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RESPONSE TESTS OF CUP, VANE, AND PROPELLER WIND SENSORS

By Dennis W. Camp, Robert E. Turner, and
Luke P. Gilchrist

Aero-Astrodynamics Laboratory

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16. ABSTRACT

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RESPONSE TESTS OF CUP, VANE, AND PROPELLER WIND SENSORS

SUMMARY

The results of a wind tunnel test program performed to investigate the response parameters of two types of cup anemometers, two types of wind vanes, and a propeller anemometer are presented. The distance constant for the cups (wind speed sensor) was found to be approximately 0.8 and 1.3 meters for the two types tested. Values for the damping ratio of approximately 0.48 and 0.40 were found for the two types of vanes. The main point of interest in the investigation of the propeller-type anemometer, other than its response, was how the indicated speed varied as a function of angle of attack. For an angle of attack (angle formed by the longitudinal axis of the anemometer and the wind flow direction) within ± 30 degrees into or away from the flow direction, a cosine curve would give a good approximation to the data.

I. INTRODUCTION

To interpret wind data measured by wind sensing instruments, the response characteristics of the speed and direction sensors must be known. The distance constant for wind speed and the damping ratio, damped frequency, natural frequencies, and delay distance for wind direction are the parameters generally used to determine these response characteristics. Knowledge of these parameters becomes increasingly important in measuring the higher frequency contents of the wind, especially as the limiting capability of the sensors is approached, and for this reason, a continuing program to test the various wind sensors used in the acquisition of wind data is maintained. This program is necessary to ensure understanding and proper interpretation of ground wind data vital to space vehicle and other structural design efforts. One major source of such ground wind data is NASA's 150-meter Meteorological Tower Facility located at the Kennedy Space Center, Florida [1, 2]. The wind tunnel results discussed in this report were obtained by wind sensors (cups, propellers, and vanes - see Figure 1), presently being used at this tower facility.

The Wind Instrumentation Research Facility at the White Sands Missile Range (WSMR), New Mexico, which was used in these tests, is a low speed, closed circuit wind tunnel having features which make it ideally suited for this type of testing. The test chamber is a rectangular parallelepiped (4 x 4 x 6 feet) with the six-foot side parallel to the tunnel flow. Air movement in the tunnel is generated by a blower, which has both speed and pitch controls. Speed control in increments of 0.04 meters per second is possible for the tunnel speed range of 0.22 to 38.0 meters per second. Instrumentation used to measure tunnel flow consists of a Prandtl tube, an eddy-shed hot-wire sensor, and a mean-velocity hot-wire sensor. The contraction section of the tunnel follows an exponential function and has a ratio of approximately five to one. This tunnel is described in detail in a report by Glass and Martin [3].

II. RESPONSE PARAMETERS

The distance constant was the response parameter used to determine the response of the wind speed sensors. This constant (L) is defined by Schubauer and Adams [4] to be the length of a column of air that must pass a wind speed sensor after a sharp-edge gust or partial lull has occurred for the sensor to reach 63 percent of the new equilibrium value. Since a step increase was used and no attempt was made to simulate a lull, we are concerned only with a sharp-edge gust.

The distance constant is given by

$$L = \bar{u}\tau, \tag{1}$$

where $\bar{u}$ is the tunnel equilibrium speed and τ is the time constant. In determining the time constants from the WSMR tunnel tests, no attempt was made to determine the zero time point on the chart records; rather, a convenient point on the chart was chosen. The reason for choosing a point other than zero was to minimize the possibility that the test would be affected by the procedure used to release the cups (and propellers) from a locked position. The procedure began with an electronic braking device [5] to stop the cups (or propellers) from rotating while the tunnel was at its equilibrium speed; the brake was then released allowing the speed sensors to respond.

The parameters used to study the response characteristics of the wind vane were damping ratio, damped frequency, natural frequency, and delay distance. The damping ratios were determined by use of Kingman's equations [6]

$$h = \left\{1 + [\pi/\ln(x_1/x_2)]^2\right\}^{-1/2} \tag{2}$$

or

$$h = \left\{1 + [2\pi/\ln(x_1/x_2)]^2\right\}^{-1/2} \tag{3}$$

where, for equation (2), x_1 is the number of degrees the vane is deflected relative to the tunnel flow direction and x_2 is the number of degrees the vane overshoots the tunnel flow direction. For equation (3), x_1 and x_2 are the successive amplitudes (degrees of overshoot) on the same side of the final value (tunnel flow direction). Thus, for vanes having no measurable second excursion, equation (2) should be used and equation (3) should be used for vanes with measurable second excursions.

MacCready and Jex [7] stated that it is preferable to present the response characteristics in terms of parameters which do not vary with speed. If one does not consider friction, the damping ratios (h) of equations (2) and (3) should not vary with speed. Of the other three parameters, only the delay distance does not vary as a function of speed. Other parameters, to be discussed in section III, can be computed from the two varying parameters (flow).

Damped frequency is given by

$$f_D = P^{-1}, \tag{4}$$

where P is the period of one damped oscillation; i.e., the period of time from the release (t = 0) of a vane that has been deflected a few degrees from an equilibrium flow direction to make one damped oscillation. Figure 2 illustrates the period of the damped frequency corresponding to the damping ratios given by equations (2) and (3).

The natural frequency of a vane, according to MacCready and Jex [7], and Kingman [6], is given by

$$f_n = f_D/(1-h^2)^{1/2}, \tag{5}$$

and the delay distance by

$$D = \bar{u}/2\pi\, f_n h. \tag{6}$$

The Sandborn Model 60-1300 recorder was used to record the data.

III. RESULTS OF WIND TUNNEL TEST

A. Propeller Response

The propeller anemometer used in this investigation has three wind speed sensors which are usually used in an orthogonal array. However, the sensors can be used separately. Since it is desired to obtain only the vertical component of the wind by use of the propeller sensors and to obtain the horizontal winds by use of cup anemometers, we use the sensors individually.

The distance constant, computed by equation (1), is presented in Figure 3, which shows that, as the angle of attack (α)* approaches 90 degrees, the distance constant becomes smaller. It can safely be assumed that this decrease in the distance constant will continue with increasing α until the 90-degree point is reached, where the distance constant will be zero. However, the distance constant is not a function of wind speed. The distance constants were obtained by use of wind-speed traces as illustrated in Figure 4. The figure, a copy of an actual wind trace, shows that the indicated flow (u_i) decreases as α increases for a given flow. For these examples, the tunnel flow was 9.03 m/sec.

A composite of all the propeller anemometer data for various angles of attack is presented in Figure 5, which illustrates the percentage of flow indicated as a function of α for several tunnel flows. The percentage is given by the ratio $u_i/\bar{u}$, where u_i is the indicated speed. The ratio is the cosine of the angle of attack; i.e.,

$$\cos \alpha = u_i/\bar{u}. \tag{7}$$

Thus, the ratio values should follow a cosine curve. A cosine curve (solid line) will give a good approximation to the data only for angles near the flow direction, approximately ± 30 degrees. Figure 5 also shows that a cosine-square curve gives not so good an approximation as the cosine. However, Mazarella [8] and MacCready and Jex [7] found that for vane-oriented anemometers, the ratio followed a cosine-square curve. Neither the cosine nor the cosine-square curve gives a good approximation when the angle of attack is near 90 degrees.

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*The angle of attack is the angle formed by the longitudinal axis of the anemometer and the wind flow direction (see Figure 5).

B. Cup Response

Two types of cups identified as A and B were used in these tests. Type A is similar to those which have been in use for a long time and is considered to be more or less "standard." These cups become brittle with age; thus, it was decided to investigate the use of the newer Lexan cups (Type B). Although the type B cups are more durable, their response is not as good as the older type A (see Figure 6 and Table 1).

Figure 6 shows that the time was not determined from the instant of release (unlocking) of the cups; a later time was used to minimize the effect of the brake mechanism for locking the cups. After the time constant had been determined from the traces, the distance constants were computed by use of equation (1).

Table 1 presents the average values of the distance constants for both types of cups tested. The variations in the distance constants are well within the accuracy of the system (wind sensor, sensor electronics, recorder, tunnel flow measurements, computations, etc.) used to obtain the data. The largest difference occurs for the Type B sensor between 4.50 and 8.95 m/sec, a difference of only 0.1 m.

As a result of these tests, the Type A cups were returned for use at the NASA's 150-meter Meteorological Tower to obtain better wind measurement. The poorer response of the Type B cups is evidently due to the weight difference (Type B is heavier).

C. Vane Response

Two types of wind vanes identified as A and B were tested. The vane tails of the Type A units were being destroyed by the birds and insects (primarily bees) at the 150-meter Meteorological Tower at Kennedy Space Center, Florida. Type B was developed in an attempt to improve the direction sensor and to have a vane (tail) that birds and insects would not destroy. Until the durability of the Type B vane is determined with respect to the birds and insects, the Type A vane will continue to be the standard for the meteorological tower.

The parameters used to investigate the vane response were presented in Table 2 in the form of average values for the four parameters: damping ratio, damped frequency, natural frequency, and delay distance. The damping ratio and delay distance do not vary with speed (flow); however, as stated in section II, the damped and natural frequencies vary as a function of speed. If the damped wavelength

$$\lambda_D = \bar{u}/f_D \tag{8}$$

and the natural wavelength

$$\lambda_n = \bar{u}/f_n \tag{9}$$

are computed from the damped and natural frequencies, the results obtained should be independent of the speed. Table 3 gives the values obtained for the damped and natural wavelengths. It is believed that the variation in these values is due to system accuracy and to computational error (chart reading error, round-off error, etc.).

The values presented in Tables 2 and 3 show that both types of vanes give fairly consistent data; however, Type A has the best response.

TABLE 1

Average Values of Distance Constants for Two Types of 3-Cup Anemometer

Type of Sensor	Tunnel Flow Speed		
	4.50 m/sec	8.95 m/sec	13.11 m/sec
A	0.84 ± 0.04 (m)	0.86 ± 0.04 (m)	0.79 ± 0.04 (m)
B	1.30 ± 0.04 (m)	1.40 ± 0.04 (m)	1.31 ± 0.04 (m)

TABLE 2

Average Values of Various Parameters for Two Types of Wind Vanes

Flow Speed	Variable	Vane Type A, Deflection Angle 10 Degrees	Vane Type A, Deflection Angle 20 Degrees	Vane Type B, Deflection Angle 10 Degrees	Vane Type B, Deflection Angle 20 Degrees
4.58 m/sec	Damping Ratio	0.47 ± 0.01	0.48 ± 0.01	0.39 ± 0.01	0.39 ± 0.01
	Damped Frequency (Hz)	1.11 ± 0.03	1.10 ± 0.03	1.45 ± 0.04	1.46 ± 0.04
	Natural Frequency (Hz)	1.26 ± 0.04	1.24 ± 0.04	1.62 ± 0.04	1.64 ± 0.03
	Delay Distance (m)	1.24 ± 0.05	1.22 ± 0.04	1.16 ± 0.05	1.12 ± 0.02
9.04 m/sec	Damping Ratio	0.47 ± 0.01	0.48 ± 0.01	0.40 ± 0.01	0.40 ± 0.01
	Damped Frequency (Hz)	2.10 ± 0.08	2.08 ± 0.08	2.74 ± 0.08	3.00 ± 0.08
	Natural Frequency (Hz)	2.38 ± 0.09	2.37 ± 0.07	3.04 ± 0.13	3.35 ± 0.22
	Delay Distance (m)	1.28 ± 0.06	1.29 ± 0.03	1.18 ± 0.06	1.07 ± 0.07
13.48 m/sec	Damping Ratio	0.47 ± 0.01	0.47 ± 0.01	0.41 ± 0.01	0.39 ± 0.01
	Damped Frequency (Hz)	3.12 ± 0.10	3.10 ± 0.10	4.04 ± 0.07	4.55 ± 0.16
	Natural Frequency (Hz)	3.54 ± 0.16	3.52 ± 0.12	4.62 ± 0.28	5.34 ± 0.20
	Delay Distance (m)	1.28 ± 0.07	1.26 ± 1.26	1.15 ± 0.09	1.04 ± 0.06

TABLE 3

Average Values for the Damped and Natural Wavelengths for Two Types of Wind Vanes

Flow Speed	Variable*	Vane Type A: Deflection Angle 10 Degrees	Vane Type A: Deflection Angle 20 Degrees	Vane Type B: Deflection Angle 10 Degrees	Vane Type B: Deflection Angle 20 Degrees
4.58 m/sec	λ_D (m)	4.12 ± 0.11	4.16 ± 0.11	3.15 ± 0.09	3.14 ± 0.09
	λ_n (m)	3.63 ± 0.11	3.69 ± 0.11	2.83 ± 0.07	2.79 ± 0.05
9.04 m/sec	λ_D (m)	4.30 ± 0.16	4.35 ± 0.17	3.30 ± 0.10	3.01 ± 0.08
	λ_n (m)	3.80 ± 0.14	3.81 ± 0.11	2.97 ± 0.12	2.70 ± 0.18
13.48 m/sec	λ_D (m)	4.32 ± 0.14	4.35 ± 0.14	3.34 ± 0.06	2.96 ± 0.10
	λ_n (m)	3.81 ± 0.17	3.83 ± 0.13	2.92 ± 0.18	2.52 ± 0.10

*λ_D = Damped Wavelength

λ_n = Natural Wavelength

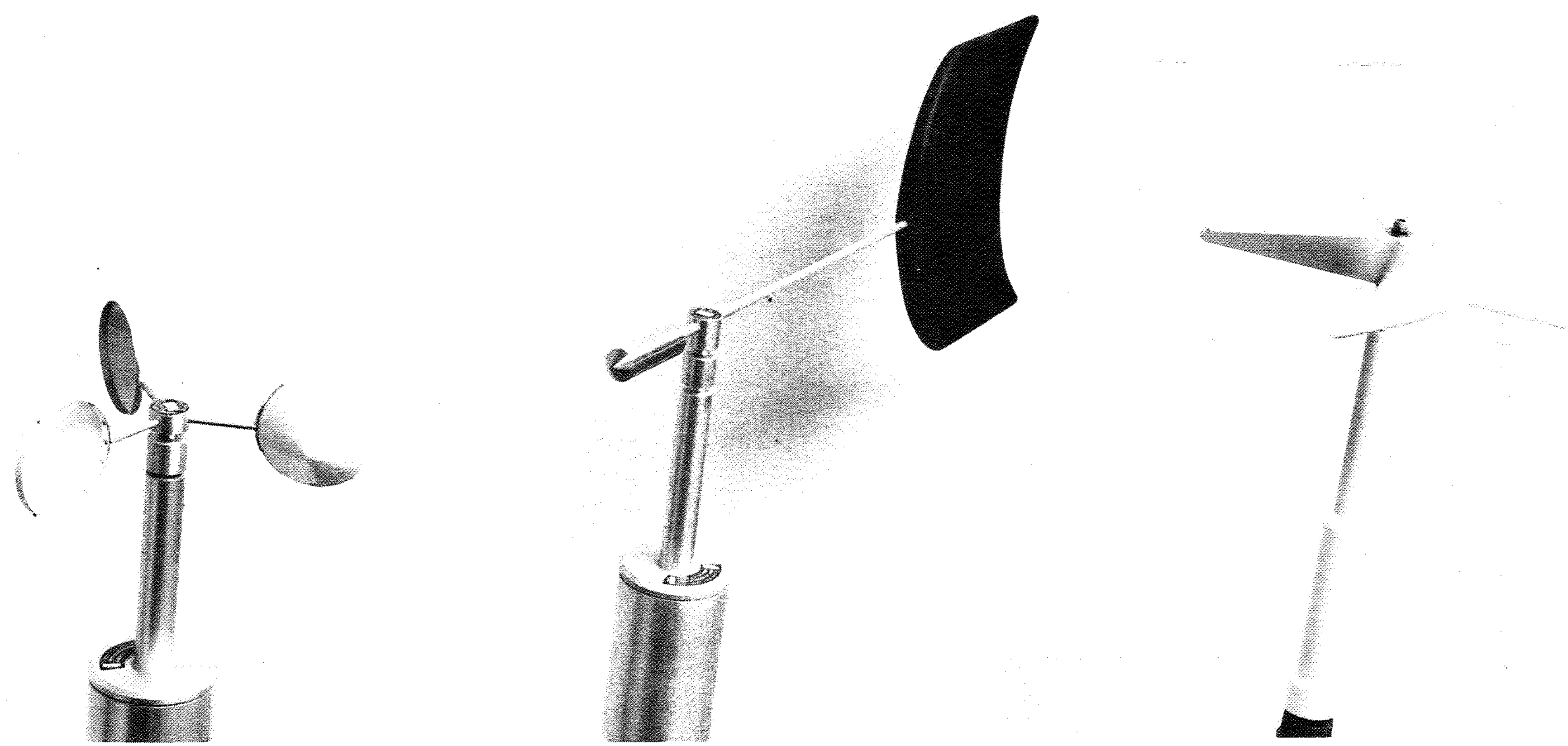


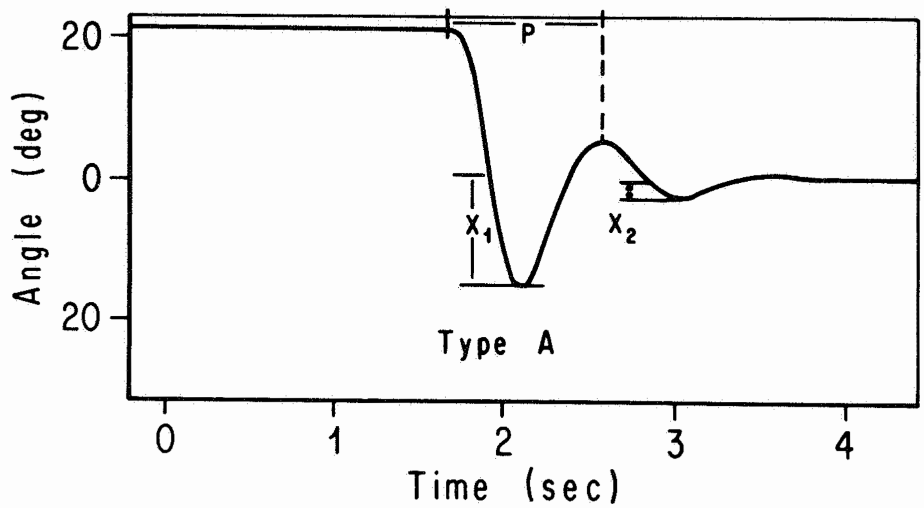
Figure 1. Types of Wind Sensors Tested: Three-Cup Anemometer, Wind Vane, and Propeller Anemometer

Damping Ratio = $\left[1 + \left(2\pi / \ln\left(\frac{X_1}{X_2}\right)\right)^2\right]^{-1/2} = 0.47$

Damped Frequecy = $f_D = P^{-1} = 1.09$ Hz

Natural Frequecy = $f_n = f_D / (1 - h^2)^{1/2} = 1.23$ Hz

Delay Distance = $\bar{u} / 2\pi f_n h = 1.26$ meters



Damping Ratio = h = $\left[1 + \left(\pi / \ln\left(\frac{X_1}{X_2}\right)\right)^2\right]^{-1/2} = 0.38$

Damped Frequency = $f_D = P^{-1} = 1.45$ Hz

Natural Frequency = $f_n = f_D / (1 - h^2)^{1/2} = 1.69$ Hz

Delay Distance = D = $\bar{u} / 2\pi f_n h = 1.13$ meters

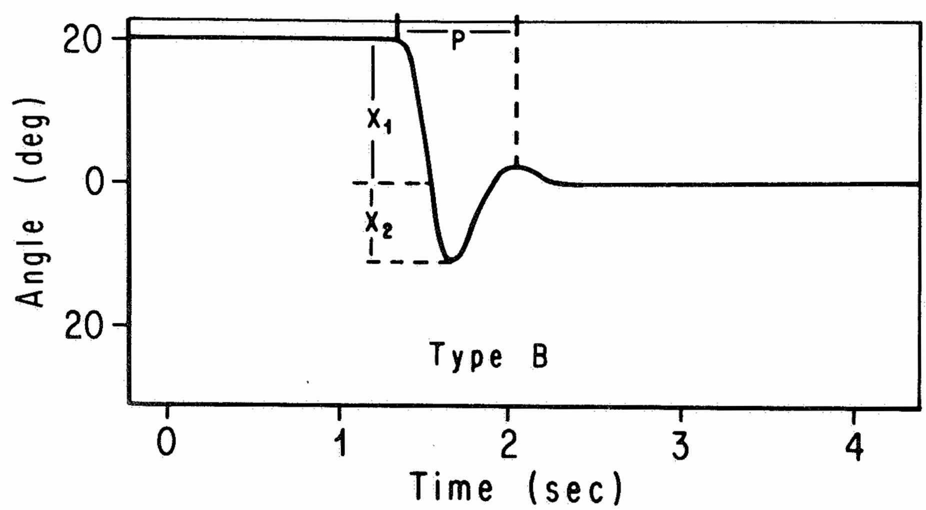


Figure 2. Pictorial Trace of Wind Vane Data

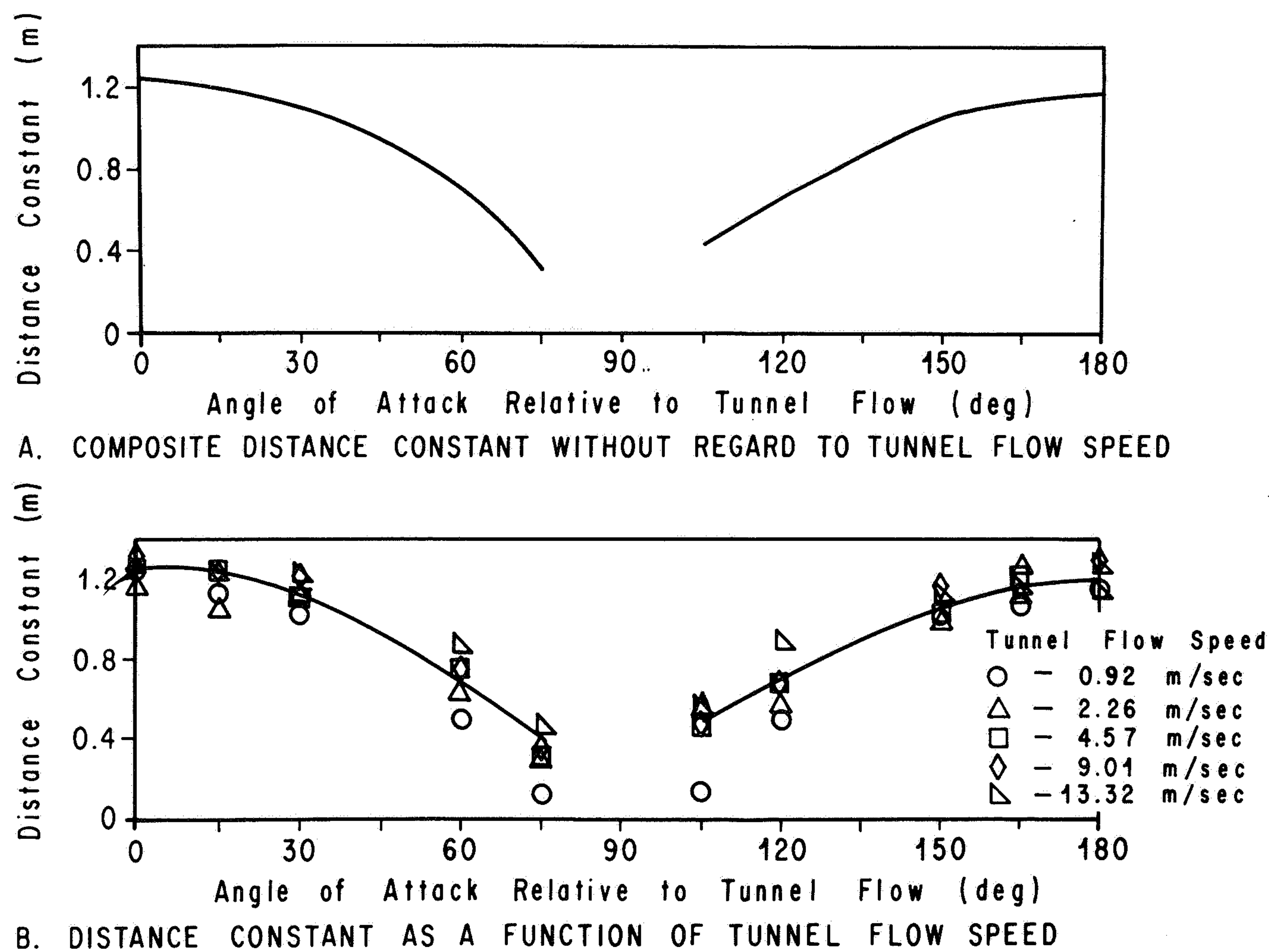


Figure 3. Propeller Anemometer's Distance Constant Presented as a Function of Angle of Attack

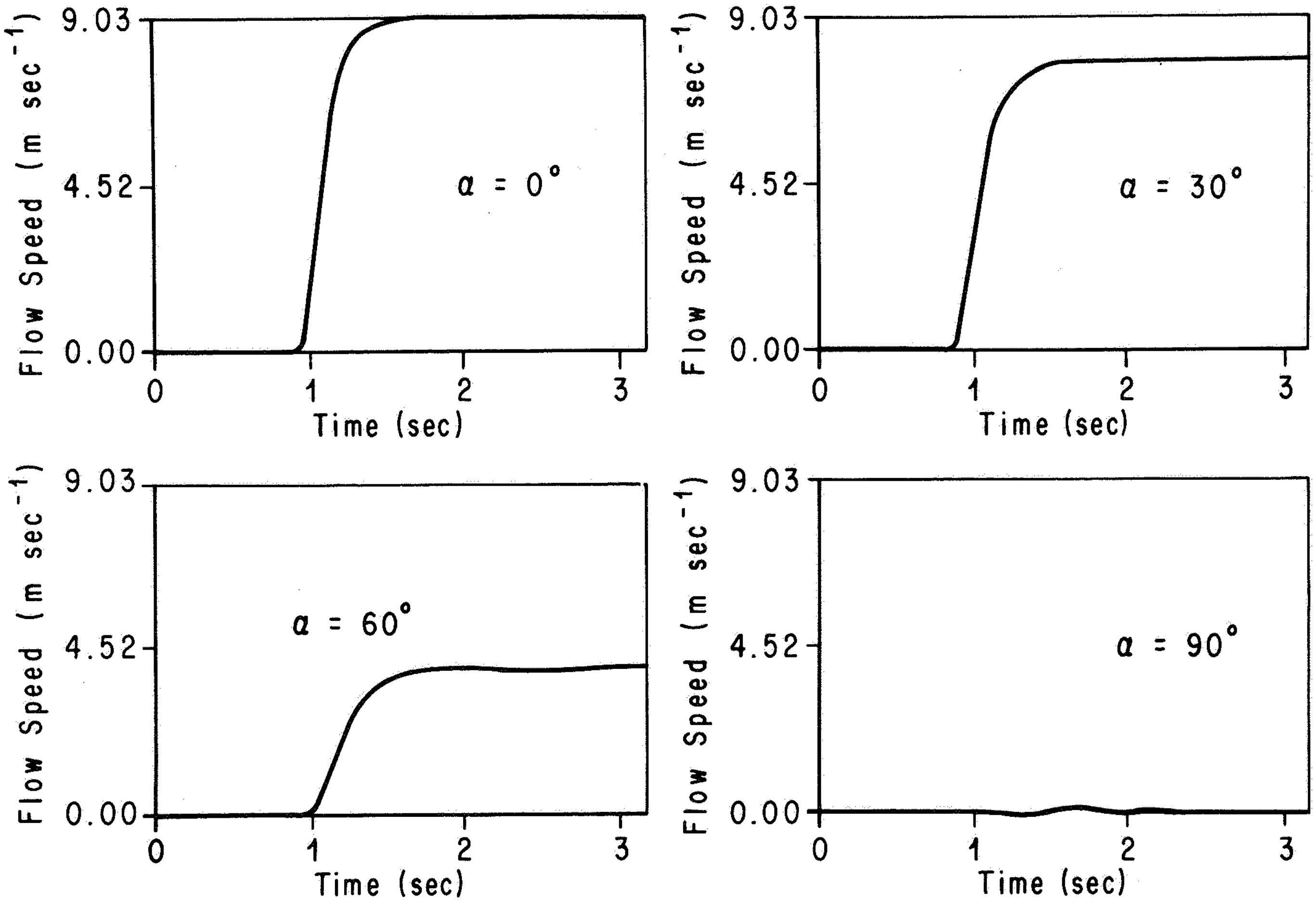


Figure 4. Pictorial Wind Speed Traces for the Propeller Anemometer for Four Different Angles of Attack.

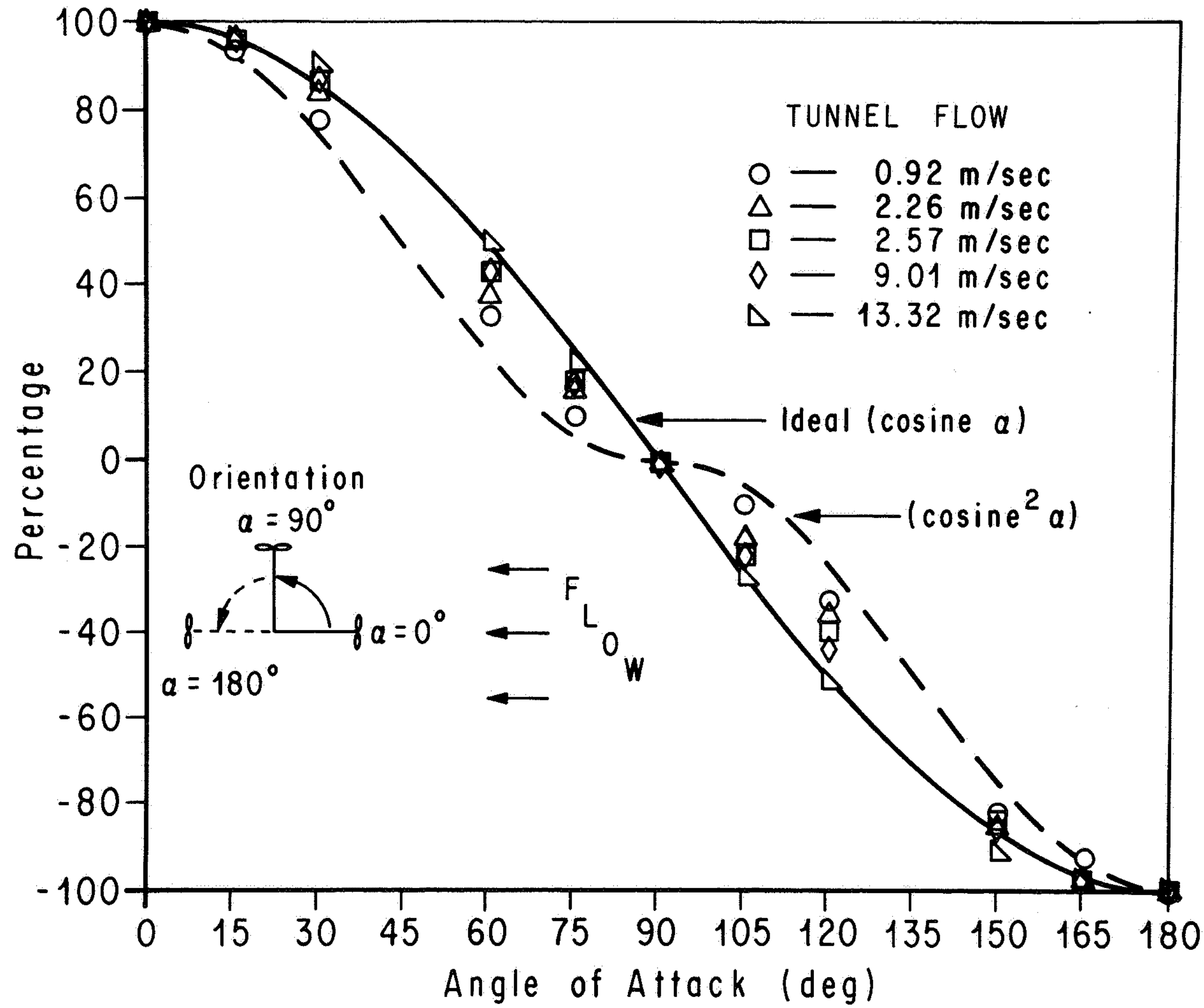


Figure 5. Response Characteristic of the Propeller Anemometer (Percentage of Flow Measured as a Function of Angle of Attack).

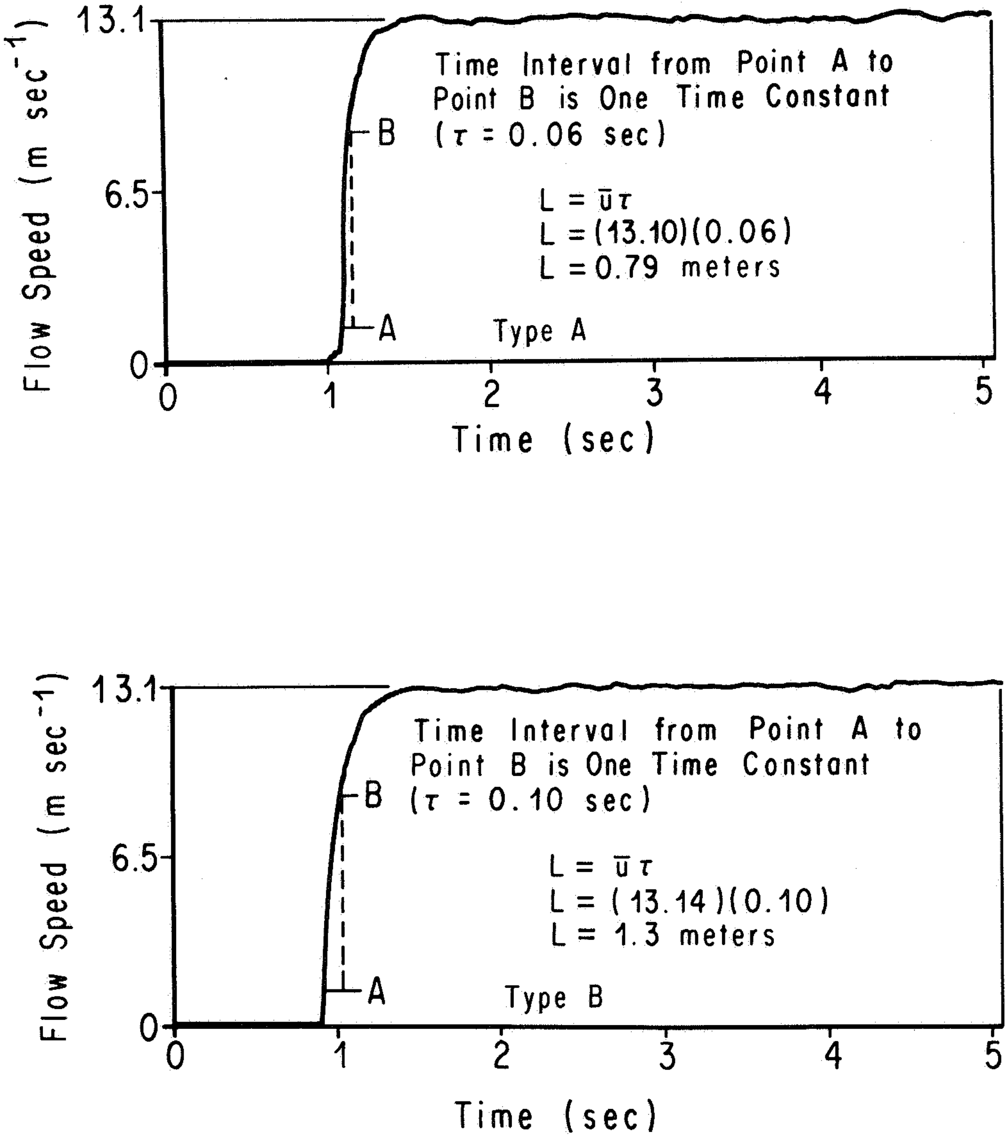


Figure 6. Pictorial Wind Speed Traces for Two Types of Cup Anemometers

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James W. Kaufman

J. W. Kaufman
Chief, Atmospheric Dynamics Branch

W. W. Vaughan
Chief, Aerospace Environment Division

for E. D. Geissler
Director, Aero-Astrodynamics Laboratory

MSFC—RSA, Ala