Wind Tunnel Performance Study of the Met One (Teledyne Geotech)
Model 1585 Bivane and
Model 1564B Cup Anemometer

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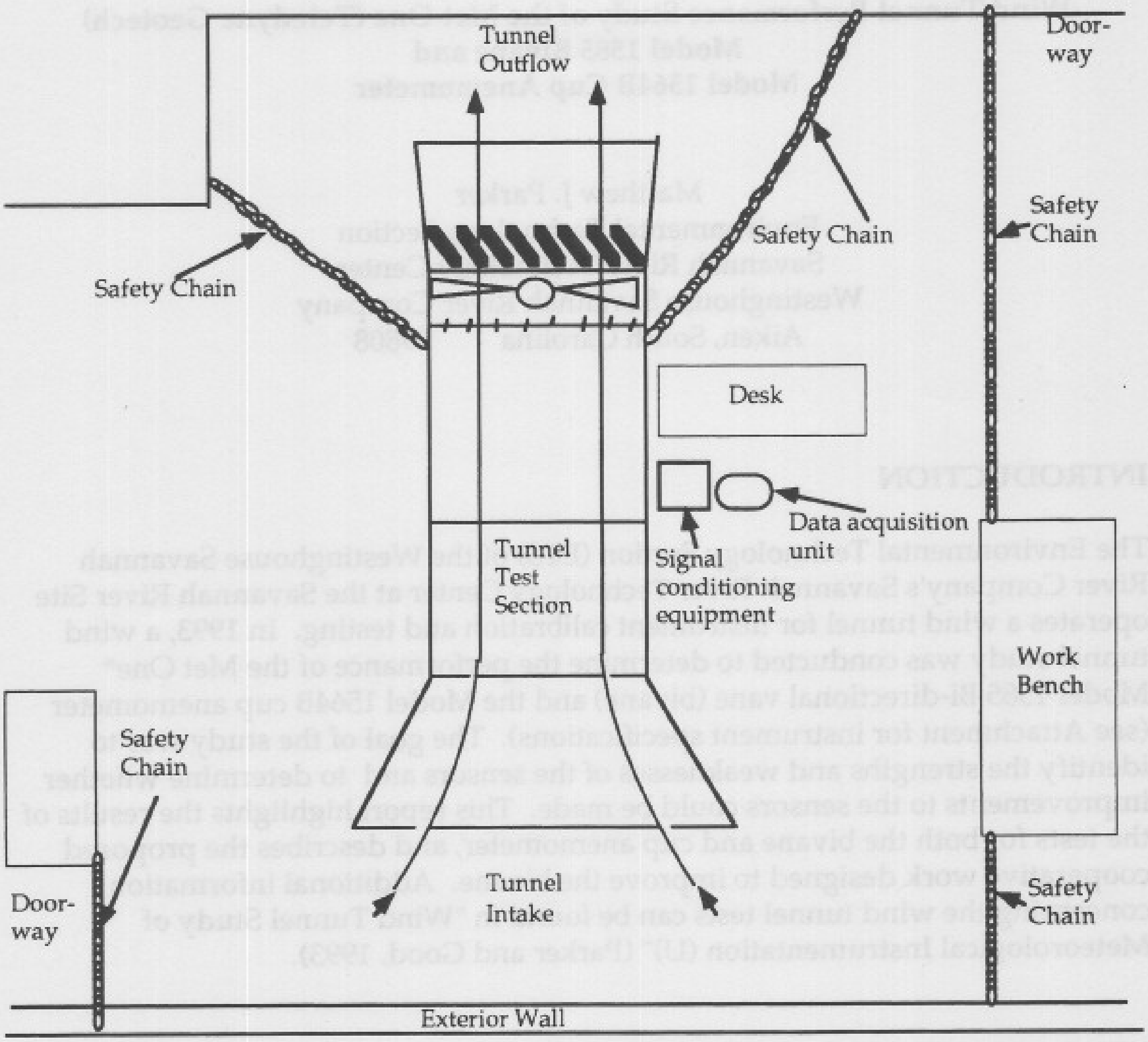
INTRODUCTION

The Environmental Technology Section (ETS) of the Westinghouse Savannah River Company's Savannah River Technology Center at the Savannah River Site operates a wind tunnel for instrument calibration and testing. In 1993, a wind tunnel study was conducted to determine the performance of the Met One* Model 1585 Bi-directional vane (bivane) and the Model 1564B cup anemometer (see Attachment for instrument specifications). The goal of the study was to identify the strengths and weaknesses of the sensors and to determine whether improvements to the sensors could be made. This report highlights the results of the tests for both the bivane and cup anemometer, and describes the proposed cooperative work designed to improve the bivane. Additional information concerning the wind tunnel tests can be found in "Wind Tunnel Study of Meteorological Instrumentation (U)" (Parker and Good, 1993).

WIND TUNNEL TEST FACILITY

Wind tunnel tests were conducted in an Aerolab Subsonic Low Turbulence Wind Tunnel (Figure 1) operated by ETS. The tunnel operates by utilizing a 15 horse power constant speed motor which turns a fan to draw air through a honeycomb grid. This air is drawn through the test section and exhausted beyond the fan blades. The test section is 36" x 36" x 60". Air flow is regulated from 1 to about 50 mph by a variable tachometer control unit which is calibrated (WSRC, 1991). An adjacent cabinet has been equipped with the full compliment of signal processor cards and power units. Data acquisition is performed with a personal computer and Labtech Notebook (ver 6.0) software.

*Met One recently purchased the meteorological instrumentation line from Teledyne Geotech which included the Model 1585 bivane and the Model 1564B cup anemometer.



**Top-view of
Wind Tunnel in the Meteorological Engineering Facility
in Building 735-7A
Operated by the Environmental Transport Group**

Figure 1. The ETS wind tunnel.

TEST PROCEDURES

"Performance Calibration Procedures for Meteorological Instrumentation" found in Meteorological Monitoring Procedures (WSRC, 1991) were used as a guide to perform each wind tunnel test. The procedures were originally designed by Tom Lockhart in generic terms and then revised by ETS. Guidance was also provided by the American Standards for Testing and Materials (ASTM) procedures (ASTM, 1985) and Lockhart (EPA, 1989). In many cases, additional tests were performed to evaluate in greater detail the characteristics and accuracy of the meteorological instruments.

HIGHLIGHTS OF THE MODEL 1585 BIVANE TESTS

Several tests were performed on the Model 1585 bivane. Each of the tests is described in the following sections along with the results of the tests.

- *Dynamic Vane Bias*

The dynamic vane bias is the angular difference between the flow of air in the tunnel and the equilibrium position of the tail with the wind tunnel operating. Ideally, the vane bias should be less than one degree.

In general, the vane bias for the Model 1585 bivane was less than one degree for both the azimuth and elevation functions (Figure 2). Tails with dents or other

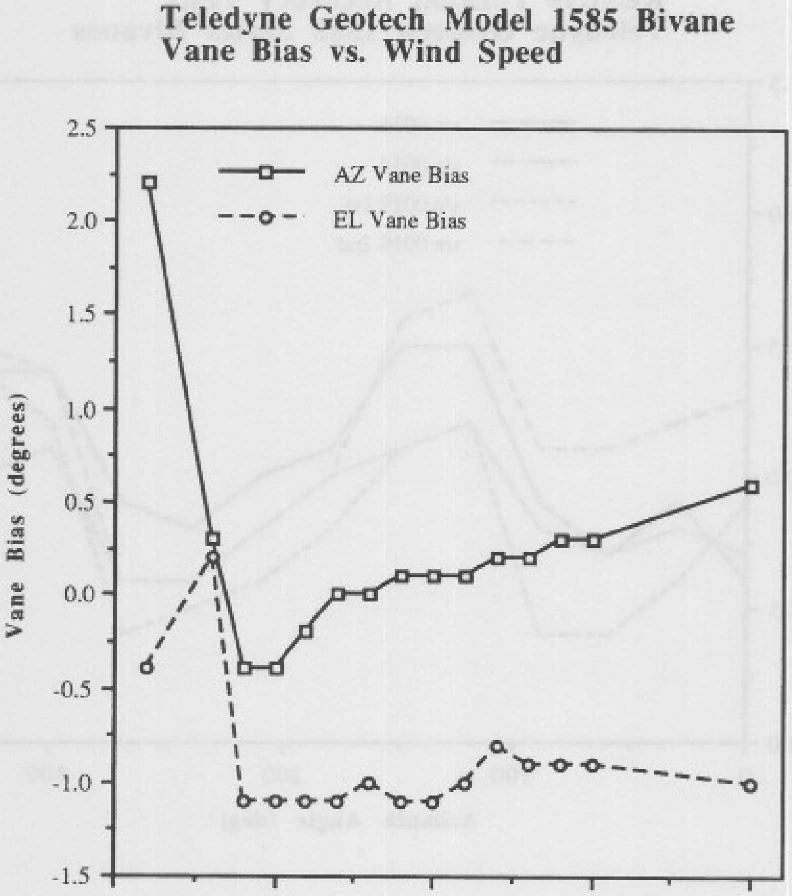


Figure 2. Vane bias for both the azimuth and elevation functions.

weather related damages, especially on the side closest to the instrument, had a worse vane bias factor because the aerodynamics of the vane were altered. Also, after removing and rebalancing a tail assembly, the elevation vane bias tended to exhibit minor variations which, however, were generally within 1°. The restoring force of the instrument can cause variations in the vane centerline when repeatedly removing, re-installing, and re-balancing the vane assembly.

- *Relative Position Accuracy*

Relative position accuracy tests were made with orientation fixtures at 10° increments for azimuth and 5° increments for elevation angles. Azimuth errors (Figure 3) are expected to be less than 2°, and elevation values (Figure 4) are expected to be less than 3° near zero degrees elevation and 5° near the ±50°

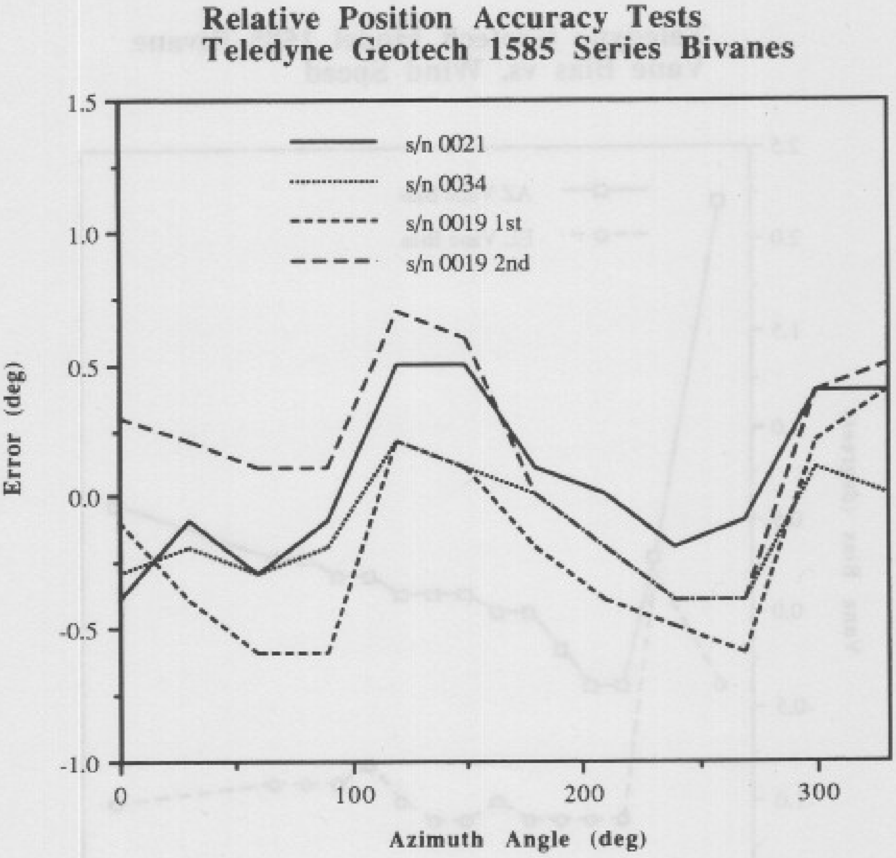


Figure 3. Examples of azimuth relative position accuracy errors.

extrema (WSRC, 1991). For each test, several individual instruments were used for comparative reasons.

The relative position accuracy for the azimuth angle was always less than 1° and was usually less than 0.5°. The high and low ends (-50°, +50°) of the elevation relative position accuracy appeared to have a higher error than near 0°. If an instrument failed the relative position accuracy test, the elevation function usually caused the bivane to do so near ±50°.

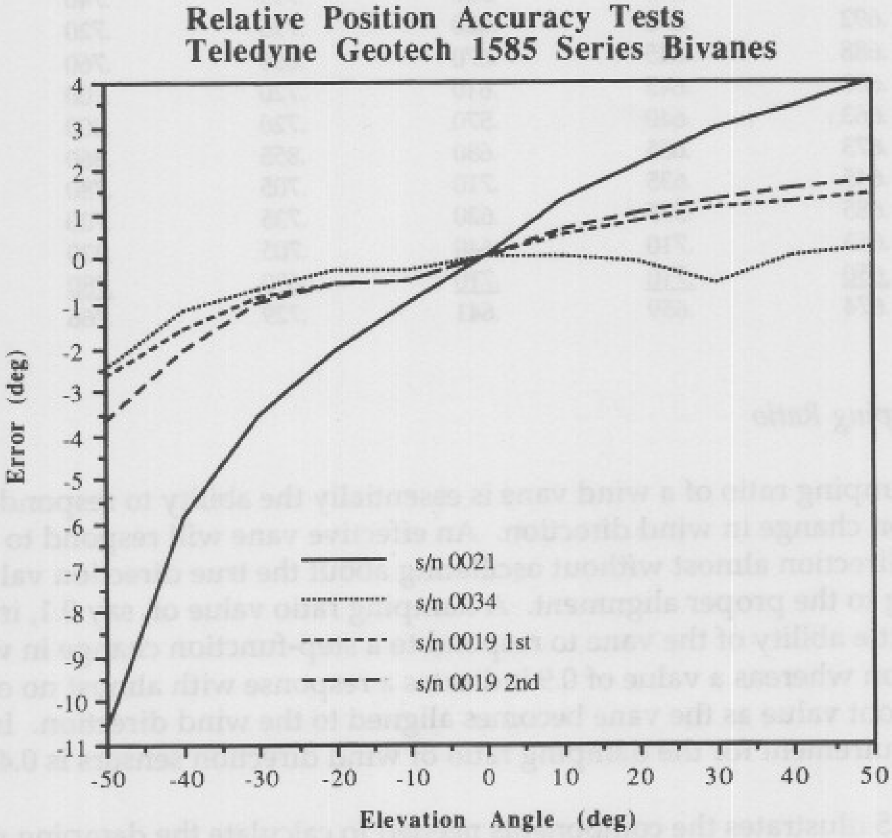


Figure 4. Examples of elevation relative position accuracy errors.

- *Delay Distance*

The delay distance is defined as the distance the air flows past a wind vane during the time it takes the vane to return to 50% of the initial displacement (Finkelstein, 1981). Normally, the delay distance is required to be two meters or less (EPA, 1989).

The delay distance of the Model 1585 bivane was found to be fairly constant regardless of the tunnel speed (Table A). As the tunnel speed reached approximately 15 m/s, the delay distance increased very slightly by about 0.08 m. Values of the delay distance ranged from 0.77 m at 20 m/s to 0.67 m at 2.5 m/s.

Table A. Azimuth delay distance results as tunnel speed increases calculated from data sampled at 650 Hz with no smoothing average.

	2.5 m/s delay distance:	5 m/s delay distance:	10 m/s delay distance:	15 m/s delay distance:	20 m/s delay distance:
ccw	.698	.660	.580	.795	.740
ccw	.692	.690	.620	.795	.720
ccw	.688	.645	.670	.630	.760
ccw	.683	.645	.610	.720	.700
ccw	.663	.640	.570	.720	.800
cw	.673	.655	.680	.855	.860
cw	.645	.635	.710	.705	.780
cw	.685	.595	.620	.735	.700
cw	.663	.710	.640	.705	.820
cw	.650	.710	.710	.630	.780
Ave.	.674	.659	.641	.729	.766

- *Damping Ratio*

The damping ratio of a wind vane is essentially the ability to respond to a step-function change in wind direction. An effective vane will respond to the "new" wind direction almost without oscillating about the true direction value before coming to the proper alignment. A damping ratio value of, say 0.1, indicates very little ability of the vane to respond to a step-function change in wind direction whereas a value of 0.9 indicates a response with almost no oscillatory overshoot value as the vane becomes aligned to the wind direction. In general, the requirement for the damping ratio of wind direction sensors is 0.4 or greater.

Figure 5 illustrates the components needed to calculate the damping ratio. Calculations for overshoot, defined as the ratio of the amplitudes of two successive deflections of a wind vane as it oscillates about the centerline of the wind tunnel after release from a ten degree offset position (EPA, 1989), were made with the following formula:

$$\Omega = (L2 - L1)/L1$$

where L1 is the angular distance between the release point and the centerline and L2 is the total angle from the release point to the maximum of the first overshoot. From the overshoot, the damping ratio (η) may be calculated by the following equation from MacCready and Jex (1964):

$$\eta = \ln(1/\Omega)/\sqrt{\pi^2 + [\ln(1/\Omega)]^2}$$

The damping ratio of the Model 1585 bivane was tested using several different methods. Clockwise and counterclockwise releases in the horizontal plane were

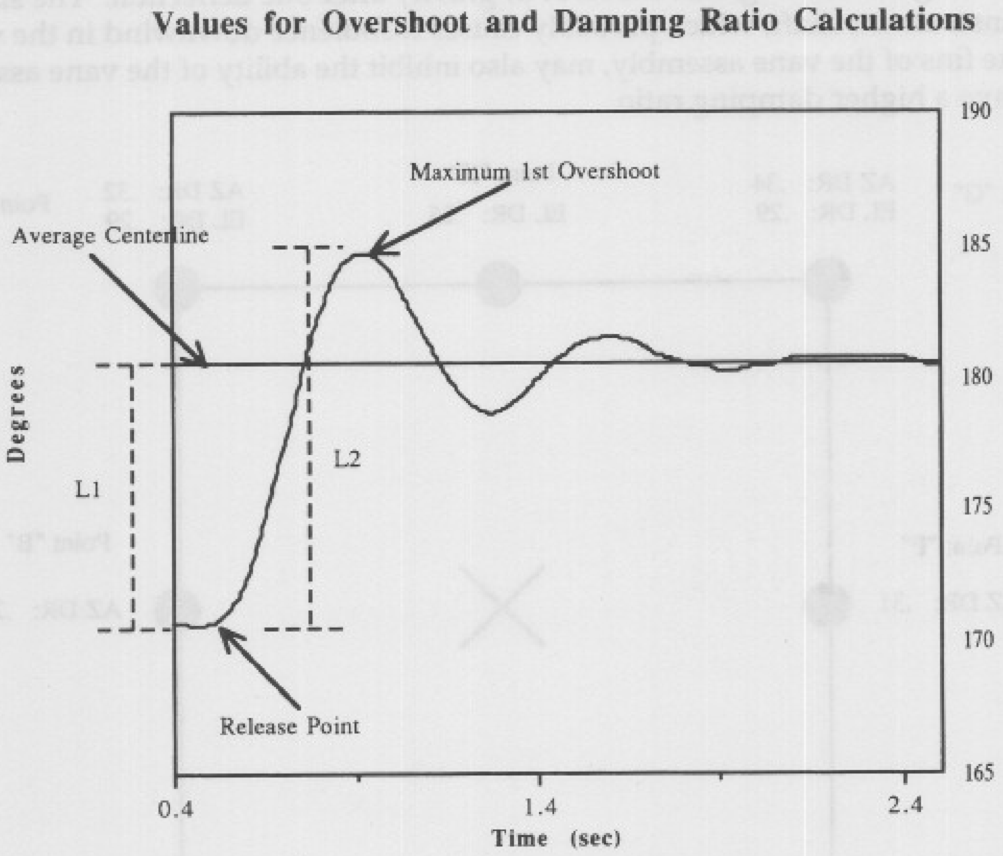

Values for Overshoot and Damping Ratio Calculations

Figure 5. An illustration of the components used to calculate the damping ratio.

made for the azimuth function. Also, releases were made through the entire range of azimuth values. The elevation damping ratio was tested for the nose-up and nose-down positions. Coupled releases were made which measured the simultaneous damping ratio of both the azimuth and elevation functions. The damping ratio as a function of wind speed was also tested.

The damping ratio of the Model 1585 bivane was, in general, found to be less than 0.4. For the azimuth function, values near 0.32 were recorded at 5 and 10 m/s. No appreciable variations with respect to azimuth value (i.e. 0°, 30°, etc.) or clockwise and counterclockwise releases were found. Elevation function damping ratios were found to be less than 0.25 for nose-down releases and near 0.35 for nose-up releases at 5 and 10 m/s. Coupled release damping ratios were shown to be similar to horizontal and vertical releases (Figure 6).

The relatively low damping ratio values exhibited by the Model 1585 bivane are likely caused by the performance of the vane assembly of the instrument. The weight and size of the vane assembly inhibits the ability to respond to sudden changes in wind direction. Also, the restoring force of the cam shaft which balances the vane assembly may inhibit a quick response to nose-down releases by pulling the vane against the force of gravity after one deflection. The size of the instrument shaft, which probably causes turbulence downwind in the vicinity of the fins of the vane assembly, may also inhibit the ability of the vane assembly to have a higher damping ratio.

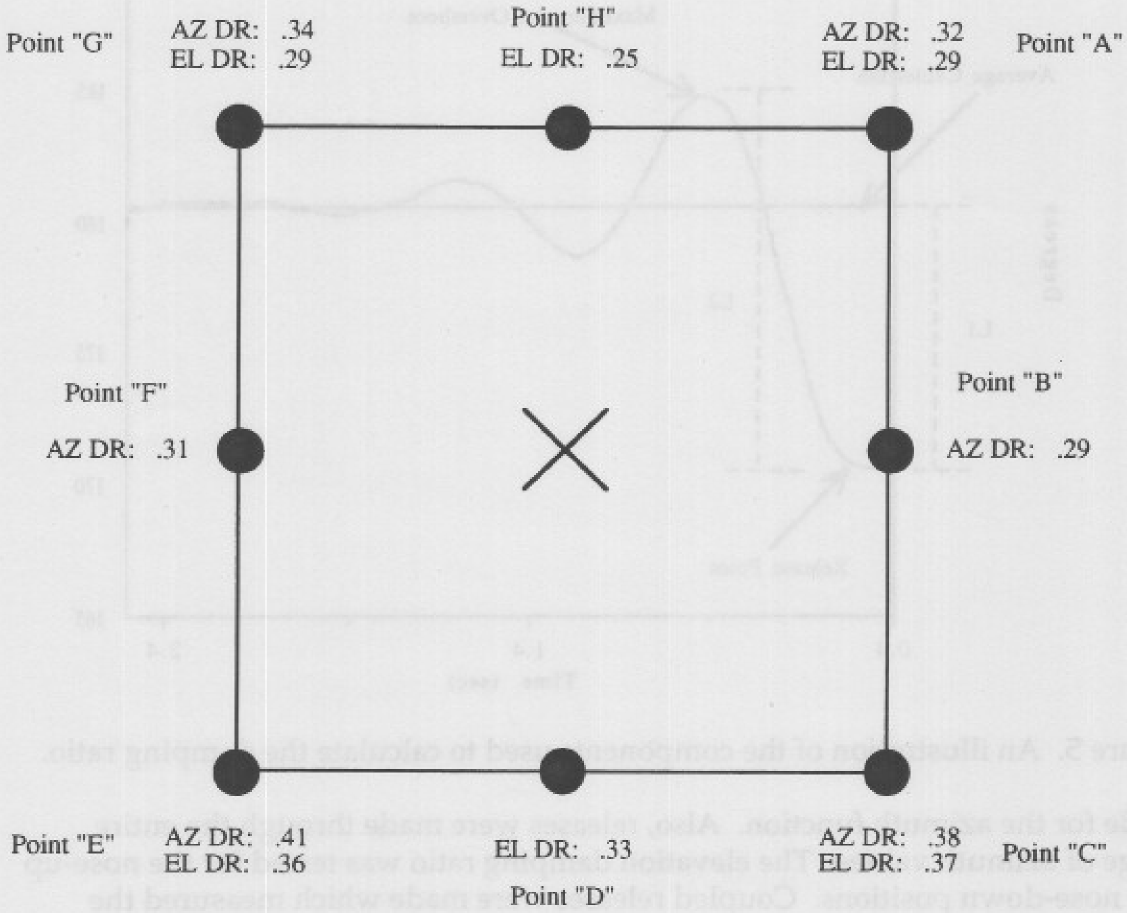


Figure 6. Coupled damping ratio values at different release points.

HIGHLIGHTS OF THE MODEL 1564B CUP ANEMOMETER TESTS

The Model 1564B cup anemometer was tested for off-axis response characteristics with both a three and six cup housing. Simulated updrafts and downdrafts were created by pointing the anemometer toward the airflow (downdrafts) and away from the airflow (updrafts). Tests were made at 5 and 10 m/s at 0°, ±5°, ±10°, ±15°, ±20°, and ±30° where negative (downdraft) indicates the sensor pointed toward the tunnel airflow.

The overall average error of the six cup housing was about 0.7% while the 3 cup housing was near 2.0% (Table B). The six cup housing measured updrafts more accurately, whereas the three cup housing was found to perform better for downdrafts.

Table B. Results of off-axis response tests using three and six cup anemometer housings.

Sensor Angle	3 Cup Error (%)	6 Cup Error (%)
0	0.17	0.05
+5	0.23	0.01
+10	1.56	0.34
+15	4.10	0.39
+20	6.10	0.18
+30	10.50	0.51
0	0.02	0.02
-5	0.37	0.06
-10	0.72	0.19
-15	0.18	0.29
-20	0.52	2.25
-30	0.09	4.98
0	0.18	0.03
	Ave: 1.90	Ave: 0.72

Reasons for better performance with different cup housings probably result from the load on the bearings of the anemometer. Since upward moving air hits six cups instead of three for the six cup housing, the load on the bearings is lessened especially for updrafts. Downward moving air affects the six cup housing in the opposite way by putting more load on the bearings and, consequently, increases the error.

COOPERATIVE RESEARCH AND DEVELOPMENT

Recent technology transfer initiatives by the U. S. Department of Energy have lead to a Cooperative Research and Development Agreement (CRADA) between Westinghouse Savannah River Company (WSRC) and Met One Instruments to redesign the vane assembly of the Model 1585 bivane. The agreement consists of six steps:

- WSRC and Met One meet to discuss potential design improvements of the vane assembly,
- Met One builds a single axis prototype (azimuth only),
- WSRC conducts wind tunnel tests of the single axis prototype,
- Met One builds a dual axis prototype based on an improved single axis design,
- WSRC conducts wind tunnel tests of the dual axis prototype,
- WSRC documents wind tunnel test results (possible co-authorship with Met One).

The ultimate end product of this particular CRADA is to produce a bivane which provides better measurements of atmospheric turbulence.

ACKNOWLEDGMENTS

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ATTACHMENT

Specifications for the Model 1585 Bivane

Distance constant	1.0 m vertical and horizontal
Accuracy	± 2°
Resolution	0.072° horizontal 0.024° vertical
Damping ratio	0.4 horizontal and vertical
Response threshold	0.5 m/s horizontal and vertical
Range	0° to 360° horizontal -60° to +60° vertical

Specifications for the Wind Speed Transmitter Model 1564B with 3 cup assembly model 170-41

Distance constant	1.5 m maximum
Accuracy	± 1 % of true wind speed
Response threshold	0.5 m/s maximum
Range	0 to 45 m/s