aerovane Model 120, and

(2) Meteorology Research, Inc.'s Velocity Vane Model 1057.

The support structure on which the anemometers were mounted for testing is shown in Figure 1. The anemometers were mounted at a height above the ground of 3.5 meters. The distance between the anemometers was approximately 1.2 meters; the height of the sensors above the crossarm was approximately 0.8 meters. When tests were made, the mean wind flow was perpendicular to the crossarm. This, however, did not restrict testing periods since the support structure can be rotated through 360 degrees. The wind directions from which no tests were made were ±45 degrees from true North. The reason for this restriction is that buildings and other obstructions are in the flow field close to the support structure in this quadrant.

Representatives of the companies whose anemometers are compared in this report have seen and agreed to the conditions and the equipment (support structure, recorders, and related components) used in this study.

The photograph in Figure 1 was taken facing a southeasterly direction. The pipe running horizontally across the figure in the background is approximately 168 meters from the support structure. The buildings in the background are about 274 meters from the support structure. The open structures in the far background are test stands which are approximately 1770 meters from the support structure.

The Honeywell 1612 Visicorder Oscillograph was used to record the wind data measured by the above named anemometers. This recorder is capable of recording data having frequencies much higher (approximately 600 cycles per second) than any of the anemometers are capable of measuring. Examples of the wind speed time histories recorded by the visicorder are given in Figures 2 and 3. Figure 2 illustrates time histories of wind speed measured by the Aerovane, Beckman & Whitley (B&W) Series 50 with 3 cups, B&W Series 100, and the Climet Model Cl-14. Figure 3 illustrates time histories for the Aerovane and the Meteorology Research, Inc. (MRI) Velocity Vane (V.V.). These time histories of the wind were recorded at a chart speed of 0.4 inches per second. The timing lines on the charts are 1.0 second apart. The wind data used in the analysis were obtained from the charts using a data interval of 0.5 seconds for 5.0-minute periods.

The arrangement of the anemometers during the first three tests is shown in Figure 1. The anemometers aligned from the northeast (left side of figure) are B&W Series 50, B&W Series 100, Aerovane, and Climet. The Climet anemometer is on the southwest (right side of figure) end of the crossarm. The B&W Series 100 and the Climet anemometers have separated mountings on the crossarm for their direction sensor and speed sensor. For Tests 5 and 6, the B&W Series 100 was replaced by the Velocity Vane. In these two tests, no data were obtained from the B&W Series 50 or the Climet anemometers.

The wind data for a given test were obtained simultaneously from all the anemometers. For example, in the first test, the wind speed was measured and recorded (Figures 2 and 3) simultaneously for the Aerovane, B&W Series 50, B&W Series 100, and the Climet.

III. DATA ANALYSIS

Three procedures were used. The first compared the basic statistical parameters of the data. These parameters were the arithmetic mean and variance which were computed for the five-minute data runs. The second procedure consisted of comparing the spectra of the five-minute data periods and the third procedure was a more or less relative comparison.

A. Comparison of Mean Wind Speeds and Variances

As evident from Tables I and II, the mean wind speeds measured by the different anemometers show variations. For example, in the first test the maximum difference of the means was 1.8 meters per second (a percentage difference of 29.2 percent). This difference existed between the Aerovane and B&W Series 100. It is interesting to note that these two anemometers were positioned next to each other (see Figure 1). For the first test the smallest difference was 0.2 meters per second, or a difference of 2.6 percent. This was between the Climet and B&W Series 100. The largest mean wind speed difference occurred only once between anemometers having the greatest horizontal separation. As noted in Figure 1, this was between the B&W Series 50 and the Climet anemometers.

The columns in Tables I and II labeled "Mean of All Anemometers" are the arithmetic means of the mean wind speeds of the individual anemometers for a given test. It is reasonable to assume that this mean is more apt to be closer to the true mean for the given test than any individual anemometer mean. This mean value is used to illustrate the variations in the individual means. No consistent bias existed; i.e., none of the anemometers measured high or low for all cases. The Aerovane and B&W Series 50 measured low for the first test and high in the second and third tests. The reverse of this is true for the B&W Series 100 and the Climet.

Probably a more interesting and informative parameter to investigate than the mean wind speed is the wind speed variance. Ideally, the true wind variance, as obtained by an anemometer, is affected only by its response. However, in the real situation, errors are introduced into the variance by other components of the anemometer system and also in handling the wind data. No attempt was made to reduce or remove any errors of the anemometer system, since it was desired that the wind measurements as obtained from the systems be compared. Further, since the wind data were handled in the same manner, the errors introduced in data handling should be equal. Thus, no attempt was made to reduce the data handling errors.

Table I shows that the Aerovane has the smallest variance compared to the other three anemometers. It is reasonable to assume that the true wind variance is greater than indicated by the Aerovane. This assumption is, in fact, substantiated by two factors: (1) the other anemometers had larger variances and (2) the Aerovane does not have the response capability for measuring short period fluctuations [1,2]. The Aerovane, for example, is only about 85.0 percent responsive to wind speed fluctuations for periods of 5.0 seconds and a mean wind speed of 10.0 meters per second [2]. For the same period and mean wind speed, the other anemometers are about 98.9, 98.2, 99.6, and 97.8 percent responsive for the B&W Series 50, B&W Series 100, Climet, and V. V., respectively. The response value for the Climet was obtained using information from Reference 3. Response values for the B&W Series 50, B&W Series 100, and V. V. were obtained using information from the respective company specifications (References 4, 5, and 6, respectively).

In the first test the B&W Series 100 had the largest variance, and for the second and third tests, the Climet had the largest variance. Very little, if anything, can be said about the variance of the third and fourth tests, since only two anemometers were used. Wind variance will be discussed further in the next section in conjunction with spectra.

B. Comparison of Wind Spectra

The procedure used to compute the spectral estimates of this report is explained in Reference 7. Since a discussion of the computational method for spectra is not pertinent to the present discussion, it will not be repeated here. However, it is expedient to state that the spectra in Figures 4 - 8 are normalized spectral estimates. These estimates were obtained from simultaneous wind speed measurements. Figures 4 - 6 are spectral estimates for wind speed data obtained by use of the B&W Series 50, B&W Series 100, Climet, and Aerovane anemometers. Figures 4 - 8 are for wind speed comparison tests 1 - 5, respectively. These tests were made on different days in order that different wind flow fields might be sampled.

It is interesting to note, from the figures, the closeness of the spectral estimates for wind gusts (variance) having periods of 5.0 seconds or longer. This is especially true for the low wind speed case (Figure 4). Since these spectral estimates show the percentage of variance as a function of period and frequency, a comparison of the information obtained from them with the computed wind speed variance is in order. The spectral estimates of Figures 4 - 6 show the wind variance obtained from the Aerovane wind data to be much lower than that obtained from the other three anemometers (B&W Series 50 and 100, and Climet) for periods less than 5.0 seconds. Thus, it is to be expected that the percentage of wind variance obtained by using the Aerovane would be larger for periods longer than 5.0 seconds than that of the other anemometers. This fact is seen to be true from the percentage values given in Table III. The closeness of the spectral estimates for the B&W Series 50, B&W Series 100, and the Climet is essentially substantiated by the variance values given in Table III. For example, Table III shows that the variance obtained by use of the Aerovane is almost entirely for gust periods of 5.0 seconds or longer. From the spectral estimates, it is seen that the wind variance obtained by use of the Aerovane decreases very rapidly for periods less than 5.0 seconds. Further, Table III shows that the wind variance obtained using the B&W Series 50, B&W Series 100, and Climet have nearly equal percentage values for periods of 5.0 seconds or longer. The spectral estimates show that these three anemometers have nearly equal wind variances for the 5.0-second and longer periods, but differ for periods shorter than 5.0 seconds.

Statistical confidence has been computed for the spectral estimates (for the 5 percent level) of this report using the procedure as given by Panofsky [8]. The major peaks of the spectra are significant according to the confidence testing. The minor peaks are the result of drawing the best curve fit to the raw spectral estimate values by eye. Thus, they should not be considered significant. Since the purpose of this report is to present results of a comparison study and not a discussion of spectra, no attempt will be made to explain these peaks nor the reason for them.

Table III gives the percentage of variance of wind speed as seen by the respective anemometers for periods of 5.0 seconds and longer. This table shows, as expected, that as the mean wind speed increases, more variance is seen in the shorter periods; i.e., spectral energy is shifted to higher frequencies. Furthermore, the table shows a smaller shift for the Aerovane and V. V. than for the cup-type anemometers. The Aerovane shift appears to be less than the shift of the V. V. A shift of 0.5 and 1.1 percent is observed for the Aerovane and V. V. for a mean wind speed change of approximately 0.1 meters per second, respectively. No significance should be attached to this comparison of the shift between the Aerovane and V. V. until more data are analyzed which have a greater change in mean wind speed.

A more valid comparison can be made between the other three tests. For the Aerovane, a shift of variance of approximately 3.8 percent occurred when the mean wind speed changed by approximately 3.8 meters per second. This same change in mean wind speed caused a shift of approximately 7.3, 5.5, and 11.1 percent for the B&W Series 50, B&W Series 100, and the Climet anemometers, respectively.

Perhaps more noteworthy than the variance shift is the amount of variance accounted for by wind gusts having periods of 5.0 seconds or longer. For example, 94.6 percent of the wind variance (gusts) as measured by the Aerovane has periods equal to or longer than 5.0 seconds (Table III). This percentage value is for a mean wind speed of approximately 7.15 meters per second. The anemometer capable of measuring, according to these preliminary tests, the largest amount of wind variance for periods less than 5.0 seconds is the B&W Series 50. However, before any definite statements can be made, more testing of the anemometers is needed, both in the wind tunnel and in the real environment. It is possible this variance is due to system errors rather than being real. The peculiar spectrum shown in Figure 4 for this anemometer remains unexplained.

C. Relative Comparison of the Various Anemometers

From what has been stated above, any of the anemometers tested can be used to obtain reasonable mean wind speed measurements. Variances indicate the cup-type anemometers to be the best for measuring short period fluctuations (gusts) of the wind; however, this conclusion needs further verification. In view of this, it is instructive to give some relative information about the anemometers and the wind data obtained from them.

The Aerovane is the least responsive of the anemometers tested. However, it is a very durable wind sensor, easy to operate, and requires very little maintenance. The durability of the V. V. with respect to longevity in the atmospheric environment is yet to be proven.

The B&W Series 100 and the Climet seem to have a fairly good durability, although it is always possible to find exceptions. These two anemometers have a mutual characteristic which could be considered unfavorable: the torque strokes of their cups which are easily seen in the output wind data from these anemometers. The Climet, however, appears to be more responsive than the B&W Series 100. The data of the B&W 50 also show a torque stroke since a 3-cup system was used.

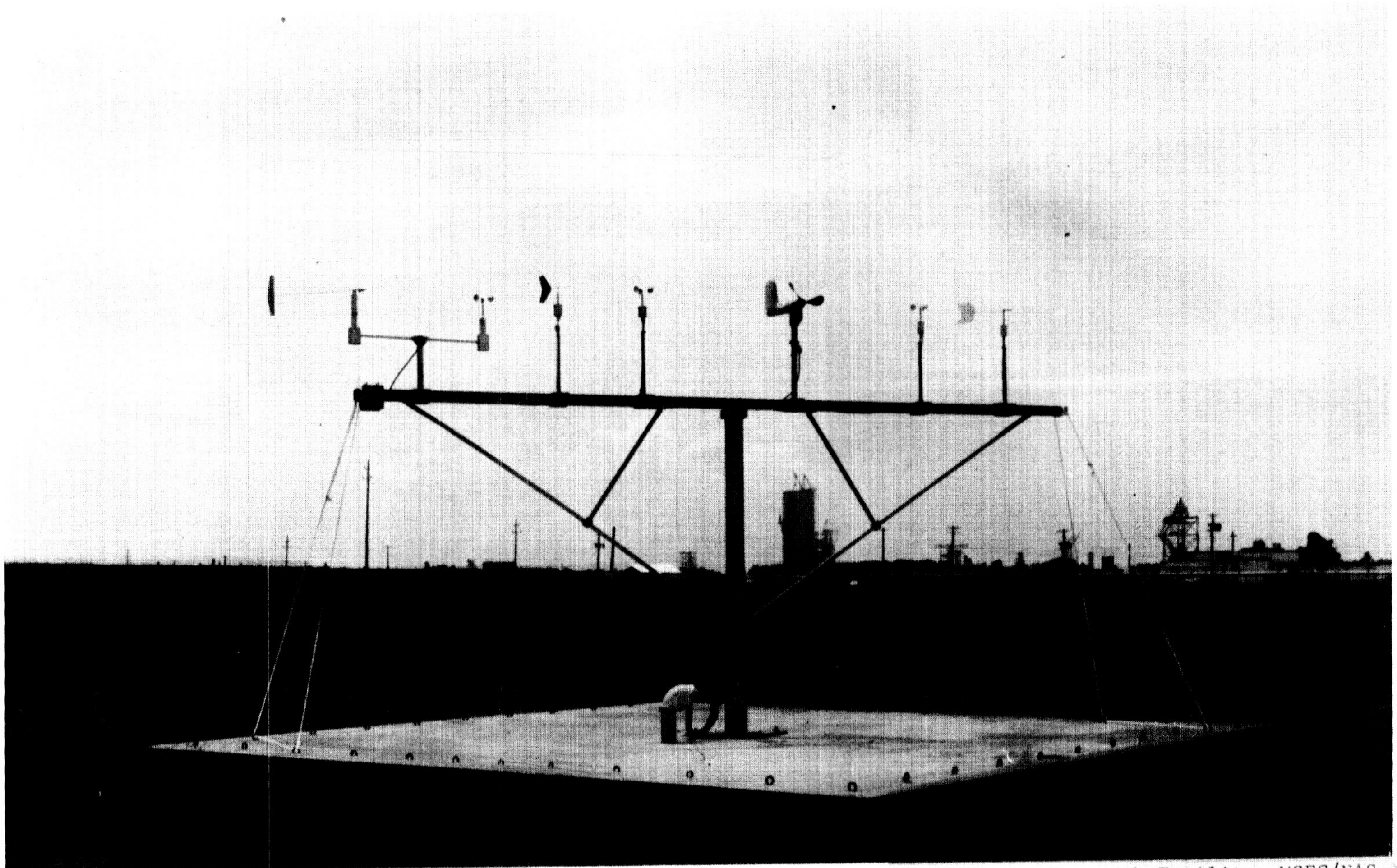
The B&W Series 50, for all practical purposes, alleviates the torque stroke seen in the output data of the B&W Series 100 and Climet, if the "Staggered-Six" cups are used. The durability of the B&W Series 50, like that of the V. V., is yet to be proven with respect to longevity in the atmosphere. It is very probable that both the B&W Series 50 and the V. V. will pass the longevity durability test of time. According to the manufacturers, the response of the B&W Series 50 is quite good. The B&W Series 50 and the Climet anemometers, which have been investigated in the White Sands Missile Range wind tunnel [3], were found to have similar response characteristics.

IV. COMMENTS

The results of this preliminary study show that any of the five anemometers tested will give a fairly good estimation of the mean wind speed. For wind speed variance, the cup-type anemometers appear to give the best results. This is most likely due to the cups being more responsive to wind speed change than are the propeller-type anemometers, but it could also be due to system error. These test results are preliminary, and more testing is needed before any definite statements can be made.

The spectra of the anemometers tested had the majority of the wind speed variance accounted for by wind tusts having periods equal to or greater than 5.0 seconds. The agreement of the spectral estimates was generally good between the cup-type anemometers. Also, good agreement existed between the spectral estimates of the Aerovane and Velocity Vane.

This preliminary study has illustrated the need for further investigation of the various types of anemometers. It is the intention of the author to continue comparing and testing these and other anemometers.



(Atmospheric Research Facility, MSFC/NASA)

Figure 1. A View of the Anemometer Support Structure and Four of the Anemometers Used in the Comparison Study (Facing Southeast)

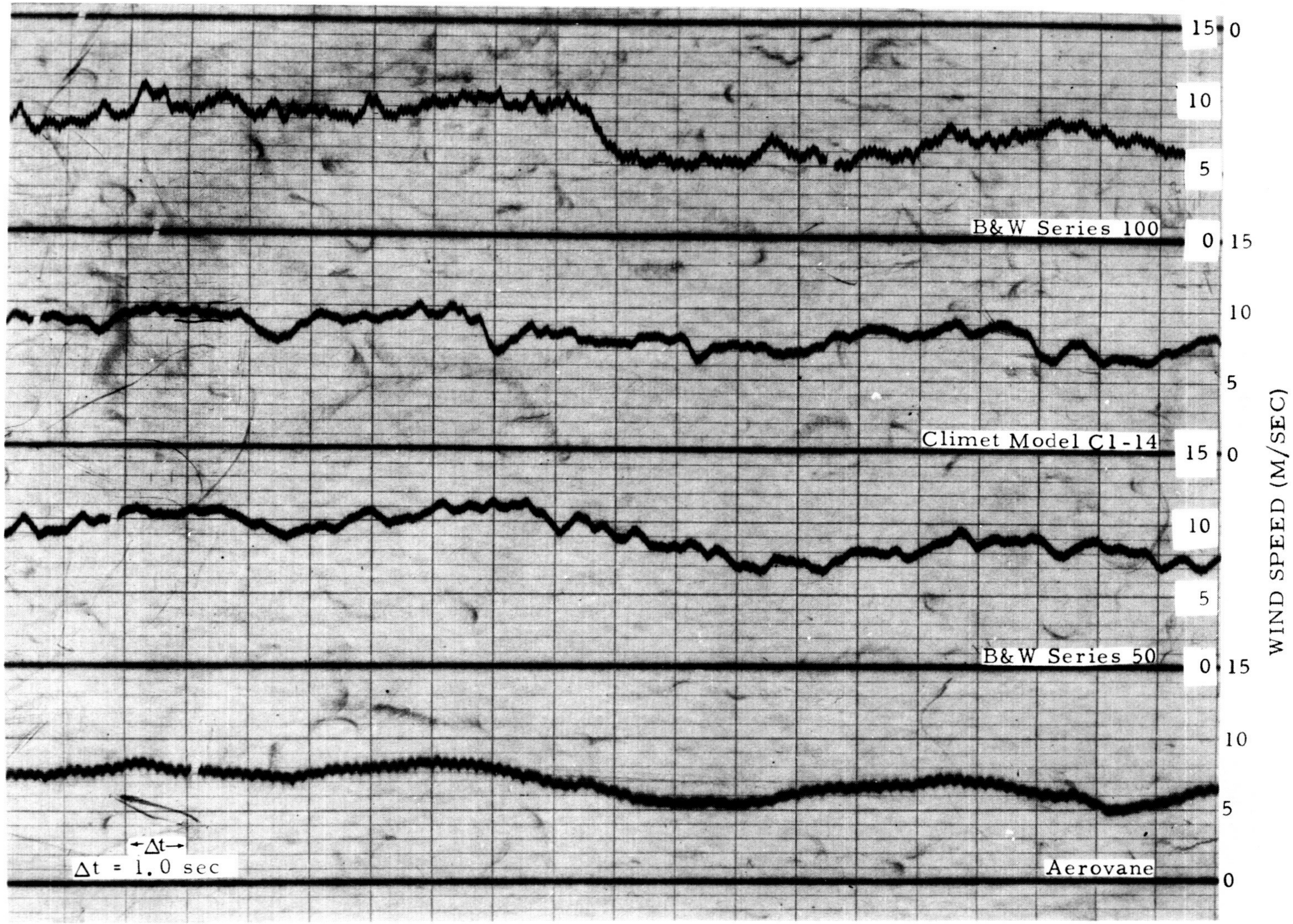


Figure 2. Wind Speed Time Histories for the Aerovane, Beckman & Whitley Series 50 and 100, and the Climet Model C1-14 as Recorded by Use of the Honeywell 1612 Visicorder

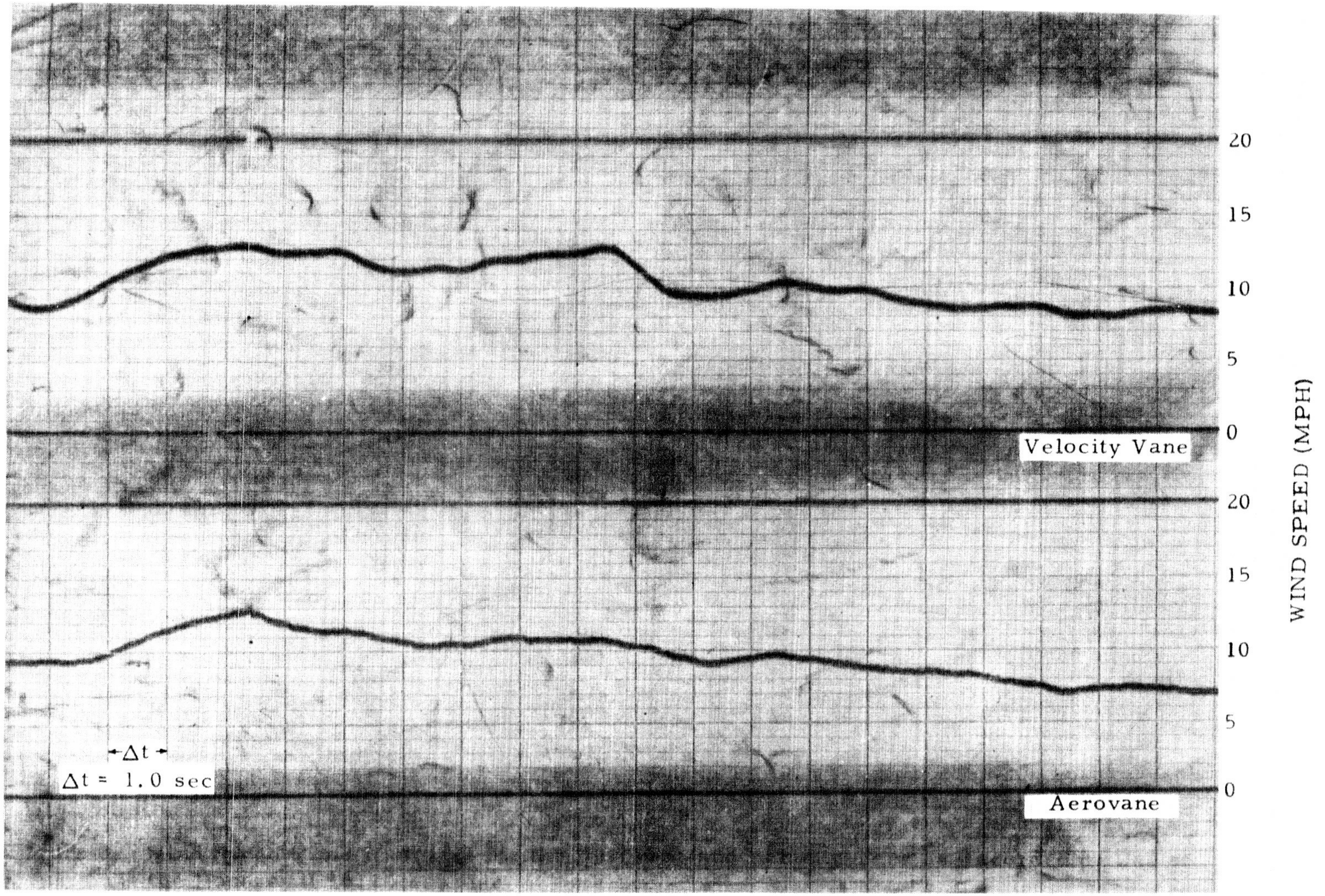


Figure 3. Wind Speed Time Histories for the Aerovane and Velocity Vane as Recorded by Use of the Honeywell 1612 Recorder

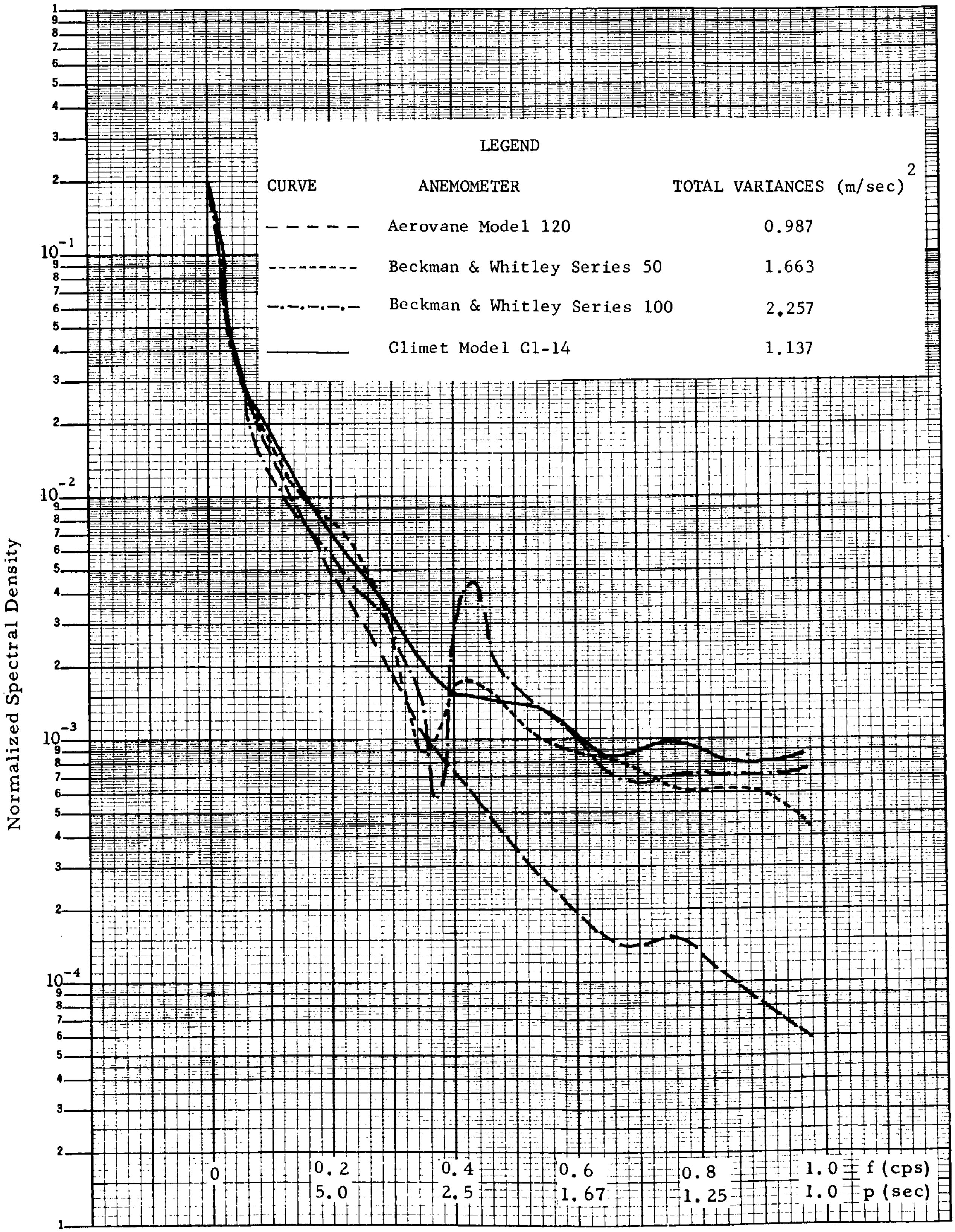


Figure 4. Spectrum of Wind Speed for Anemometer Comparison Test Number 1

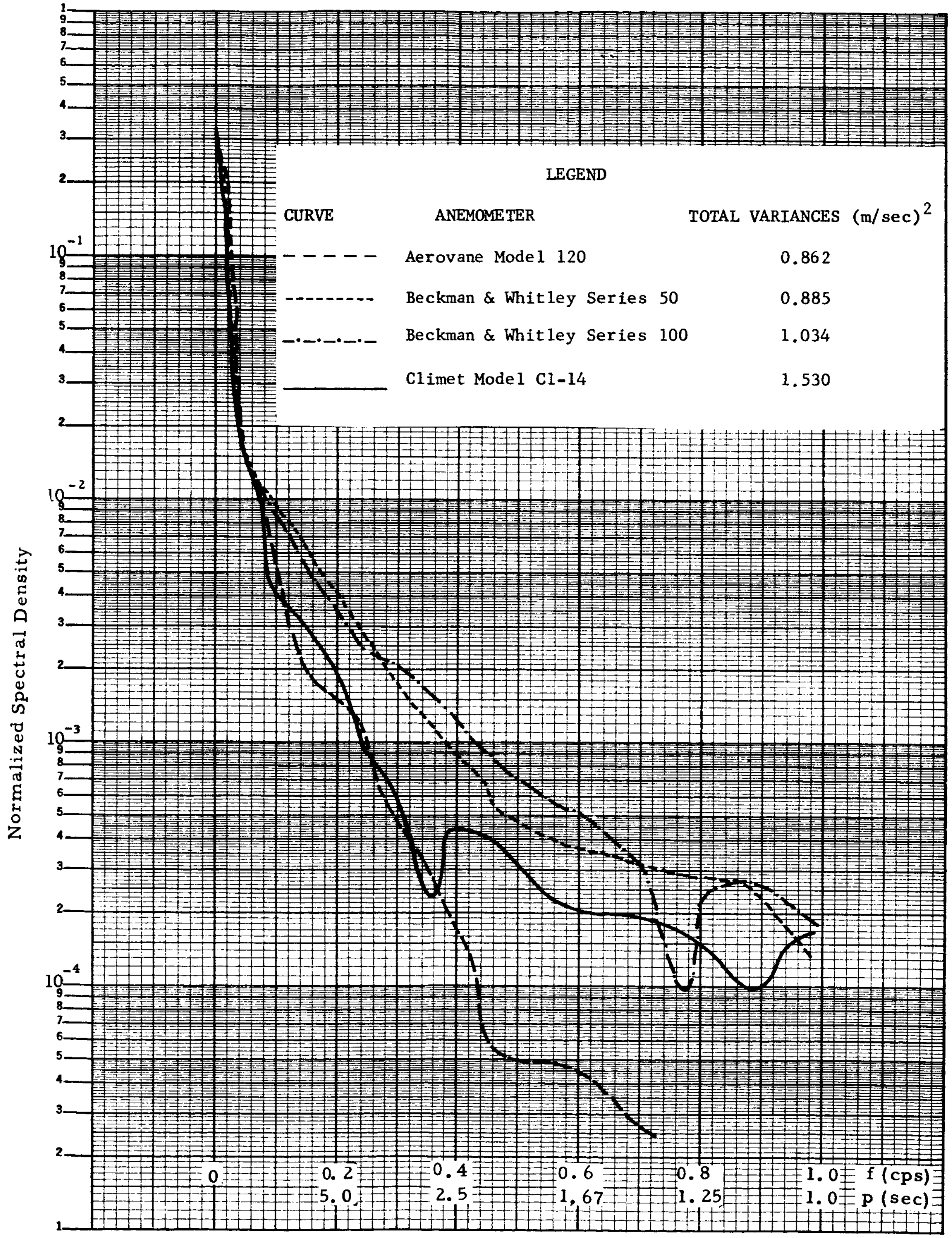


Figure 5. Spectrum of Wind Speed for Anemometer Comparison Test Number 2

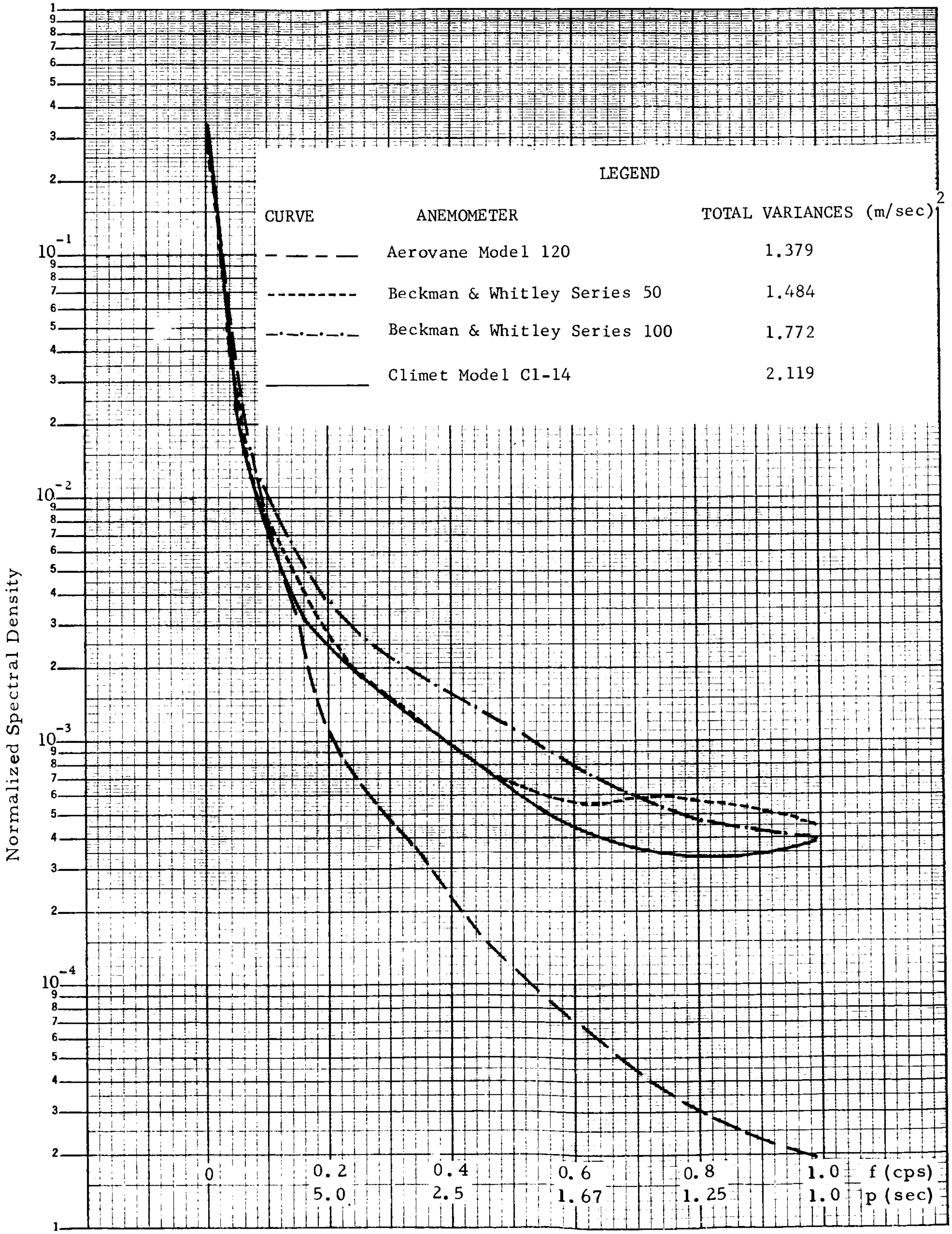


Figure 6. Spectrum of Wind Speed for Anemometer Comparison Test Number 3

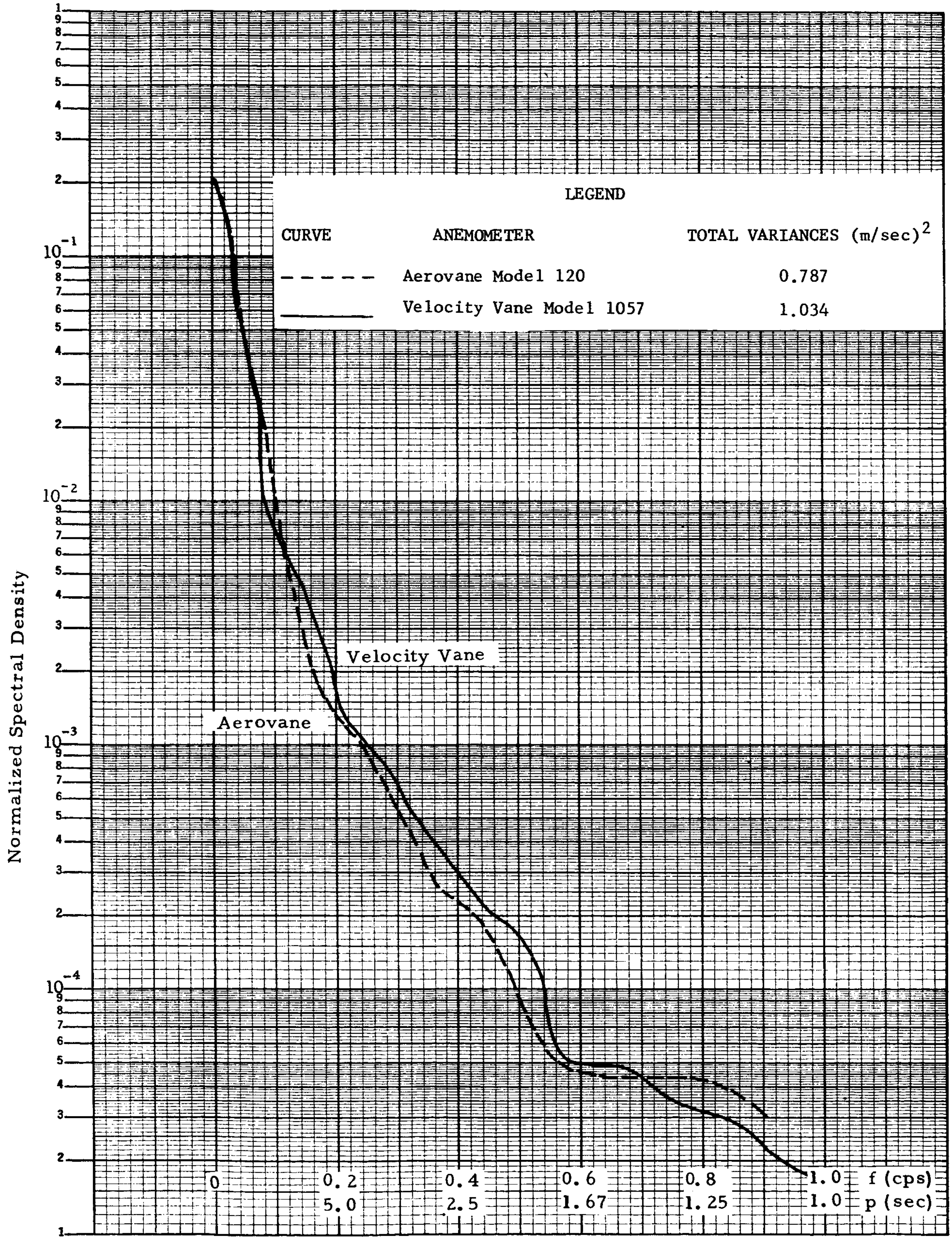


Figure 7. Spectrum of Wind Speed for Anemometer Comparison Test Number 4

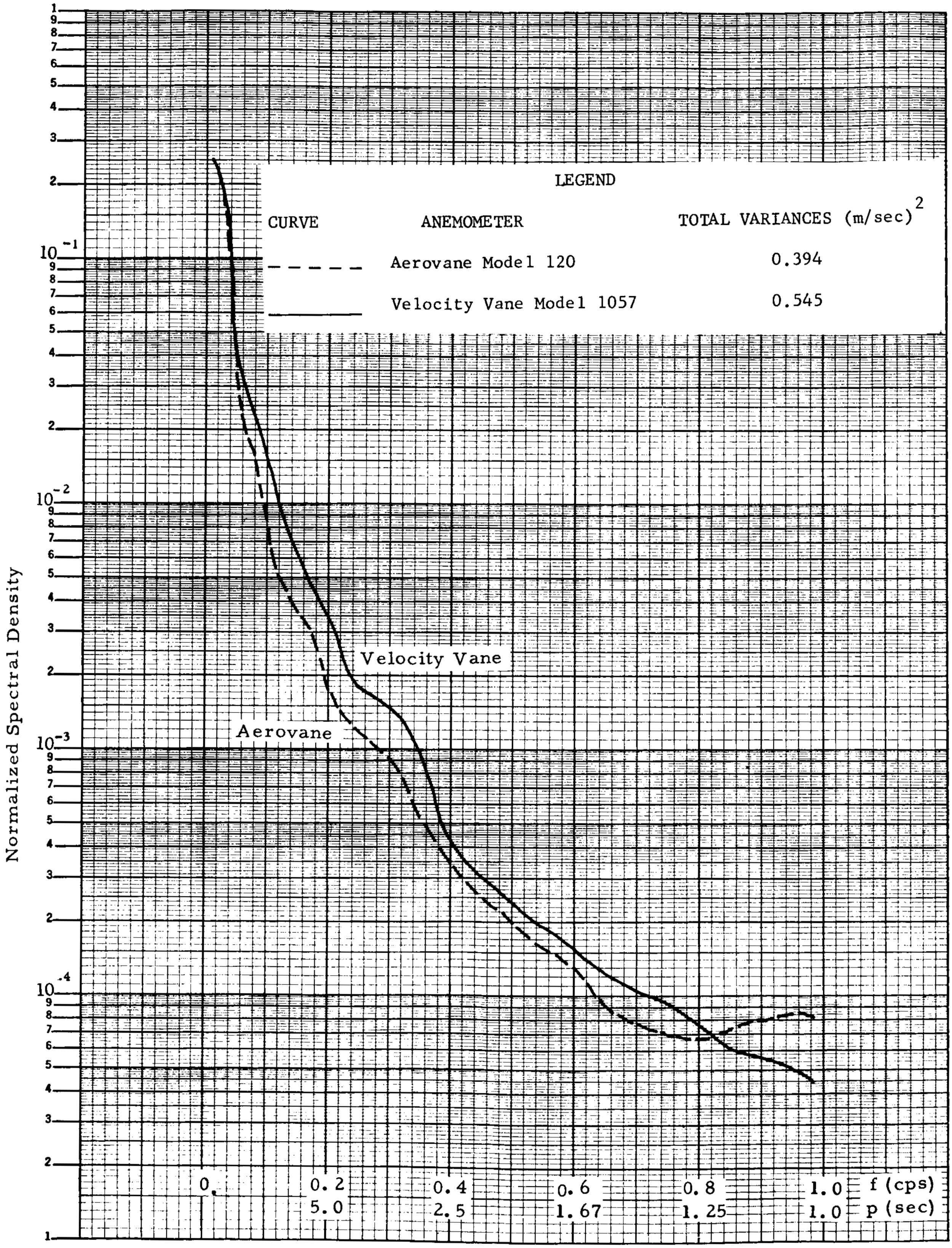


Figure 8. Spectrum of Wind Speed for Anemometer Comparison Test Number 5

TABLE I

Tabulated Statistical Values for Anemometer
Comparison Tests Numbers 1, 2, and 3.

Test Number	Parameter Computed	Anemometer (meters/second)				Mean of All Anemometers (Test Mean) (m/sec)
		Aerovane Model 120	Beckman&Whitley Series 50	Beckman&Whitley Series 100	Climet Model C1-14	
1	Mean	6.16	6.73	7.96	7.76	7.15
	Variance	0.99	1.66	2.26	1.14	
	Percentage * of Test Mean	-13.8	-5.9	11.3	8.5	
2	Mean	3.52	3.51	2.94	3.30	3.32
	Variance	0.86	0.88	1.03	1.53	
	Percentage * of Test Mean	6.0	5.7	-11.4	-0.6	
3	Mean	3.74	3.88	3.32	3.06	3.50
	Variance	1.38	1.48	1.77	2.12	
	Percentage * of Test Mean	6.8	10.8	-5.1	-12.6	

* $\frac{\bar{X} - \bar{\Sigma}}{\bar{\Sigma}} \times 100\%$

$\bar{X}$ = mean of respective anemometer wind data

$\bar{\Sigma} = \frac{\Sigma \bar{X}}{4}$ = mean of all four anemometers

TABLE II

Tabulated Statistical Values for Anemometer Comparison Tests Numbers 4 and 5

Test Number	Parameter Computed	Anemometer (meters/second)		Mean of Both Anemometers (Test Mean) (m/sec)
		Aerovane Model 120	Velocity Vane Model 1057	
4	Mean	4.23	4.67	4.45
	Variance	0.79	1.03	
	Percentage of Test Mean*	-4.9	4.9	
5	Mean	4.28	4.47	4.38
	Variance	0.39	0.54	
	Percentage of Test Mean*	-2.2	2.2	

* $\frac{\overline{X} - \overline{\Sigma}}{\overline{\Sigma}} \times 100\%$

$\overline{X}$ = mean of respective anemometer wind data

$\overline{\Sigma} = \frac{\Sigma \overline{X}}{2}$ = mean of both anemometers

TABLE III

Percent of Wind Speed Variance for Gusts Having Periods Equal to or Greater Than 5.0 Seconds as Measured by Various Anemometers

Anemometer	Test Number				
	1	2	3	4	5
Beckman & Whitley Series 50	84.8	92.1	90.0		
Beckman & Whitley Series 100	87.6	93.1	92.1		
Climet Model C1-14	85.6	96.7	93.3		
Aerovane Model 120	94.6	98.4	98.3	98.2	97.7
Velocity Vane				97.8	96.7
Mean Wind Speed of All Anemometers for given test (m/sec)	7.15	3.32	3.50	4.45	4.38

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Office. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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