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An Evaluation of the ASTM Standard Method for Determining the Performance of a Wind Vane

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AN EVALUATION OF THE ASTM STANDARD METHOD FOR DETERMINING THE PERFORMANCE OF A WIND VANE

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FOREWORD

Measurement and monitoring research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has the responsibility for: assessment of environmental monitoring technology and systems; implementation of agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency including the Office of Air, Noise and Radiation, the Office of Toxic Substances and the Office of Enforcement.

This study was conducted in cooperation with the American Society for Testing of Materials (ASTM). It was done to evaluate a proposed standard method for determining the performance of a wind vane. This and other standard methods for testing meteorological monitoring equipment will be needed in the development of a comprehensive quality control program for meteorological measurements. A quality control and assurance program is needed for these measurements in order to support pollutant dispersion studies, model validation studies, and mandated monitoring activities. A program to develop a quality assurance plan for meteorological measurements is now under way at EMSL/RTP.

Thomas R. Hauser
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ABSTRACT

The American Society for Testing and Materials (ASTM) has proposed a standard method for testing the performance characteristics of a wind vane. This report presents the procedures used to test and evaluate the ASTM method, and the results of that evaluation. Twelve wind vanes were borrowed from their manufacturers and tested using the ASTM procedures. The theory of wind vane dynamics is briefly reviewed, and equipment and procedures are described. The starting threshold, starting accuracy, delay distance, overshoot ratio, and damped wavelength were measured. Damping ratio and natural wavelength were computed from the measurements. Based on the results of these tests, it is concluded that the ASTM method provides a reasonable and reliable technique for determining performance characteristics for many types of wind vanes.

CONTENTS

LIST OF SYMBOLS

d	Aerodynamic damping
d_o	Critical damping
D	Delay distance
$\vec{F}$	Force of wind on vane
J	Moment of inertia of vane
$\vec{N}$	Torque per unit angle of wind on vane
r	Distance between pivot and center of mass of vane
t	Time
t_d	Damped period of time
t_o	Natural period of vane
t_1	Delay time
$\vec{u}$	Wind velocity
u'	Turbulent fluctuation of wind speed
β	Angle between vane and wind
β_o	Initial offset angle
β_v	Effective angle of attack
$\dot{\beta}$	$d\beta/dt$
$\ddot{\beta}$	$d\dot{\beta}/dt$
ΔP	Axial pressure differential in wind tunnel
η	Damping ratio
λ_d	Damped wavelength
λ_o	Natural wavelength
σ	Standard deviation
Ω	Overshoot ratio

ACKNOWLEDGMENTS

This work was able to be done only because of the cooperation of many people and organizations. We are most grateful to the companies that loaned us the wind vanes that were used in these tests; Bendix Co., Environmental Science Division; Climet Instruments Company; Electric Speed Indicator Co.; Meteorology Research Inc.; R.M. Young Company; Teledyne Geotech; Texas Electronics Inc., and WeatherMeasure Corporation. Clearly the support of EPA's Fluid Modeling Facility was essential, and I wish to thank its director, Dr. William H. Snyder, for his support and many helpful discussions of flow vector orientation and members of the very capable staff, Milton Fabert, Robert E. Lawson, Myron Manning, Michael Shipman, and Roger S. Thompson, for their generous help and many kindnesses. Finally and most especially I'd like to thank Ms. Kathy Brehme (now Lieutenant, USAF) for her many hours of excellent assistance collecting and reducing the data for this project.

SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has a continuing need for high quality meteorological data. There are, obviously, no legal standards based upon meteorological data, but air quality models used in multi-million dollar decision-making are verified, validated, calibrated, modified and used in rule-making that requires very accurate and representative data. The Environmental Monitoring Systems Laboratory at Research Triangle Park (EMSL/RTP) has recognized this need and, in response, has begun work to develop a quality assurance program for meteorological data.

One part of any quality assurance program must be the determination of whether or not new and used instruments meet manufacturers and/or users performance specifications. For meteorological instrumentation this area has always been difficult, in part because there are no widely agreed upon testing procedures for determining these performance characteristics. Thus, while manufacturers may state in their literature certain properties of their instruments, or state that they will meet users specifications, there is usually no information available on how the manufacturer determined the specifications of these instruments, and no uniform way the users can check to see if instruments they purchase or are using will meet their requirements.

The American Society for Testing and Materials (ASTM) has started to address this problem. They have published a standard for measuring pressure and are developing standards for measuring humidity and wind velocity. ASTM is also developing a standard method to test the dynamic performance of a wind vane, and it is that method that is the subject of this report.

Since EPA has published standards for the performance of wind vanes (OAQPS, 1978) and is involved in the development and validation of air quality models, it is apparent that a uniform method for evaluating wind vanes would be of benefit to the agency. For this reason, EMSL/RTP decided to undertake a program to test and evaluate the proposed standard method. The purposes of these tests were to determine if (1) the procedures could be carried out by personnel with a reasonable level of experience, (2) the procedures led to precise results, (3) the results were reproducible, and (4) the method met the overall needs of EPA and ASTM.

The proposed ASTM standard method involves a specific detailed procedure for determining the "starting threshold," "delay distance," "overshoot" and accuracy of a vane in a wind tunnel. These values were determined by recording the response of a vane after release from an initial displacement and analyzing the response curves. Basically, this required holding the vane ten degrees off the wind tunnel centerline axis, releasing it without imparting any torque, recording its response on a strip chart recorder, and analyzing the results. (A copy of the proposed methodology is given in Appendix A.)

For the purpose of this evaluation, the method was applied to a number of different new wind vanes which were loaned to EPA by their manufacturers for these tests. (A list of vanes tested is given in Section 3.)

It must also be pointed out here that because, with one exception, only one vane of each type was tested in this program, we know nothing about the reproducibility of these tests vis-a-vis the particular model instrument.

Therefore we do not advise anyone to use these results in evaluating whether or not the vanes tested are or are not suitable for a specific function, or meet any particular set of criteria.

This report presents a short review of the theory of wind vane behavior, a description of the test method and procedures, and a presentation and evaluation of the results.

SECTION 2

THEORY

Following the development of Wirenga (1967), the torque per unit angle on a wind vane which is at some angle β to the wind (Figure 2.1) may be expressed:

$$\vec{N} = r\vec{F}/\beta \qquad (2.1)$$

where $\vec{N}$ is the torque per unit angle and r is the distance from the pivot point of the vane to the center of effort of the force ($\vec{F}$) of the wind acting on the vane.

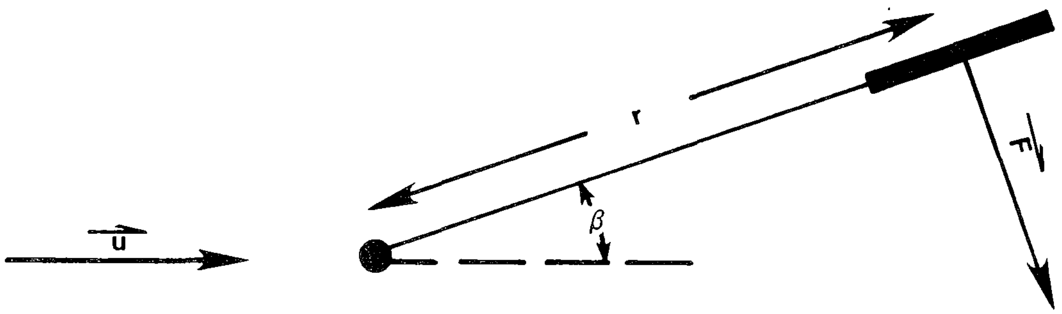

Figure 2.1 The force on a wind vane.

As the vane moves in response to a change in wind direction, the center of force has a velocity $r\dot{\beta}$. Air resistance to the motion of the vane produces a force on the vane and causes the effective wind angle to change to β_v. It has been shown (Barthelt and Ruppersberg (1957)) that:

$$\beta_v = \tan^{-1}\left(\frac{u \sin\beta + r\dot{\beta}}{u \cos\beta}\right) \tag{2.2}$$

$$\simeq \beta + (r\dot{\beta}/u) \tag{2.3}$$

For a vane with moment of inertia J, the equation of motion may be written:

$$-J\ddot{\beta} = N\beta + (Nr/u)\dot{\beta} \tag{2.4}$$

Let:

$$d \equiv Nr/u \tag{2.5}$$

where (d) may be considered a damping force acting on the vane.

If "N" is a constant, equation (2.4) has two well known solutions; one represents an overdamped or aperiodic return of the vane to equilibrium, and the other represents a damped harmonic oscillation of the vane as it returns to equilibrium. Since most wind vanes are not overdamped, we write the solution to (2.4) as:

$$\beta = \beta_o \exp\left[\frac{-d}{2J}t - 2\pi i \frac{t}{t_d}\right] \tag{2.6}$$

where β_o is some initial position, and

$$t_d = 2\pi \left[\left(\frac{N}{J}\right) \quad \left(\frac{d}{2J}\right)^2\right]^{-\frac{1}{2}} \tag{2.7}$$

t_d is the oscillation, or in this case, damped oscillation period of the vane

The undamped, or natural period of the vane (t_o), is given when d=0:

$$t_o = 2\pi(N/J)^{-\frac{1}{2}} \tag{2.8}$$

For critical damping the damping coefficient $d=d_o$ and

$$N/J = (d_o/2J)^2 \tag{2.9}$$

The damping ratio (η) is defined as the ratio of actual to critical damping coefficients.

$$\eta = d/d_o \tag{2.10}$$

Substituting from (2.8), (2.9) and (2.5) into (2.10):

$$\eta = \pi r/ut_o \tag{2.11}$$

but ut_o is the natural, or undamped wavelength of the vane (λ_o), so that

$$\eta = \pi r/\lambda_o \tag{2.12}$$

Rearranging (2.7):

$$t_d = \frac{2\pi}{\sqrt{\frac{N}{J}}} \left[1 - \frac{d^2}{4NJ}\right]^{-\frac{1}{2}} \tag{2.13}$$

and, substituting from (2.8), (2.9) and (2.10):

$$t_d = t_o/\sqrt{1-\eta^2} \tag{2.14}$$

The damped, or actual wave length of the vane (λ_d) may now be defined as:

$$\lambda_d \equiv ut_d = \lambda_o(1-\eta^2)^{-\frac{1}{2}} \tag{2.15}$$

Figure 2.2 shows a typical response of a vane released from a position β_o away from the wind direction and allowed to return to its equilibrium position ($\beta=0$).

At a maximum, or minimum point on the curve ($t=0$, $t=t_d/2$, $t=t_d$, etc.), the oscilatory term is ± 1, so that:

$$\beta = \beta_o \exp(-dt/2J) \tag{2.16}$$

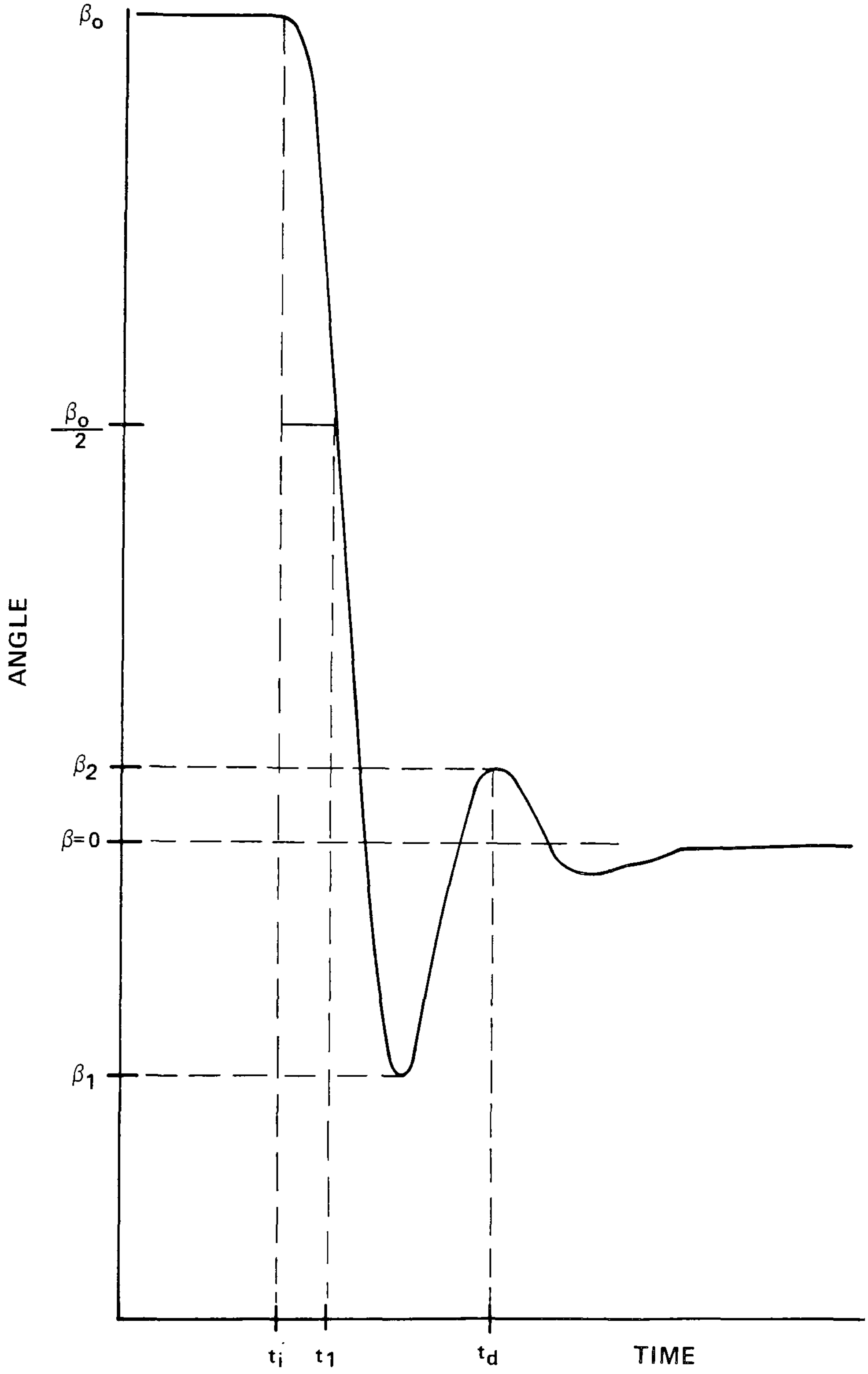

Figure 2.2 Typical response of wind vane showing displacement and overshoot.

The overshoot ratio (Ω) is defined as the ratio of the amplitudes of two successive peaks.

$$\Omega = \beta_i/\beta_{i-1} = \exp\{-(d/2J)(t_d/2)\} \tag{2.17}$$

Substituting from equation (2.14), and then equations (2.8), (2.9), and (2.10), we find:

$$\Omega = \exp(-\pi\eta/\sqrt{1-\eta^2}) \tag{2.18}$$

With some systems which are well damped ($\eta>0.5$), it may be difficult to measure the damped period for a full wavelength. Some authors (Wolkovitch, et. al, 1962; MacCready and Jex, 1964) have suggested measurement of the delay distance, D, to solve this problem. The delay time (t_1) is defined as the time required for the vane to move from its offset position (β_0) to 50 percent of its final equilibrium value. (See Figure 2.2). The delay distance, like the damped wavelength, should be invariant with wind speed (Moses, 1968), and it is simply the delay time multiplied by the wind speed. MacCready and Jex (op cit) have suggested the following empirical relationship (Jex, 1979):

$$\lambda_d = \frac{D(6.0 - 2.4\eta)}{\sqrt{1 - \eta^2}} \tag{2.19}$$

How well this approach fits the data will be examined in Section 5. Acheson (1970) has also suggested some alternative methods for measuring the response characteristics of vanes which have large damping ratios ($\eta>0.7$). Since the vanes we tested (and normally use) have damping ratios much less than that, the method was not evaluated.

SECTION 3

APPARATUS

The procedures used to evaluate the starting speed, delay distance, and over-shoot of the wind vanes were done in a wind tunnel. The vane was held in a fixed off-axis position, calibrated, and released. The position of the vane was recorded as a function of time. The following equipment was used for this program.

WIND TUNNEL

These tests were performed in a Kenney model 1391 wind tunnel located in the Fluid Modeling Facility, Division of Meteorology, Environmental Sciences Research Laboratory, EPA. The tunnel has a cross section of approximately 1 meter square, with a test length of 3 m. The tunnel has an air speed range which is continuously adjustable between zero and 15 m/s. The levels of turbulence in the tunnel are low, with the turbulence intensity ($\sqrt{\overline{u'^2}}/u$) of approximately 1 percent at wind speeds greater than one meter per second.

DATA COLLECTION

All but two of the wind vanes tested used a rotary potentiometer in conjunction with a power supply to sense the position of the vane. In normal use the vane is connected to a regulated, fixed d.c. power supply, which is usually part of the equipment supplied by the manufacturer of the vane.

The output signal is usually conditioned in some way (frequently time averaged) and passed on to a recording device.

Since one goal of this study was to measure the performance of the vanes themselves, and not their accompanying electronics, and since it was desirable to have the small angular displacements used in the study amplified as large as possible on the recording devices, it was deemed necessary to supply a controllable voltage from an external source and record the output from the vane directly, rather than use the manufacturers power supplies, signal conditioning, and recording devices.

A fast response strip chart recorder or computer was set up between the vane and a ten-thousand ohm adjustable biasing potentiometer (trim pot) as shown in Figure 3.1. The power supply was a Dynoscan Precision Regulated Power Supply, model 1601. For the lower wind speeds, an Esterline Angus Speed Servo II recorder was used, while for higher speeds, the signal was sent to an analog-to-digital converter, and thence to a PDP 11/40 computer, which recorded the output on magnetic tape and then plotted the data in graphic form.

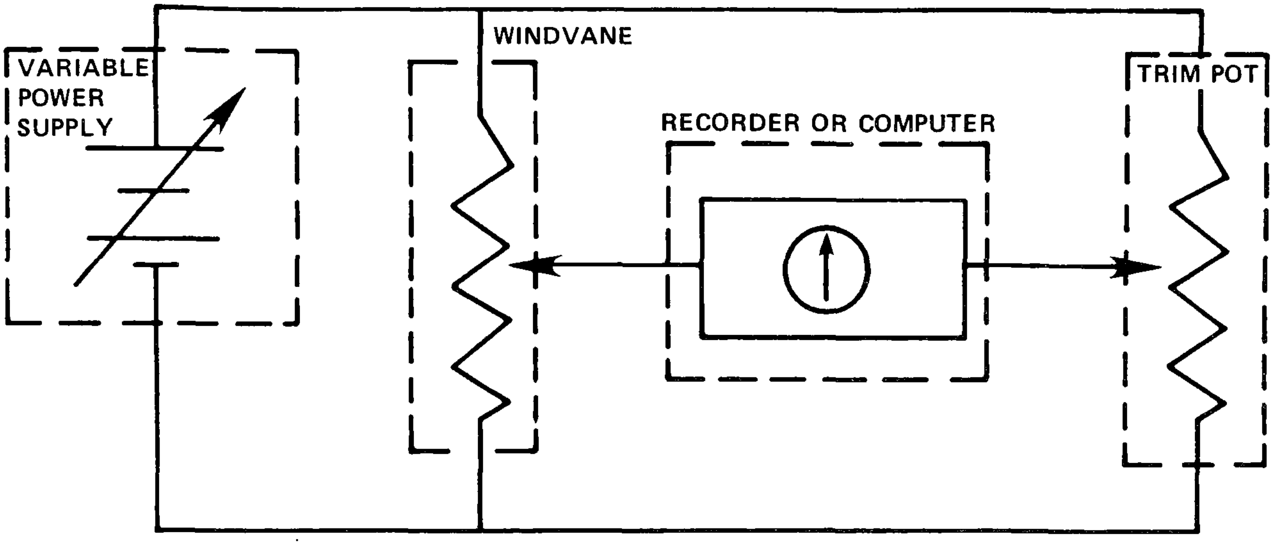

Figure 3.1 Data collection arrangement.

VANE CALIBRATION AND RELEASE

The directional output of wind vanes was calibrated by holding the vanes in an aluminum jig which was mounted on a theodolite head (Figures 3.2 and 3.3). A large mounting hole was made in the jig, and individual adaptors machined for each vane to correspond to its individual geometry and mounting requirements. Using this device the position of a vane could be determined within an accuracy of $\pm 0.1^{\circ}$.

A 115 V a.c. solenoid with a throw of approximately 2.5 cm was used to hold the vane tail off-axis in the wind tunnel. Attached to the throw arm

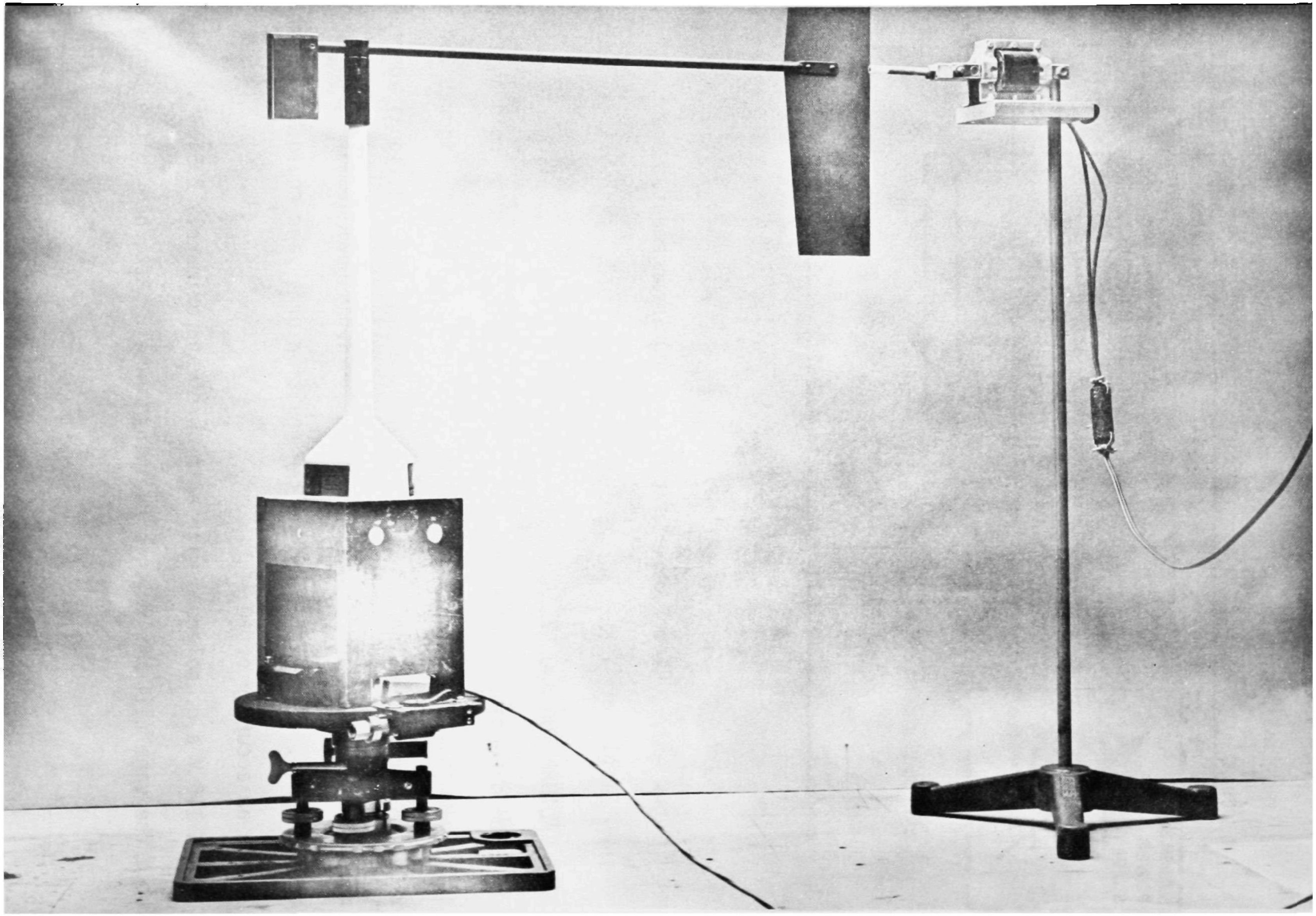

Figure 3.2 Test apparatus with vanes in place.

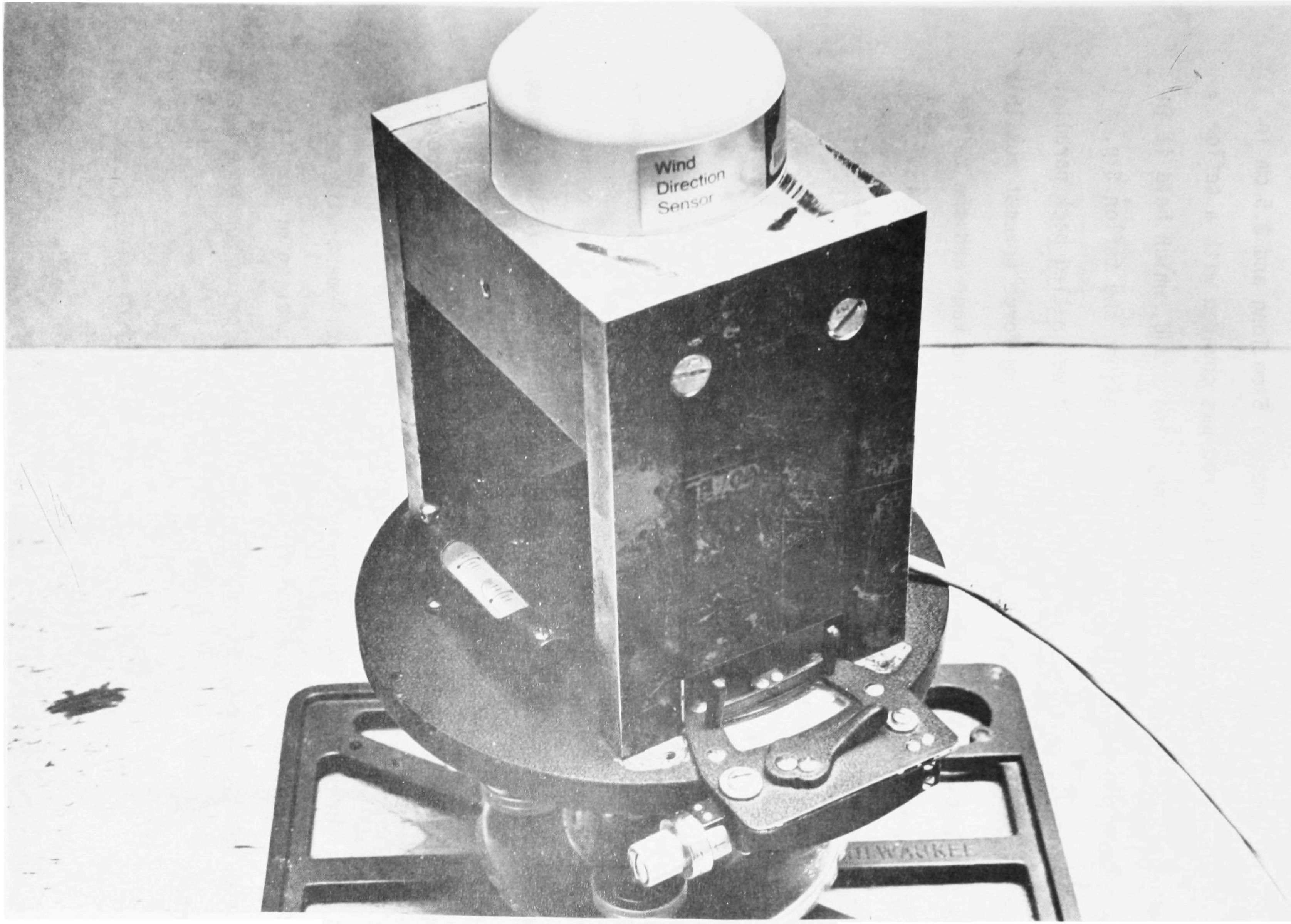

Figure 3.3 Vane holder and theodolite head.

of the solenoid was an aluminum rod approximately 5 cm long and 0.5 cm in diameter. One centimeter of the tip of the rod was covered with a teflon tube. This device was mounted on a laboratory ring stand, which held it in place (see Figure 3.2), and the vane tail rested against the teflon tip. When the solenoid was activated, the tip of the rod was pulled back parallel to the axis of the vane, so that no lateral or turning force (except possibly for a very small moment due to the friction between the vane and the teflon tip) was applied to the vane. This was tested by resting the vane tail against the solenoid arm and activating the solenoid when the tunnel was off. No motion of the vane was observed.

WIND VANES

A letter (Appendix B) was sent to many major U.S. manufacturers of wind vanes describing the purposes of this test and requesting the loan of one or two models of the wind vanes they manufacture. A number of these companies indicated that they were interested in participating in the EPA/ASTM program, and subsequently sent vanes to EPA for testing. A list of the vanes which were tested under this program is given in Table 3.1. As the letter pointed out, the purpose of this program was to evaluate the ASTM draft method, not the wind vanes themselves. The program had neither involvement with determining if any equipment was suitable for any specific function or compliance with any regulation, nor was it evaluating equipment prior to purchase by the government.

TABLE 3.1 LIST OF WIND VANES TESTED

Name	Model
Bendix	Aerovane
Bendix	Wind Vane
Climet	12-15
Meteorology Research Inc.	1022
R.M. Young	Microvane
R.M. Young	Wind Vane
Weather Measure	102
Weather Measure	200
Weather Measure	204
Teledyne Geotech	53.2
Texas Electronics	2010(A)
Texas Electronics	2010(B)*

*Two similar vanes were sent and tested.

SECTION 4

PROCEDURE

ASTM METHOD

As stated in the introduction, the purpose of this study was to evaluate the "Standard Method for Determining the Dynamic Performance of a Wind Vane" prepared by Sub-committee D22.11 of the American Society for Testing and Materials (ASTM). In this section we will review the requirements of the ASTM method (reproduced in Appendix A), and the details of the procedures used to meet these requirements.

The ASTM standard method gives a procedure whereby several dynamic parameters of wind vane performance may be measured in a wind tunnel. These parameters are starting threshold, delay distance, overshoot, and dynamic vane bias.

Definitions

Starting threshold--the lowest wind speed at which a vane will turn to within 5 degrees of the tunnel centerline from an initial displacement of 10 degrees.

Delay distance (D)--the distance the air flows past a wind vane during the time it takes the vane to return to 50 percent of the initial displacement.

Overshoot ratio (Ω)--the ratio of the amplitudes of two successive deflections of a wind vane as it oscillates about the equilibrium position after release from an offset position, as expressed by the equation:

$$\Omega = \frac{\beta_{n+1}}{\beta_n} \qquad (4.1)$$

where β_n and β_{n+1} are the amplitudes of the n and n+1 deflections, respectively. Because all deflections after the first to the side opposite the release point are small, the initial release point (i.e., the n=zero deflection) and the first deflection after release (n=1) are commonly used in determining overshoot.

Dynamic vane bias--the maximum displacement of the vane from the undisturbed flow direction at the center of the wind tunnel (typically the wind tunnel centerline) caused by the free response of the vane to the tunnel flow.

Derived Parameters

The ASTM method lists two calculated values as follows:

Damping ratio (η)--the ratio of the actual damping coefficient to the critical damping coefficient. The damping ratio is calculated using the overshoot ratio (Ω) by:

$$\eta \doteq \frac{\ln \frac{1}{\Omega}}{\sqrt{\pi^2 + (\ln \frac{1}{\Omega})^2}} \qquad (4.2)$$

Damped natural wavelength (λ_d)--at sea level in the U.S. Standard Atmosphere, damped natural wavelength is related to delay distance (D) and damping ratio (η) by the approximate expression (MacCready, 1964):

$$\lambda_d \doteq \frac{D\,(6.0 - 2.4\eta)}{\sqrt{1 - \eta^2}} \quad (4.3)$$

These terms were discussed in more detail in Section 2.

Synopsis of Method

The standard method requires that wind vanes be tested in a previously calibrated tunnel, with recording equipment which has a resolution of at least 0.5° and will not distort the output signal.

Starting speed is measured by releasing the vanes from a 10° offset from the tunnel centerline with the speed of the tunnel set quite low. In this condition if the torque caused by the air is large enough, the vane will move toward the centerline of the tunnel. It will continue to move until the torque is no longer strong enough to overcome the dynamic friction. At this point the vane slowly stops. The starting threshold is that speed at which the vane will move from the 10° offset to within 5° of the tunnel centerline. This requirement must be met on 10 consecutive releases; five on each side of the centerline. The accuracy at starting speed is the mean of the absolute value of the angular position at which the vane comes to rest at that starting speed.*

*It was noted in this study that the mean of the at-rest positions when the vane was released from one side were frequently quite different from that when the vane was released from the other. Because the mean of these two values may be misleading to the user of wind vanes, the method has been changed to report the greater of the two average at-rest positions.

Delay distance and overshoot are measured at 2, 5, and 10 m/s unless the starting speed of the vane is 1.75 m/s or greater, in which case only 5 and 10 m/s speeds are used. For these tests the vane is released from a 10° offset, and as with starting speed, the response is recorded. At each speed 10 tests are done; five on each side, and the results from each test averaged. Delay distance is measured by measuring the time required for the vane to go from its offset position to a point halfway between the offset position and the point at which it initially crosses the final equilibrium position (tunnel centerline). The time, multiplied by the air speed in the tunnel, gives the delay distance.

Overshoot is measured on the same record used to compute a delay time. It is simply the ratio of the first peak displacement to the initial displacement. All ratios are averaged to arrive at the final overshoot ratio. This value may then be used to calculate the damping ratio by equation (4.2).

TUNNEL CALIBRATION

Air speed in the EPA instrument wind tunnel is monitored with a tachometer on the fan. This requires calibration before it can be used as a reliable monitor. Two methods of calibration were used. For speeds greater than 1 m/s a pitot tube was used. For speeds less than 1 m/s, smoke puffs were timed with a stop watch. The two methods gave comparable results near 1 m/s.

Pitot Tube

A NPL standard pitot tube was placed in the mid-point of the tunnel. Pressure differences were measured with a Baration pressure sensor. Velocity was calculated using the formula:

$$V(m/s) = 14.82 \quad \Delta P(mm\ Hg) \text{ at } 20^{\circ}\ C \tag{4.4}$$

Repeated calibration tests were made, and the standard deviation at several speeds were calculated. The mean percent deviation ($<\bar{\sigma}/\bar{u}>x100$) was determined to be 2.5 percent.

Low Speed Calibration

For speeds between 0.3 and 1.0 m/s the wind tunnel was calibrated by timing puffs of titanium tetrachloride smoke with a stop watch over a path length of 2 m. Multiple runs at each speed were made. It was found that at lower speeds (0.3 to 0.5 m/s) heat from photo flood lights placed in the tunnel to more clearly observe the smoke caused convection currents which upset the flow in the tunnel. Slight air flow caused by other wind tunnels in the Fluid Modeling Facility also had a disruptive effect. After correcting these problems, overall accuracy of speed determinations at this range was estimated to be $\pm$ 0.1 m/s. Below 0.3 m/s the flow in the tunnel was judged to be too erratic to be used with confidence.

A device with photosensitive transistors was developed to time the smoke puffs, but because of the ambiguity in the shape of the output, and resolution of the oscilliscope used to monitor the signal, the accuracy was not as good as a hand-held stop watch. Development of this approach was not pursued further.

VANE SIZE DETERMINATION

The ASTM method suggests that the cross sectional area of the wind vanes perpendicular to the flow be no larger than 10 percent of the cross sectional area of the tunnel. To avoid lengthy trigonometric calculations, a photograph was taken of the vane set at the proper angle. Included in the photograph was a square of known size (see Figure 4.1). A measurement of the

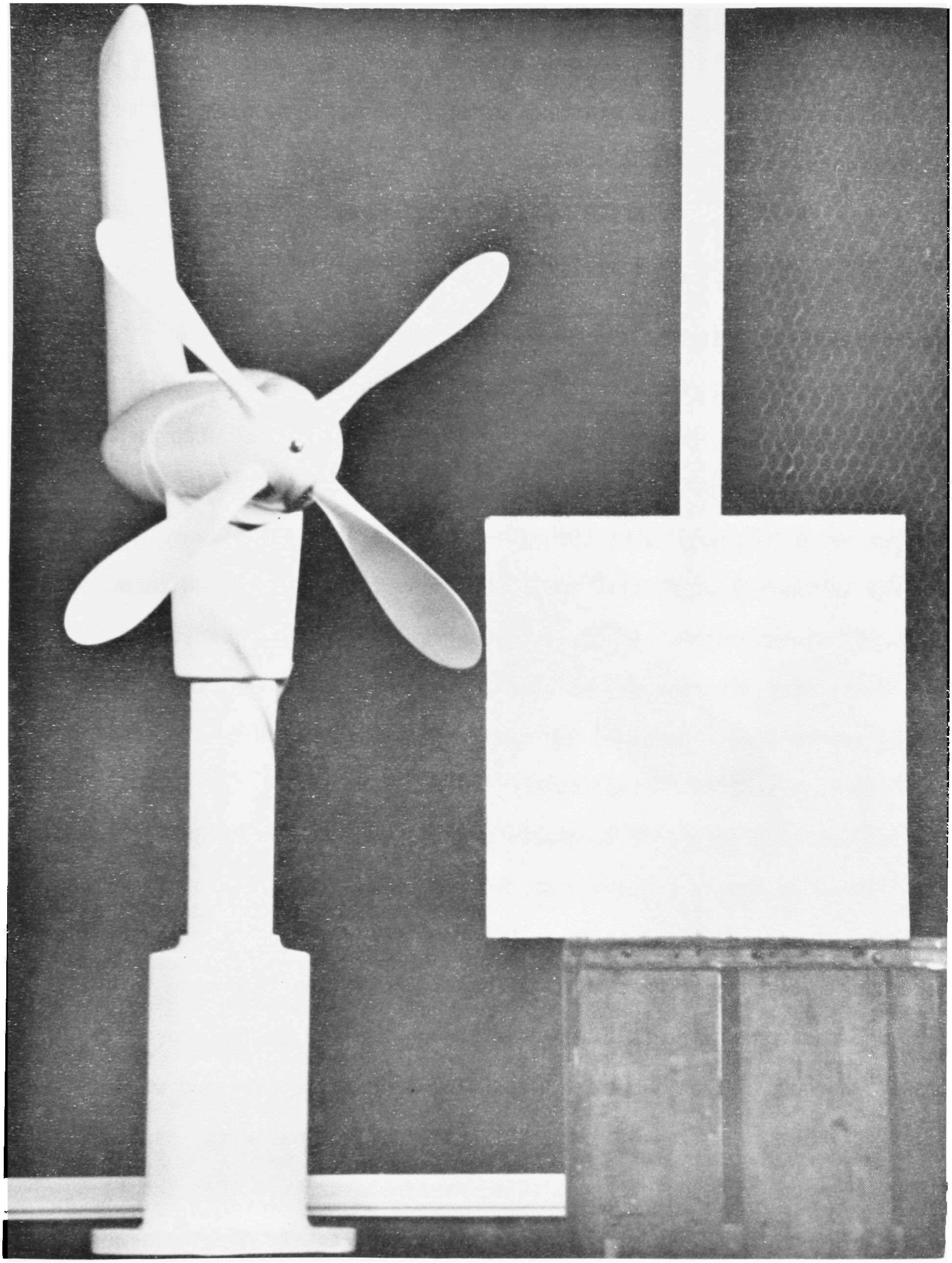

Figure 4.1 Example of vane cross section determination.

cross sectional area could then be made directly using a planimeter. A telephoto lens (300 mm) was used to minimize parallax error, which was estimated to be approximately 5 percent.

The area at a 10^0 offset angle of the largest vane tested in this program was 4 percent of the cross sectional area of the tunnel.

WIND VANE CALIBRATION

Once the tunnel was calibrated the individual vanes could be tested for delay distance, overshoot, and starting threshold. The initial step in this procedure was to calibrate the measurement system so that the strip chart recorder pen would be centered on the paper when the vane was aligned with the air flow in the tunnel, and on the outer edge of the paper when the vane was displaced a known number of degrees (usually 20^0) from the centerline.

As a first step the vane was mounted in the theodolite head vane holder (individual adaptors were machined for each vane) which was placed in the center of the test section of the tunnel.

The fan was then turned on to obtain a speed between 5 and 10 m/s, and the vane allowed to freely line-up with the air flow. The d.c. voltage output and trim pot were adjusted so that the chart recorder indicated a voltage somewhere near mid-scale. The tunnel fan was stopped, and referring to the chart output, the vane tail was clamped at the centerline position using a ring stand and three-finger pipette clamp. The theodolite head and wind vane base were rotated to the desired full scale deflection on the side which caused the voltage to go toward zero. The chart recorder was then set to zero using the trim pot. The wind vane base was next rotated to the same number of degrees on the other side of the centerline, and a full scale reading was obtained by adjusting the voltage control. Two or three iterations were usually sufficient to complete and stabilize this zeroing procedure.

The resolution and linearity of the vane were checked by stepping the vane base through 0.1° increments and noting the output on the chart recorder.

TEST PROCEDURE

Starting Threshold

After calibration, the tail clamp was removed and replaced by the release mechanism. The vane was offset 10°, with the tail resting against the teflon tip of the release rod. The air flow was set at some low speed, and after waiting a few minutes for the flow to stabilize, the vane was released.

If the vane failed to move 5 or more degrees, the speed was increased (usually in 0.1 m/s increments) and the test repeated. If the vane did move the required 5 degrees, the position at which it came to rest was noted, and the test repeated nine more times, five of which were done with the vane displaced to the opposite side of the centerline. If the vane failed to move the required 5 degrees during any of the 10 tests, the data were discarded; the air flow was increased, and the tests were repeated. The starting speed was, therefore, that speed at which the vane first succeeded in all ten trials.

Displacement Distance and Overshoot

Tests to determine displacement distance, overshoot, and damped wave length were conducted in the same manner as starting speed, except that the speeds were set at 2, 5, and 10 m/s. (The 2 m/s speed was not used on those few vanes whose starting speed was close to, or greater than 1.75 m/s.) For the 10 m/s, and some of the 5 m/s tests, the signals were analyzed by an analog-to-digital converter and computer rather than the chart recorder because of the slow response time of the recorder. The resulting output data were analyzed manually, regardless of the method of collection.

As illustrated previously, Figure 2.2 shows a typical displacement distance and overshoot test. The displacement distance (D) is the length of the column of air that passes the vane from the time it is released until it has reached 50 percent of the initial displacement.

$$D = u(t_1 - t_i) \quad (4.5)$$

The overshoot ratio (Ω) is the ratio of successive maxima. Usually it was determined using the initial displacement and the first overshoot peak.

$$\Omega = \beta_1/\beta_0 \quad (4.6)$$

For a perfect, damped system, this would equal the ratio of the second overshoot peak to the first, and so on,

$$\Omega = \beta_2/\beta_1 \quad (4.7)$$

but it rarely is.

The damped wave length (λ_d) can also be found if the second peak is clearly defined.

$$\lambda_d = u(t_d - t_i) \quad (4.8)$$

Each of the thirty tests, plus starting speed tests were analyzed in this way for each vane tested. The results are given in the following section.

SECTION 5

RESULTS

VANE TESTS

While the ultimate goal of this study was to evaluate the ASTM methodology, this was difficult to do without collecting some data on individual vanes. Because this information may be of interest, it is presented in the following tables. Certain caveats should be kept in mind, however, while examining these results, or comparing them with manufacturers specifications or other published results. These caveats are (1) for all but one case only one vane of each model was tested. While care was taken to eliminate faulty vanes, some of the ones tested may not have been representative of its species, and (2) the ASTM method differs significantly from some other vane testing techniques, and the results should not be expected to be comparable.

Table 5.1 gives the manufacturers' names and model numbers of the vanes tested, the starting thresholds and accuracies, the delay distances, measured damped wave lengths (where available), and overshoot and damping ratios. The precision figures given are for one standard deviation. The various vanes are given in alphabetical order by manufacturer. The starting threshold was measured in 0.1 m/s increments between 0 and 1.0 m/s, and 0.25 m/s increments above 1.0 m/s.

TABLE 5.1 TABULATION OF WIND VANE TEST RESULTS

Company	Model	Starting Threshold (m/s)	Starting Accuracy (deg.)	Delay Distance (m)	Damped Wavelength (m)	Overshoot Ratio	Damping Ratio
Bendix	Aerovane*	1.5	3.3±0.19	2.0 ±0.20	11.5±0.40	0.49±0.05	0.22
Bendix	Windvane	0.9	4.0±0.34	1.0 ±0.08	5.5±0.22	0.33±0.01	0.33
Climet	12-15	0.7	2.0±0.58	0.65±0.07	3.3±0.21	0.28±0.01	0.38
Meteorology Research Inc.	1022	0.4	2.2±0.21	0.6 ±0.08	3.4±0.14	0.23±0.02	0.43
R.M. Young	Microvane	0.5	2.9±0.27	0.8 ±0.11	4.8±0.24	0.14±0.03	0.53
R.M. Young	Windvane/6301	0.6**	2.8±0.22	1.2 ±0.10	7.2±0.26	0.27±0.05	0.39
WeatherMeasure	102*	2.5	1.8±0.4	2.2 ±0.14	10.6±0.40	0.50±0.06	0.21
WeatherMeasure	200*	2.25	2.7±0.4	1.0 ±0.07	4.6±0.06	0.47±0.02	0.23
WeatherMeasure	204	0.8	3.7±0.45	1.1 ±0.11	5.8±0.11	0.48±0.07	0.23

(continued)

TABLE 5.1 (Continued)

Company	Model	Starting Threshold (m/s)	Starting Accuracy (deg.)	Delay Distance (m)	Damped Wavelength (m)	Overshoot Ratio	Damping Ratio
Teledyne Geotech	53.2	0.3***	1.7±0.26	0.65±0.08	2.6±0.18	0.30±0.04	0.36
Texas Electronics	2010(a)	1.25	2.9±0.5	1.2 ±0.10	6.0±0.20	0.29±0.01	0.37
Texas Electronics	2010(B)	1.0	4.3±0.28	1.1 ±0.08	Missing	0.32±0.02	0.35

*For vanes with starting threshold 1.75 m/s or greater, tests of delay distance and overshoot at tunnel speeds of 2 m/s were not done. Results for these vanes is based on tests at 5 and 10 m/s only.

**A second test of the starting threshold of this vane done on a subsequent day showed a lower starting speed. The reason for this is not known. The first result is given in conformity with test procedures.

***The starting threshold of this vane is probably less than 0.3 m/s, but the wind tunnel was not reliably calibrated below that speed, so no measurements could be made.

UNSUCCESSFUL TESTS

A number of vanes were received for this program from various manufacturers which were not tested for one reason or another. In some cases the vanes were slightly damaged. For example it was noted that small dents in the tail of one vane caused it to continuously oscillate at wind speeds above a few meters per second. Other vanes could not be properly balanced, even though the balance weight was adjusted throughout its designed limit of travel.

An Electric Speed Indicator Co. model F420C-2 Wind Direction Transmitter was received from the National Weather Service. This vane was tested using the standard procedure. The vane is designed to drive a pointer on a dial to indicate wind direction, rather than give a linear electronic output. Due to this factor, the resolution we were able to observe and record was greater than 5 degrees. The instrument probably has a better resolution than that when used in its normal configuration, and if rewired it could be set-up to give a better resolution, but for purposes of this evaluation modification of the vanes was not possible. It was estimated that the starting speed of the vane was between 1.5 and 2 m/s. Estimates of the other variables, however, were impossible with any precision. Therefore we must conclude that the test method as presently formulated is not applicable to this design of wind vane. Substituting a standard potentiometer for the present electronics in the vane could have been done, but this was deemed unwarranted because if the friction or moment of inertia of the new parts were not substantially similar to the originals the results would be misleading.

STARTING THRESHOLD

Starting threshold and its corresponding accuracy are somewhat indeterminate numbers. They will depend on the size of the finite steps that are taken in doing the tests as well as the desired accuracy range. In performing these tests, the wind speed was increased in 0.1 m/s increments from 0.3 to 1.0 m/s and in 0.25 m/s increments above 1.0 m/s. The lowest speed at which the first five tests on each side had a deflection of more than 5^o was recorded as the starting threshold. It was not unusual to have several successful individual trials be followed by one with a deflection of less than the required 5 degrees. Under the procedure one would then proceed to the next higher speed and try again. Since the final rest positions were somewhat random, however, it is not at all unlikely that five consecutive successful tests which were all successful could be done at the lower speed. On the other hand, if one wished to report a higher accuracy and was willing to sacrifice a lower starting threshold, the test could be commenced at a higher tunnel air speed. With this in mind, and considering that the accuracy with which the air speed in the tunnel is known at the lower range is on the order of 0.1 m/s, it is estimated that the accuracy of the threshold speed determination is within ± 0.2 m/s.

Associated with each starting accuracy given in Table 5.1 is a one standard deviation precision value. The coefficient of variation for this measurement ($\bar{\sigma}/\overline{SA}$) is approximately 13 percent.

Averaging Starting Accuracy

Early drafts of the ASTM method specified that the absolute value of the accuracies from displacements to the left of the centerline and the right of the centerline were to be averaged, with this value representing the starting accuracy. Upon examining some preliminary results of this study, the ASTM committee noted that there was a distinct bi-modal distribution, or that the displacement on one side had a much lower degree of accuracy than did the other. An average of the two sides then would give a misleadingly optimistic picture of the accuracy of the vane. The committee changed the method to require that the higher of the two average displacements (less accurate) be reported as the starting accuracy. Figure 5.1 is a scatter plot of the new, or one sided accuracy figures versus the old, or two sided figures. As can be seen, for most vanes the change was not substantial, but for a few it was close to the maximum possible factor of two difference.

OVERSHOOT AND DAMPING RATIOS

Overshoot ratios ranged from 0.14 to 0.49, with a mean of 0.34. The average standard deviation of the overshoot measurement for each instrument had a wider range, from 0.008 to 0.07, with a mean value of 0.032 for all instruments. The coefficient of variation for this measurement is 9.9 percent. Thus 10 percent would be a good estimate of the precision of the overshoot measurements. Since the damping ratio (η) is roughly inversely proportional to overshoot ratio, 10 percent is also a reasonable estimate for its precision.

DELAY DISTANCE

Delay distances measured in this study ranged from 0.61 m to 2.2 m, with a mean of 1.12 m. The standard deviation of the delay distance measurement for each instrument ranged from 0.07 m to 0.2 m, with a mean value of 0.1 m for all instruments. The coefficient of variation was 9.6 percent,

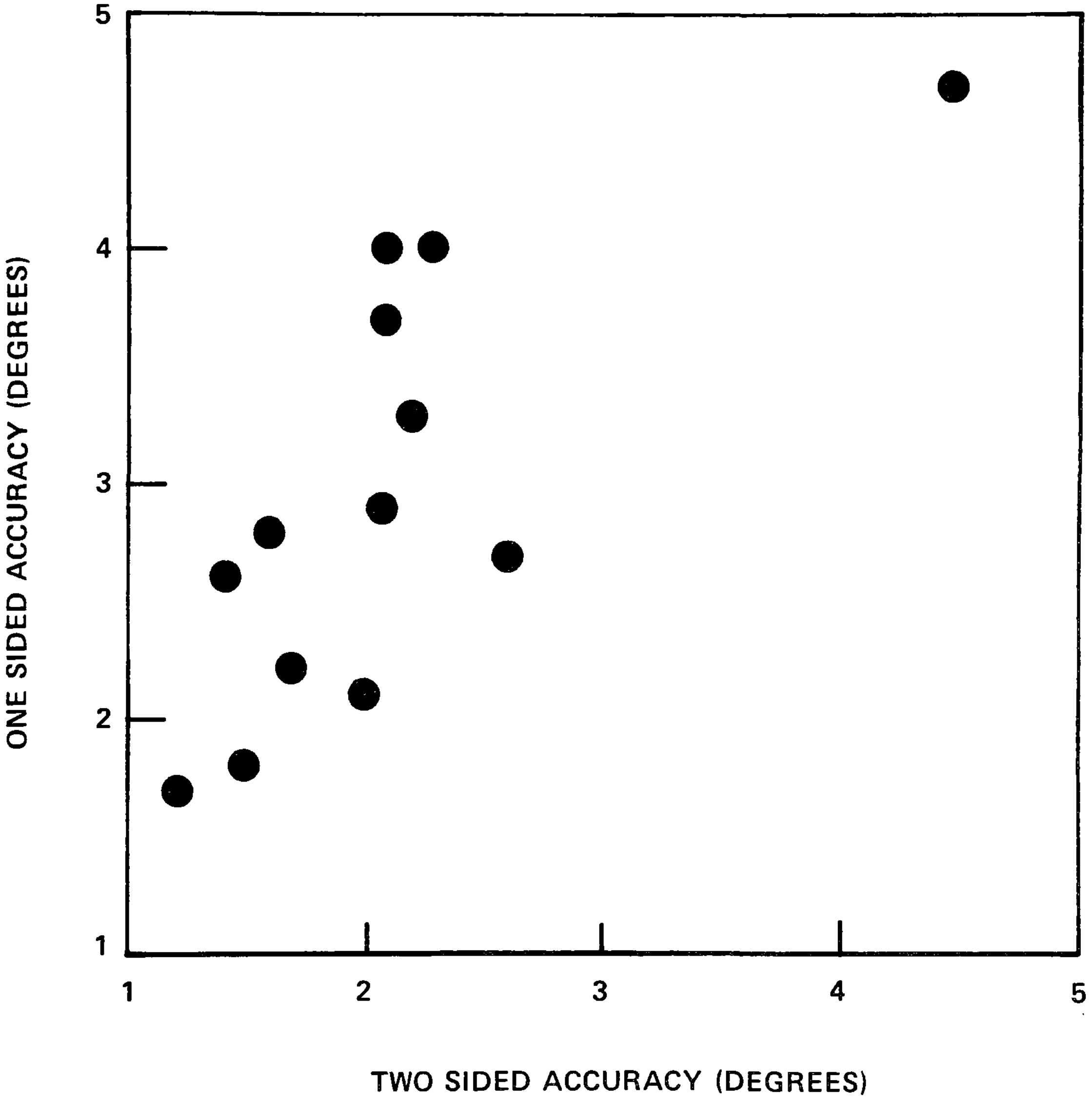

Figure 5.1 Comparison of one sided and two sided starting accuracy.

thus implying that 10 percent is also a reasonable expectation for the precision of this measurement.

In general, vanes with higher starting thresholds had longer delay distances. This can be seen in the scatter plot shown in Figure 5.2. Its usefulness may be limited, but in principal one could design a vane with a long delay distance and a low starting threshold.

DAMPED WAVELENGTH

The damped wavelength (λ_d) measured in this study ranged from 2.6 to 11.5 meters, with a mean of 5.94 meters. The average of the standard deviations for all instruments was 0.22 meters, with a coefficient of variation of 3.9 percent. One could thus reasonably expect a precision of approximately 5 percent for this measurement.

Comparing this with 10 percent precision for the delay distance measurement, it would seem that the damped wavelength would be the better of the two measurements to take. However it should be realized that for vanes with large damping ratios (0.5 or greater), the second peak may be very difficult to define, and for these vanes, delay distance measurements may be much more precise. In actual practice, either may be easily measured, and as shown below, the relationships between the two is quite reliable.

Comparison of Delay Distance and Damped Wavelength

As is noted in Section 2, Jex (op cit) has suggested the relationship between delay distance, damping ratio, and damped wavelength given in equation (2.19) and reproduced here.

$$\lambda_d = D(6 - 2.4\eta)/(1-\eta^2)^{+\frac{1}{2}} \qquad (2.19)$$

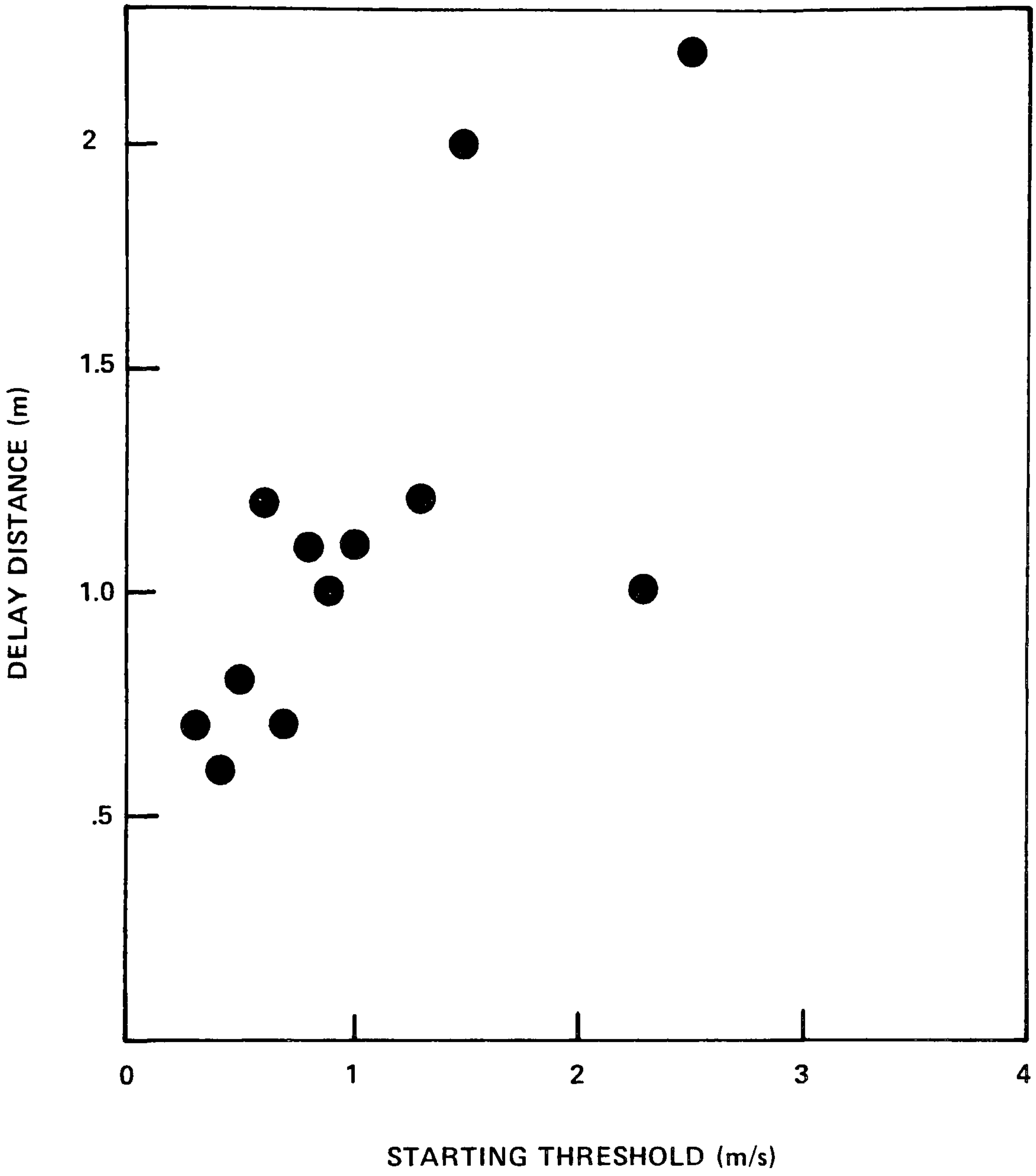

Figure 5.2 Comparison of starting threshold vs. delay distance.

A comparison of calculated λ_d, using the measured delay distance and damping ratio, and measured λ_d is shown in Figure 5.3. As can be seen the agreement is quite good. The line of best fit has a slope of 1.015 and an intercept of 0.21. The standard error of estimate is 0.71 and the correlation coefficient is 0.97 (using calculated λ_d as the dependent variable).

Equation (2.19) can be rewritten as:

$$\lambda_d = kD \qquad (5.1)$$

where

$$k = (6-2.4\eta)/(1-\eta^2)^{+\frac{1}{2}}$$

for η between 0.2 and 0.5 (the range of all vanes tested), k varies between 5.5 and 5.6.

The relationship between delay distance and measured λ_D is shown in Figure 5.4. As can be seen, the assumption of a straight line fit is reasonable. The linear regression best fit for the line is:

$$\lambda_d = 5.27D + 0.06$$

with $S_{y \cdot x} = 0.64$ and the correlation coefficient equal to 0.97.

There would seem to be little justification in the data for preferring one form of the relationship over the other (equation (2.19) vs. linear) so the choice is left up to the user.

DUPLICATE VANES

The Texas Electronics Co. sent two model 2010 vanes for the tests. The results of these tests are summarized in Table 5.2.

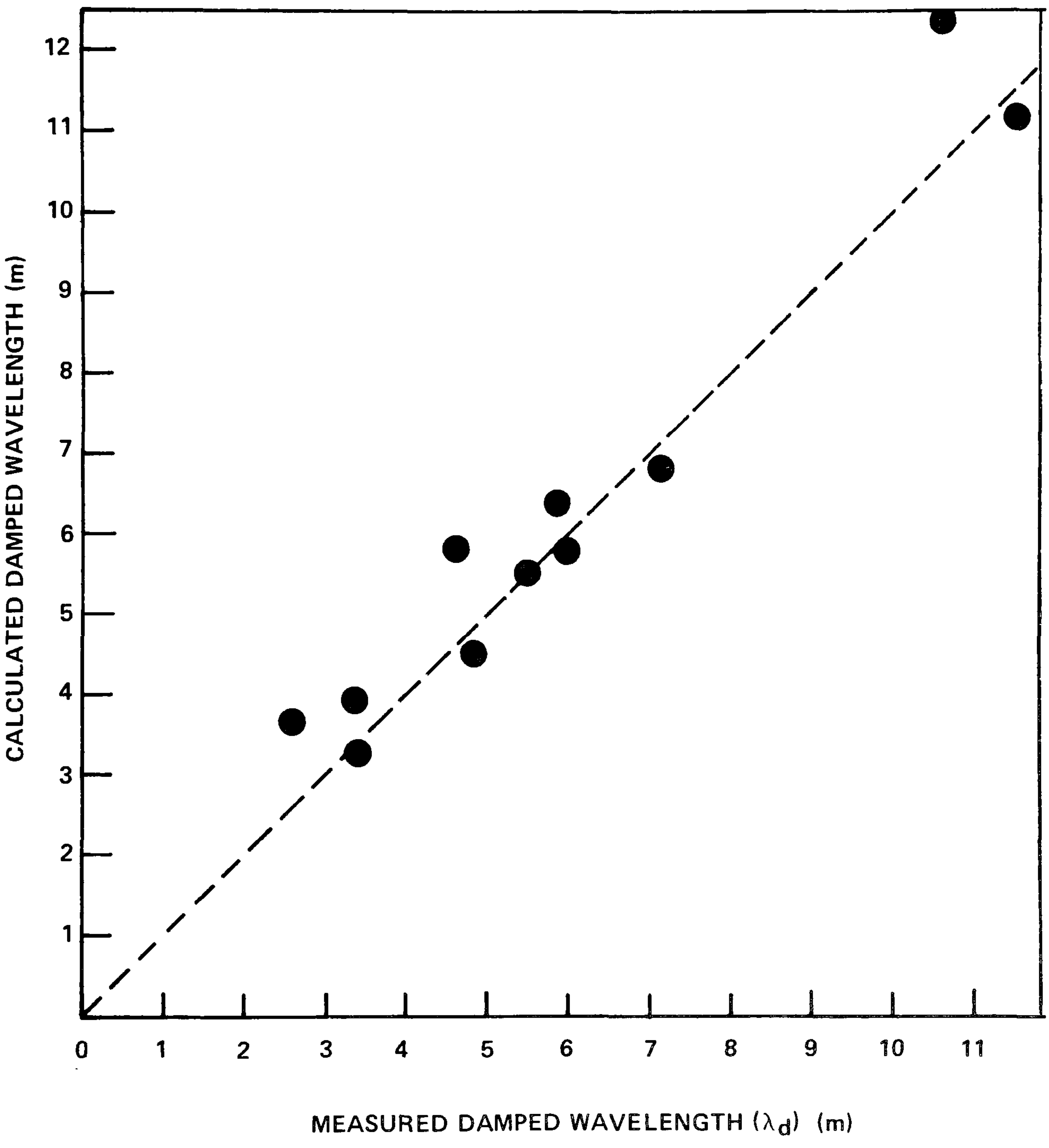

Figure 5.3 Calculated vs. measured damped wavelength.

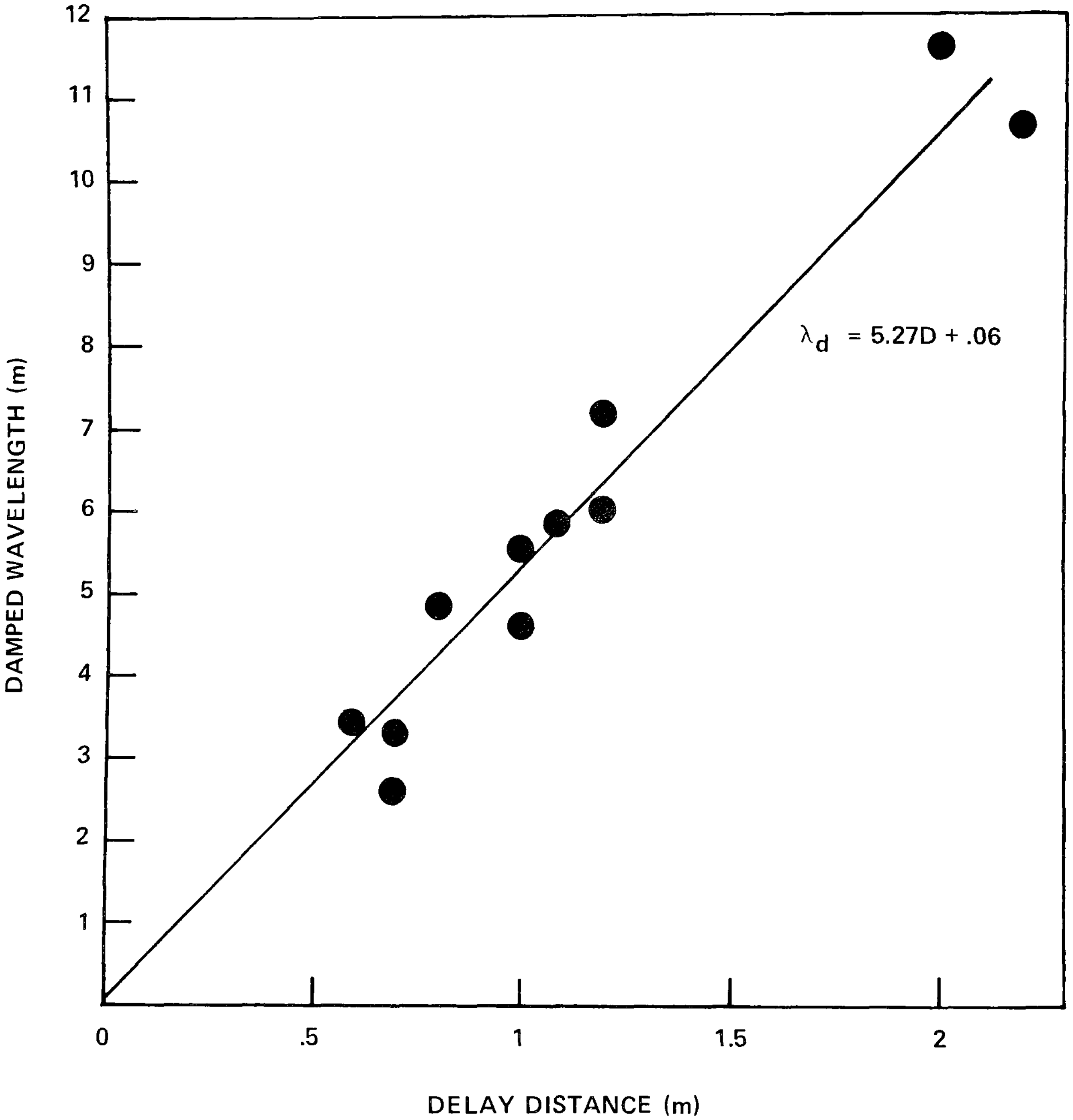

Figure 5.4 Measured damped wavelength vs. delay distance.

TABLE 5.2 COMPARISON OF TWO TEXAS ELECTRONIC MODEL 2010 VANES

	Vane A	Vane B
Starting Threshold	1.25 m/s	1.0 m/s
Accuracy	$2.9^{o} \pm 0.5^{o}$	$4.3^{o} \pm 0.3^{o}$
Delay Distance	1.2m $\pm$ 0.10m	1.1m $\pm$ 0.08m
Overshoot	0.29 $\pm$ 0.01	0.32 $\pm$ 0.02
Damping Ratio	0.37	0.35

This comparison indicates that the method gives reproducible results on two similar vanes within the precision bounds given above, at least for these two vanes. It is interesting to note that while vane "A" had a higher starting threshold than did "B", its accuracy at that speed was better than "B's" at its starting threshold. This is consistent with the discussion of starting threshold and accuracy as given above. The differences in the other parameters are statistically insignificant.

OFFSET ANGLE

The ASTM method requires an offset angle or displacement of 10^{o} from the tunnel centerline. In the past other angles have been used by various manufacturers and others studying vane response. We were able to do a very limited comparison of the effects of various offset angles on the response of one vane, the Texas Electronics 2010(A). The results of the tests are given in Table 5.3. Slight differences can be seen in the 10^{o} test between Tables 5.2 and 5.3. The tests at 15^{o} and 20^{o} were run without the 10 m/s wind speed so the 10 m/s results from the 10^{o} test were not used in order to make the comparison more meaningful.

TABLE 5.3 COMPARISON OF VANE PARAMETERS FOR OFFSETS OF 10^{o}, 15^{o} AND 20^{o} MEASURED ON THE TEXAS ELECTRONICS 2010 VANE A (Parameters for this test were not measured at 10 m/s)

	10^{o}	15^{o}	20^{o}
Starting Threshold	1.25 m/s	1 m/s	1 m/s
Accuracy	$2.9^{o} \pm 0.5^{o}$	$2.1^{o} \pm 0.8^{o}$	$1.6^{o} \pm 0.7^{o}$
Delay Distance	1.2m $\pm$ 0.1m	1.3m $\pm$ 0.1m	1.5m $\pm$ 0.1m
Overshoot	0.26 $\pm$ 0.02	0.28 $\pm$ 0.01	0.27 $\pm$ 0.02
Damping Ratio	0.39	0.37	0.38

The results do confirm that the test results are dependent on offset angle. All the vane parameters showed significant differences. Not surprisingly, the starting threshold decreased (or the accuracy increased) with increasing offset angle.

The delay distance also increased with increased offset angle. Since the delay distance is in a sense the length of an air column needed to move the vane from one position halfway to a new one, and since that distance is increasing with increasing offset angle, the increase in delay distance may also be an understandable event. One should note, however, that theoretically the natural and damped wavelengths are not functions of offset angle. This implies a number of possibilities: (1) delay distance is a function of offset angle and equation (2.19) needs to be modified; (2) natural and damped wavelengths are a function of offset angle. A more complete study of the subject is suggested to investigate these effects.

Overshoot also changed with offset angle, although not in any obviously systematic way. While the difference between the offset at 10^{o} and 15^{o} is significant, the results may still be an artifact of the small sample size or experimental error. This too could be resolved with a more thorough study

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The basic conclusion of this study is that the ASTM draft Standard Method for Determining the Dynamic Performance of a Wind Vane does provide a reasonable and reliable technique for determining standard performance characteristics for many commercially available wind vanes. The method also provides good standard definitions for many terms which have a history of imprecise use.

Using reasonable care, most laboratories with proper facilities should be able to measure performance characteristics of many of the wind vanes on the market today. For those vanes for which we were not able to perform these tests, modifications which do not affect dynamic performance may be possible so that organizations with interest in them will be able to evaluate these vanes.

Because of the facilities required, it is not reasonable to expect that many of the users of wind vanes will be able to test their own equipment. If the manufacturers and various independent testing laboratories adopt the ASTM method, vanes could then be certified by the manufacturer to meet specified performance criteria and could be returned to the manufacturer or other laboratory for recertification should it become necessary. A reliable program of this type should take much of the guess work that is now necessary out of the evaluation of meteorological data.

RECOMMENDATIONS FOR FURTHER RESEARCH

One precept associated with any scientific research program is that it should raise new questions as it answers old ones. This study has met that requirement.

The general area of delay distance and its relationship to damped wavelength, damping ratio, and offset angle has not been adequately resolved. Theoretical relationships to replace the present empirical ones, plus a more thorough experimental program would be needed to attack this problem.

The variability of results is a major area of uncertainty. This includes variability between similar models, variability with age, and variability of results measured at different laboratories. Variability between similar models would be an easy question for the manufacturer of wind vanes to address It should be addressed in order to determine whether all vanes performance specifications need to be measured, or whether representative sampling of vanes of the same design will be adequate.

Variability between laboratories would be easily addressed by an interlaboratory comparison test. Such a test is being planned by members of the ASTM Meteorological Measurements subcommittee and should answer this question.

The question of variability with age could also be addressed in a straight-forward test. It would be interesting to see if changes in the various parameters could be related directly to bearing wear, so that simple measurements of torque could be substituted for the wind tunnel tests on older vanes as a method of field calibration.

A final area of concern is the bimodal nature of the vanes during starting threshold and accuracy measurements. A preferred direction of motion is obviously not a desirable characteristic for wind vanes. It is hoped that meteorological instrument manufacturers will look into this problem and correct or at least improve upon their wind vane performance.

BIBLIOGRAPHY

Acheson, Donald T. 1970. "Response of Cup and Propeller Ratios and Wind Direction Vanes to Turbulent Wind Fields." Meteorological Monographs, Vol. 11, No. 33, pages 252-261.

Barthelt, H.P. and G.H. Ruppersberg. 1957. "Die Mechanesche Wind fahne, eine Theoretiscke und experimientelle Untersuchung." I. Beitr. Phys. Atmos., Vol. 29, pages 154-185.

Camp, Dennis W. and Robert E. Turner. 1970. "Response Tests of Cup, Vane, and Propeller Wind Sensors." J. of Geophysical Res., Vol. 75, No. 27, pages 5265-5270.

Environmental Protection Agency. 1978. Ambient Monitoring Guidelines for Prevention of Significant Deterioration. EPA-450/2-78-019, OAQPS, RTP, N.C., 86 pages.

Jex, H.R. 1979. Personal communication.

MacCready, P.B. and H.R. Jex. 1964. "Response Characteristics and Meteorological Utilization of Propeller and Vane Wind Sensors." J. Appl. Meteor., No. 3, pages 182-193.

Moses, H. 1968. Meteorology and Atomic Energy. A.E.C., pages 257-308.

Wieringa, J. 1967. "Evaluation and Design of Wind Vanes." J. Appl. Meteor., Vol. 6, No. 6, pages 1114-1122.

Wolkovitch, J.R., et al. 1962. Performance Criteria for Linear Constant Coefficient Systems with Deterministic Inputs. USAF, ASD-TR-61-501.

APPENDIX A

The following is a copy of the ASTM "Standard Method for Determining the Dynamic Performance of a Wind Vane."

Draft No. 4
3/11/80

STANDARD METHOD FOR DETERMINING THE DYNAMIC PERFORMANCE OF A WIND VANE

1. Scope

1.1 This method covers the determination of the

Starting Threshold

Delay Distance

Overshoot

Dynamic Vane Bias

of a wind vane from direct measurement in a wind tunnel for wind vanes having measurable overshoot.

1.2 This method provides for determination of the performance of the wind vane and its transducer in wind tunnel flow. Transference of values determined by these methods to atmospheric flow must be done with an understanding that there is a difference between the two flow systems.

2. Applicable Documents

D 1356 Definitions of Terms Relating to Atmospheric Sampling Analysis

E 380 Metric Practive Guide

3. Summary of Method

3.1 This method requires a wind tunnel described in Section 6, Apparatus.

3.2 Wind Direction (θ, degrees) is measured as the angular position of the vane with respect to some index (real or imaginary) position on the sensor assembly. Displacements of 10 degrees must be within ± 1 degree.

3.3 Starting Threshold (S_0, m/s) is determined by measuring the lowest speed at which a vane released from a position 10 degrees off the wind tunnel centerline moves to within five degrees of the centerline. Tests must include initial displacements to each side of the centerline.

3.4 Delay Distance (D, m) may be measured at a number of wind speeds but must include 5 m/s, and 10 m/s. A measurement is made of the time required for the vane to reach 50 percent of the initial displacement from 10 degrees off wind tunnel centerline release. This time in seconds (s) is converted to the Delay Distance by multiplying by the tunnel wind speed in meters per second. Tests must include displacements to each side of the centerline.

3.5 Overshoot (Ω) may be measured at the same time as the Delay Distance. The maximum angular excursion on the opposite side of the at-rest position from the initial 10 degrees off wind tunnel centerline displacement is measured. This value is divided by the initial displacement to obtain the ratio Ω.

3.6 Dynamic Vane Bias (θ_B) is the maximum displacement of the vane from the undisturbed flow direction at the center of the wind tunnel (typically the wind tunnel centerline) caused by the free response of the vane to the tunnel flow at all speeds above three times the vane Starting Threshold. This measurement will identify wind vanes with unbalanced aerodynamic response because of damage (bent tail) or design. θ_B must be $\leq |1°|$.

4. Significance and Use

This method will provide a standard for comparison of wind vanes of different types. Specifications by regulatory agencies (1-4) and industrial societies have specified performance values. This standard provides an unambiguous method for measuring Starting Threshold, Delay Distance, Overshoot and Dynamic Vane Bias.

5. Terminology

5.1 Definitions

delay distance (D)-- the distance the air flows past a wind vane during the time it takes the vane to return to 50 percent of the initial displacement

overshoot (Ω)--the ratio of the amplitudes of two successive deflections of a wind vane as it oscillates about the equilibrium position after release from an offset position, as expressed by the equation

$$\Omega = \frac{\theta_{(n+1)}}{\theta_n}$$

where θ_n and $\theta_{(n+1)}$ are the amplitudes of the n and n + 1 deflections, respectively. Because all deflections after the first to the side opposite the release point are small, the initial release point (i.e., the n = zero deflection) and the first deflection after release (n = 1) are used in practice in determining overshoot.

starting threshold--the lowest wind speed at which a vane will turn to within five degrees of θ_s from an initial displacement of 10 degrees.

5.2 Calculated or Estimated Values

damping ratio (η)--the damping ratio is calculated from the overshoot ratio (Ω) (5).

$$\eta \doteq \frac{\ln \frac{1}{\Omega}}{\sqrt{\pi^2 + \left(\ln \frac{1}{\Omega}\right)^2}}$$

damping coefficient--define

critical damping coefficient--define

damped natural wavelength (λ_d)--at sea level in the U.S. Standard Atmosphere, damped natural wavelength is related to delay distance (D) and damping ratio (η) by the approximate expression (5)

$$\lambda_d \doteq \frac{D\ (6.0 - 2.4\ \eta)}{\sqrt{1 - \eta^2}}$$

6. Apparatus

6.1 Wind Tunnel

6.1.1 Size. The wind tunnel must be large enough so that the projection of the sensor and vane in its displaced position is less than 10 percent of the tunnel cross sectional area.

6.1.2 Calibration. The mean flow rate must be verified at the mandatory speeds by use of transfer standards which have been calibrated at the National Bureau of Standards or by a fundamental physical method. Speeds below 2 m/s for threshold determination must be verified by some other technique, such as smoke puffs or heat puffs.

6.2 Measuring System

6.2.1 Direction. The resolution of the wind vane transducer limits the measurement. The resolution of the measuring or recording system must represent the 10 degree displacement on each side of the wind tunnel centerline with a resolution of 0.2 degree. The accuracy of the position (resistance for example) to output conversion must be within ± 0.1 degree.

6.2.2 Time. The resolution of time must be consistent with the distance accuracy required. For this reason, the time resolution may be changed as the wind tunnel speed is changed. If one wants a distance constant measurement to 0.1 meter resolution one must have a time resolution of 0.05 seconds at 2 m/s and 0.01 seconds at 10 m/s. If time accuracy is based on 60 Hz power frequency it will be at least an order of magnitude better than the resolution suggested above.

6.3 Techniques. One simple technique is to use a fast-response recorder (flat to 40-60 Hz or better) with enough gain so that a vane can be oriented in the wind tunnel with the tunnel centerline direction represented at mid scale on the recorder and ± 10 degrees of vane displacement providing zero and full scale on the recorder. If the recorder has a fast chart speed of 10 to 50 mm/sec or more, one can record the vane performance and extract the data properly. Care must be taken to avoid electronic circuits with time constants which limit the apparent vane performance.

Digital recording systems and appropriate reduction programs will also be satisfactory if the sampling rate is at least 100 per second.

An FM tape recorder may be used for the signal. When played back at lower speed a slow analog strip chart recorder is acceptable. Oscilloscopes with memory and hard copy capability may also be used.

7. Sampling

7.1 Starting Threshold. Ten consecutive tests at the same speed meeting the method requirement, five in each direction off the wind tunnel centerline, are required for a valid starting threshold measurement.

7.2 Delay Distance and Overshoot. The arithmetic mean of ten tests, five in each direction off the wind tunnel centerline, is required for a valid measurement at each speed. The results of the measurements at two or more speeds should be averaged to a single value for delay distance and a single ratio for overshoot.

8. <u>Procedure</u>

8.1 Starting Threshold

8.1.1 Provide a mechanical method for holding and releasing the vane at 10 degrees from θ_B. Test the release mechanism with the wind tunnel off to verify that the release method moves the vane by less than 0.5 degrees when activated. The release device must not move in the direction the vane will move when released.

8.1.2 Set the wind tunnel to a speed which you expect will be lower than the starting threshold. Displace the vane 10 degrees and release by the procedure described in 8.1.1. Observe where the vane stops. Adjust the speed until the vane consistently stops within five degrees of θ_B.

8.1.3 Using this speed record five consecutive samples to one side of the centerline followed by five samples to the other side.

8.1.4 If all ten samples resulted in the vane coming to rest within five degrees of θ_B, the wind speed may be used as the starting threshold in accordance with this method. The average of the absolute angular displacement, θ_B, on each side should be calculated. The higher of the two is the accuracy at the threshold speed. For example, if the average displacement is two degrees from θ_B the accuracy of the wind vane at threshold is specified as two degrees. To match the accuracy at starting threshold to the accuracy of the vane measurement at higher speeds, find the starting speed where the accuracy at starting threshold equals the wind vane measurement accuracy.

8.2 Delay Distance

8.2.1 Set the wind tunnel speed to 2 m/s. Displace the vane 10 degrees and release by method in 8.1.1. Take four more samples in the same direction and five samples in the opposite direction.

8.2.2 Repeat procedure of 8.2.1 using 5 and 10 m/s.

8.2.3 Measure the time from release to crossing five degrees (or 50 percent of the actual release displacement at a nominal 10 degrees) for each of the samples (10 at each speed). Convert each of these times to a distance by multiplying by the tunnel speed. Average the distances to arrive at the delay distance.

8.3 Overshoot

8.3.1 Read the maximum overshoot from the data recorded for 8.2 above. Convert each of the samples to a ratio by dividing the overshoot by the difference between initial displacement and the equilibrium direction. Average the ratios to arrive at the overshoot.

9. Precision and Accuracy

9.1 Precision. Using this equipment and procedure, an estimate of the precision of the method follows.

9.1.1 Starting Threshold. The precision of the speed reported as the threshold relates to the wind tunnel used for this method. A precision of the average of the angular displacement from θ_s is the same as the precision for measuring the position of the direction vane. The apparatus prescribed will provide a precision of 0.2 degree. A precision of one degree is required.

9.1.2 Delay Distance

The precision by this method is 0.1 metre.

9.1.3 Overshoot

The precision by this method is 0.02.

9.2 Accuracy

9.2.1 Starting Threshold. The accuracy of the wind tunnel is the accuracy of this method. An accuracy of 0.1 ,/s is required. This must be documented at the wind tunnel facility and be related to measurements at National Bureau of Standards by National Bureau of Standards report on the transfer standard which will carry the same accuracy limit. Documentation of other methods is required. The accuracy of the angle measurement will be 0.5 degrees for this method.

9.2.2 Delay Distance

The accuracy of this method is 0.1 metre.

9.2.3 Overshoot

The accuracy of this method is 0.05.

References

1. American Nuclear Society-Guideline for Obtaining Meteorological Information at Nuclear Power Sites (ANS-2.5, draft).

2. International Atomic Energy Agency-Safety Guide on Meteorology-Climatology, Diffusion and Transport in Nuclear Power Plant Siting.

3. U.S. Environmental Protection Agency-Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD) (OAQPS No. 1.2-096).

4. U.S. Nuclear Regulatory Commission-Safety Guide 1.23

5. MacCready, Jr., P. B. and H. R. Jex, 1964: Response characteristics and meteorological utilization of propeller and vane wind sensors. J. Appl. Meteor., Vol. 3, No. 2, pp 185.

APPENDIX B

On the following page is a copy of the letter sent to many manufacturers of wind vanes, requesting their participation in this project.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY
RESEARCH TRIANGLE PARK
NORTH CAROLINA 2771'

May 23, 1979

Dear Sirs:

The ASTM sub-committee D22.11 (chaired by Tom Lockhart of MRI) has developed a draft "Standard Method for Determining the Performance of a Wind Vane." This standard method specifies with needed clarity a way of determining starting threshold, delay distance, overshoot, and dynamic vane bias.

We and other laboratories are cooperating with the ASTM by testing the proposed method. We hope to be able to determine the procedure's accuracy, precision, ease of application, and general suitability. In order to do this we would like to test a variety of different vanes, of different types, and from various manufacturers. Since our budget for this project is very limited, we will not be able to purchase the vanes for this test, but hope that you will want to participate with us by loaning us one or two of the wind vanes you manufacture. The equipment would be returned to you as soon as the tests are complete. All of our tests will be conducted in our wind tunnel, with none of the equipment being used out of doors.

I must point out that we are not testing or evaluating the vanes themselves for suitability for any function, or compliance with any regulation, nor are we evaluating the vanes prior to purchase.

Should you choose to join with us, the results of the tests will be made available for your review prior to publication. Reports on the project will, I anticipate, identify the various vanes used with the usual EPA disclaimer to the effect that mentioning a product does not imply endorsement. I am enclosing a copy of the EPA Property Loan Agreement form for your information. I have been told by our purchasing office that this is the only paper work required on this end.

I hope this project will be of interest to you and look forward to hearing from you.

Sincerely yours,

Peter Finkelstein

Peter L. Finkelstein, Ph.D.
Meteorologist
Statistical and Technical
Analysis Branch (MD-75)
(919/541-2347)

Attachment

Draft No. 4
3/11/80

STANDARD METHOD FOR DETERMINING THE DYNAMIC PERFORMANCE OF A WIND VANE

1. Scope

1.1 This method covers the determination of the

Starting Threshold

Delay Distance

Overshoot

Dynamic Vane Bias

of a wind vane from direct measurement in a wind tunnel for wind vanes having measurable overshoot.

1.2 This method provides for determination of the performance of the wind vane and its transducer in wind tunnel flow. Transference of values determined by these methods to atmospheric flow must be done with an understanding that there is a difference between the two flow systems.

2. Applicable Documents

D 1356	Definitions of Terms Relating to Atmospheric Sampling Analysis
E 380	Metric Practive Guide

3. Summary of Method

3.1 This method requires a wind tunnel described in Section 6, Apparatus.

3.2 Wind Direction (θ, degrees) is measured as the angular position of the vane with respect to some index (real or imaginary) position on the sensor assembly. Displacements of 10 degrees must be within ± 1 degree.

3.3 Starting Threshold (S_0, m/s) is determined by measuring the lowest speed at which a vane released from a position 10 degrees off the wind tunnel centerline moves to within five degrees of the centerline. Tests must include initial displacements to each side of the centerline.

3.4 Delay Distance (D, m) may be measured at a number of wind speeds but must include 5 m/s, and 10 m/s. A measurement is made of the time required for the vane to reach 50 percent of the initial displacement from 10 degrees off wind tunnel centerline release. This time in seconds (s) is converted to the Delay Distance by multiplying by the tunnel wind speed in meters per second. Tests must include displacements to each side of the centerline.

3.5 Overshoot (Ω) may be measured at the same time as the Delay Distance. The maximum angular excursion on the opposite side of the at-rest position from the initial 10 degrees off wind tunnel centerline displacement is measured. This value is divided by the initial displacement to obtain the ratio Ω.

3.6 Dynamic Vane Bias (θ_B) is the maximum displacement of the vane from the undisturbed flow direction at the center of the wind tunnel (typically the wind tunnel centerline) caused by the free response of the vane to the tunnel flow at all speeds above three times the vane Starting Threshold. This measurement will identify wind vanes with unbalanced aerodynamic response because of damage (bent tail) or design. θ_B must be $\leq |1°|$.

4. Significance and Use

This method will provide a standard for comparison of wind vanes of different types. Specifications by regulatory agencies (1-4) and industrial societies have specified performance values. This standard provides an unambiguous method for measuring Starting Threshold, Delay Distance, Overshoot and Dynamic Vane Bias.

5. Terminology

5.1 Definitions

delay distance (D)-- the distance the air flows past a wind vane during the time it takes the vane to return to 50 percent of the initial displacement

overshoot (Ω)--the ratio of the amplitudes of two successive deflections of a wind vane as it oscillates about the equilibrium position after release from an offset position, as expressed by the equation

$$\Omega = \frac{\theta_{(n+1)}}{\theta_n}$$

where θ_n and $\theta_{(n+1)}$ are the amplitudes of the n and n + 1 deflections, respectively. Because all deflections after the first to the side opposite the release point are small, the initial release point (i.e., the n = zero deflection) and the first deflection after release (n = 1) are used in practice in determining overshoot.

starting threshold--the lowest wind speed at which a vane will turn to within five degrees of θ_s from an initial displacement of 10 degrees.

5.2 Calculated or Estimated Values

damping ratio (η)--the damping ratio is calculated from the overshoot ratio (Ω) (5).

$$\eta \doteq \frac{\ln \frac{1}{\Omega}}{\sqrt{\pi^2 + \left(\ln \frac{1}{\Omega}\right)^2}}$$

damping coefficient--define

critical damping coefficient--define

damped natural wavelength (λ_d)--at sea level in the U.S. Standard Atmosphere, damped natural wavelength is related to delay distance (D) and damping ratio (η) by the approximate expression (5)

$$\lambda_d \doteq \frac{D\ (6.0 - 2.4\ \eta)}{\sqrt{1 - \eta^2}}$$

6. Apparatus

6.1 Wind Tunnel

6.1.1 Size. The wind tunnel must be large enough so that the projection of the sensor and vane in its displaced position is less than 10 percent of the tunnel cross sectional area.

6.1.2 Calibration. The mean flow rate must be verified at the mandatory speeds by use of transfer standards which have been calibrated at the National Bureau of Standards or by a fundamental physical method. Speeds below 2 m/s for threshold determination must be verified by some other technique, such as smoke puffs or heat puffs.

6.2 Measuring System

6.2.1 Direction. The resolution of the wind vane transducer limits the measurement. The resolution of the measuring or recording system must represent the 10 degree displacement on each side of the wind tunnel centerline with a resolution of 0.2 degree. The accuracy of the position (resistance for example) to output conversion must be within ± 0.1 degree.

6.2.2 Time. The resolution of time must be consistent with the distance accuracy required. For this reason, the time resolution may be changed as the wind tunnel speed is changed. If one wants a distance constant measurement to 0.1 meter resolution one must have a time resolution of 0.05 seconds at 2 m/s and 0.01 seconds at 10 m/s. If time accuracy is based on 60 Hz power frequency it will be at least an order of magnitude better than the resolution suggested above.

6.3 Techniques. One simple technique is to use a fast-response recorder (flat to 40-60 Hz or better) with enough gain so that a vane can be oriented in the wind tunnel with the tunnel centerline direction represented at mid scale on the recorder and ± 10 degrees of vane displacement providing zero and full scale on the recorder. If the recorder has a fast chart speed of 10 to 50 mm/sec or more, one can record the vane performance and extract the data properly. Care must be taken to avoid electronic circuits with time constants which limit the apparent vane performance.

Digital recording systems and appropriate reduction programs will also be satisfactory if the sampling rate is at least 100 per second.

An FM tape recorder may be used for the signal. When played back at lower speed a slow analog strip chart recorder is acceptable. Oscilloscopes with memory and hard copy capability may also be used.

7. Sampling

7.1 Starting Threshold. Ten consecutive tests at the same speed meeting the method requirement, five in each direction off the wind tunnel centerline, are required for a valid starting threshold measurement.

7.2 Delay Distance and Overshoot. The arithmetic mean of ten tests, five in each direction off the wind tunnel center-line, is required for a valid measurement at each speed. The results of the measurements at two or more speeds should be averaged to a single value for delay distance and a single ratio for overshoot.

8. <u>Procedure</u>

8.1 Starting Threshold

8.1.1 Provide a mechanical method for holding and releasing the vane at 10 degrees from θ_B. Test the release mechanism with the wind tunnel off to verify that the release method moves the vane by less than 0.5 degrees when activated. The release device must not move in the direction the vane will move when released.

8.1.2 Set the wind tunnel to a speed which you expect will be lower than the starting threshold. Displace the vane 10 degrees and release by the procedure described in 8.1.1. Observe where the vane stops. Adjust the speed until the vane consistently stops within five degrees of θ_B.

8.1.3 Using this speed record five consecutive samples to one side of the centerline followed by five samples to the other side.

8.1.4 If all ten samples resulted in the vane coming to rest within five degrees of θ_B, the wind speed may be used as the starting threshold in accordance with this method. The average of the absolute angular displacement, θ_B, on each side should be calculated. The higher of the two is the accuracy at the threshold speed. For example, if the average displacement is two degrees from θ_B the accuracy of the wind vane at threshold is specified as two degrees. To match the accuracy at starting threshold to the accuracy of the vane measurement at higher speeds, find the starting speed where the accuracy at starting threshold equals the wind vane measurement accuracy.

8.2 Delay Distance

8.2.1 Set the wind tunnel speed to 2 m/s. Displace the vane 10 degrees and release by method in 8.1.1. Take four more samples in the same direction and five samples in the opposite direction.

8.2.2 Repeat procedure of 8.2.1 using 5 and 10 m/s.

8.2.3 Measure the time from release to crossing five degrees (or 50 percent of the actual release displacement at a nominal 10 degrees) for each of the samples (10 at each speed). Convert each of these times to a distance by multiplying by the tunnel speed. Average the distances to arrive at the delay distance.

8.3 Overshoot

8.3.1 Read the maximum overshoot from the data recorded for 8.2 above. Convert each of the samples to a ratio by dividing the overshoot by the difference between initial displacement and the equilibrium direction. Average the ratios to arrive at the overshoot.

9. Precision and Accuracy

9.1 Precision. Using this equipment and procedure, an estimate of the precision of the method follows.

9.1.1 Starting Threshold. The precision of the speed reported as the threshold relates to the wind tunnel used for this method. A precision of the average of the angular displacement from θ_B is the same as the precision for measuring the position of the direction vane. The apparatus prescribed will provide a precision of 0.2 degree. A precision of one degree is required.

9.1.2 Delay Distance

The precision by this method is 0.1 metre.

9.1.3 Overshoot

The precision by this method is 0.02.

9.2 Accuracy

9.2.1 Starting Threshold. The accuracy of the wind tunnel is the accuracy of this method. An accuracy of 0.1 ,/s is required. This must be documented at the wind tunnel facility and be related to measurements at National Bureau of Standards by National Bureau of Standards report on the transfer standard which will carry the same accuracy limit. Documentation of other methods is required. The accuracy of the angle measurement will be 0.5 degrees for this method.

9.2.2 Delay Distance

The accuracy of this method is 0.1 metre.

9.2.3 Overshoot

The accuracy of this method is 0.05.

References

1. American Nuclear Society-Guideline for Obtaining Meteorological Information at Nuclear Power Sites (ANS-2.5, draft).

2. International Atomic Energy Agency-Safety Guide on Meteorology-Climatology, Diffusion and Transport in Nuclear Power Plant Siting.

3. U.S. Environmental Protection Agency-Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD) (OAQPS No. 1.2-096).

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The American Society for Testing and Materials (ASTM) has proposed a standard method for testing the performance characteristics of a wind vane. This report presents the procedures used to test and evaluate the ASTM method, and the results of that evaluation. Twelve wind vanes were borrowed from their manufacturers and tested using the ASTM procedures. The theory of wind vane dynamics is briefly reviewed. Description of the equipment and procedures used is given. Measurements of starting threshold, starting accuracy, delay distance, overshoot ratio, and damped wavelength were made. Damping ratio and natural wavelength were computed from the measurements. Based on the results of this test, it is concluded that the ASTM method provides a reasonable and reliable technique for determining performance characteristics for many wind vanes.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Wind Direction Measurement Wind Vanes Meteorological Measurements Meteorological Quality Assurance	Meteorological Instrument Evaluation	43F 68A

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