7.1 FIELD AND OPERATIONAL TESTS OF A SONIC ANEMOMETER FOR THE AUTOMATED SURFACE OBSERVING SYSTEM

Richard Lewis*
National Weather Service
Sterling, VA 20166

Jennifer M. Dover
Science Applications International Corporation
Sterling, VA 20166

1. INTRODUCTION

The National Weather Service (NWS) and Federal Aviation Administration (FAA) are is replacing the cup and vane anemometers that are currently used in the Automated Surface Observing System (ASOS) with sonic anemometers. The primary problem with the current cup and vane technology is its susceptibility to lock-ups in freezing precipitation conditions. When the cups and/or vanes are immobilized by freezing precipitation, they will generally remain immobilized until the temperature rises above freezing, which can lead to extended periods when wind data is inaccurate and/or unavailable. Another problem with the cup speed measurement is that when wet snow attaches to the cups their rotation speed is slowed. The result is a wind speed measurement that is lower than the actual speed. Sonic anemometers overcome problems associated with icing and wet snow by applying heat to their transducers, thus melting ice or wet snow that would otherwise interfere with the speed and direction measurement. While sonic anemometers were originally developed to measure wind speeds that are too low for mechanical anemometers to measure, the technology has evolved to the point where speeds up to 125 Knots can be measured accurately. This paper will discuss the extensive testing in the field and on operational ASOS systems in a wide variety of weather conditions to verify that the sonic anemometers will provide accurate speed and direction measurements for ASOS.

2. ANEMOMETERS USED IN TEST

The test results reported on in this paper are a continuation of many years of prior testing of the relationship of the sonic anemometer measurements of speed and direction to more conventional anemometer designs, particularly the cup and vane anemometer that it would replace (Winans,1999 and Childs, 2001). For the field tests described in this paper, two different conventional anemometers were used for comparison. These are described in the next two sections.

* *Corresponding author address*: Richard Lewis, National Weather Service, 43741 Weather Service Rd., Sterling, VA 20166; e-mail: Richard.Lewis@noaa.gov

2.1 Belfort 2000

The Belfort 2000, pictured in figure 1, is the cup and vane anemometer that is used in the ASOS. It uses a light chopper and pulse counter to obtain speed from the rotating cups and a potentiometer to obtain direction from the vane. The speed and direction are available as a serial data message for ease of interfacing to computer-based data acquisition systems.

Figure 1. Belfort 2000 cup and vane anemometer

2.2 R.M. Young

The R.M. Young 9305-AQ-SE, pictured in figure 2, uses a propeller and vane arrangement to measure wind speed. The propeller is mounted on the vane in such a way that as the vane rotates, the propeller is pointed into the wind. The anemometer is compact and easy to install. It has also been found to agree well with the Belfort 2000 with a somewhat faster response to changes in wind speed and direction due to its lighter weight. Additionally, it has demonstrated less susceptibility to icing induced failures or degradation in performance due to rime icing or wet snow.

Figure 2. R.M. Young propeller vane anemometer

2.3 Vaisala 425NWS

The Vaisala 425NWS ultrasonic anemometer, shown in Figure 3, has an array of three equally spaced transducers which project and receive ultrasonic pulses in a horizontal plane. The anemometer measures the transit times of the pulses in both directions on three tranducer pairs for a total of six measurements of transit time. The speed and direction are derived directly from these six transit time measurements. Heat is applied to prevent ice and snow from blocking the transducers.

Figure 3. 425NWS sonic anemometer

3. TEST LOCATIONS

3.1 Johnstown, PA

Johnstown, PA is the NWS's Winter Test Facility. It is located at the Johnstown-Cambria County Airport at an elevation of 700 meters. This site is particularly susceptible to severe winter weather due to its mountaintop location. Thus the primary objective at Johnstown was to expose the sonic anemometers to harsh winter conditions of snow, ice pellets and freezing rain.

At Johnstown, the Belfort 2000 cup and vane anemometer and R.M. Young propeller vane anemometer were used as comparison sensors. The Belfort was mounted on a standard ASOS wind tower to simulate an ASOS configuration. This served as the comparison anemometer for a 425NWS also mounted on an ASOS tower about 30 meters away from the Belfort. The R.M. Young was mounted at a height of about 3 meters. This served as the comparison sensor for a 425NWS at 3 meters about 6 meters away from the R.M. Young.

3.2 Sterling, VA

Sterling, VA is the NWS's primary location for testing surface sensors. Anemometers at Sterling were all located at approximately the same height, about 10 meters above ground, on three steel towers that could accommodate multiple anemometers or on standard ASOS towers. Two Belfort 2000 anemometers and two R.M Young anemometers were available as comparison sensors against which two 425NWSs were compared.

3.3 Operational ASOS Locations

For testing at operational ASOS locations, the Belfort 2000 and 425NWS were mounted at the same height on the same tower and positioned to avoid interference between the two. Thus data reported by the two anemometers with regard to average wind speed and direction, and peak wind speed and direction could be compared. Figure 4 shows the configuration of the sensors. A list of the ASOS sites that were used for the analysis is given in Table 1.

Figure 4. ASOS wind tower with dual installation of Belfort 2000 and 425NWS

Table 1. ASOS test locations

TEST SITES	
CITY	**STATE**
Ketchikan	AK
Sitka	AK
Aurora	IL
Grand Forks	ND
Hancock	MI
Oshkosh	WI
Terre Haute	IN
Topeka	KS
Burlington	VT
Caribou	ME

4. TEST RESULTS

4.1 Results of Field Test at Sterling and Johnstown

Tests results are displayed in Figures 5 showing average and peak speed differences in intervals of one knot and Figure 6 showing direction differences in intervals of 3°. These comprise all the data from all the anemometers at Johnstown and Sterling, approximately 570 sensor days of operation from fall 2002 through mid-summer 2003. The average for speed and direction were based on 2-minute averages and the peak was based on 3-second running averages of test anemometer vs. comparison anemometer. The overall results were that the difference between the comparison anemometer and test anemometer was within ±2 knots 100% of the time. There is, however, a tendency for the Belfort average speed to be slightly higher than the 425NWS average speed (less than 1 knots difference). The bias towards slightly higher speed reported by the comparison anemometer results may be related to the phenomenon of "overrun" whereby "the mean wind recorded by a cup anemometer in variable wind is higher than the true mean" (Shrenk, 1929).

With respect to peak wind, there is a slight tendency for the 425NWS to report higher peak wind. This is attributed to the faster response of the 425NWS to rapid fluctuations in speed which is especially true in gusty wind conditions. Overall the peak from the 425NWS was within ±2 knots of the comparison anemometer 98.5% of the time.

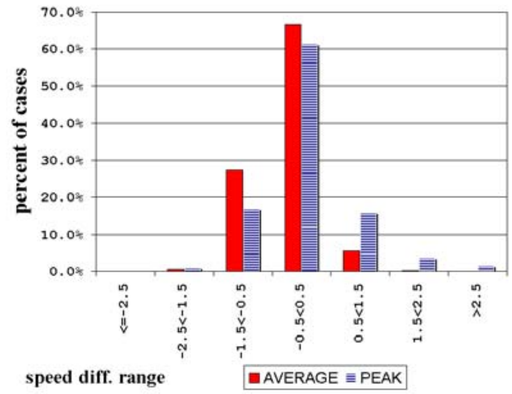

Figure 5. Average and peak wind speed difference histograms for Sterling and Johnstown (425NWS - comparison anemometer).

Agreement in direction is within ±4° 97.7% of the time and within ±7° 99.3% of the time. The R.M. Young anemometer was used when possible for this comparison because of its ability to respond more quickly to changes in wind direction than the Belfort. This is especially true when winds are light.

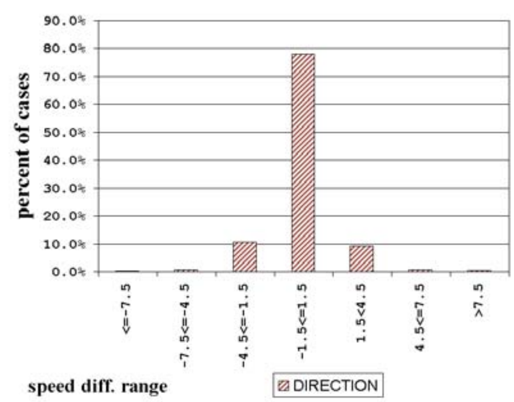

Figure 6. Average direction difference histograms for Sterling and Johnstown (425NWS - comparison anemometer).

4.2 Wind Test Results for 425NWS to 425NWS Anemometer Comparability

At the Sterling test site there were two 425NWS anemometers operating simultaneously at the same height and over a period of about 8 months. Eight anemometers (four anemometer pairs) were used during the eight month period. This permitted analysis of anemometer to anemometer comparability which is shown in Figures 7 and 8.

The difference in average speed was within ±2 knots 100% of the time and within ±1 knots 99.9% of the time. The difference in peak speed was within ±2 knots 99.5% of the time and within ±1 knots 97.1% of the time. The difference in average direction was within ± 7° 99.9% of the time and within ± 4° 99.2% of the time. This demonstrates the high degree of precision between 425NWS anemometers operating side-by-side in the field.

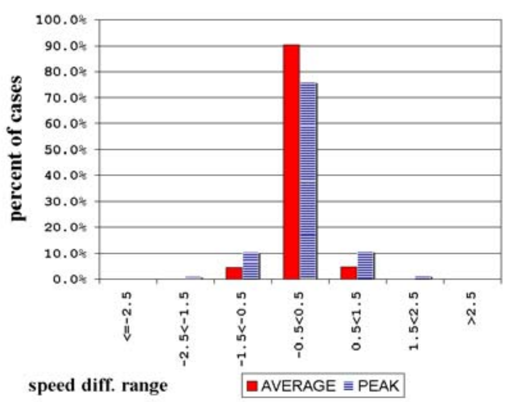

Figure 7. Average speed and peak speed difference histogram for 425NWSs.

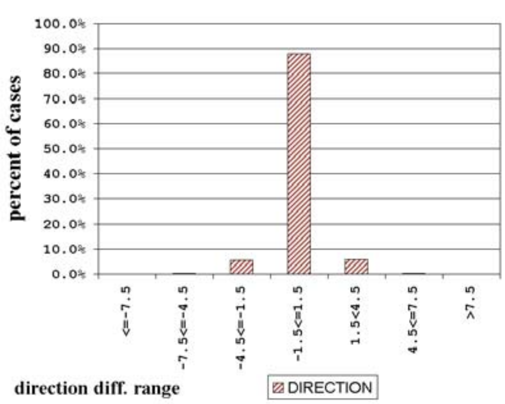

Figure 8. Average direction difference histogram for 425NWSs.

4.3 Operational Test Results

The following sections comprise over 4300 minutes of data gathered and analyzed from Aurora, Illinois (KARR) during the spring and summer of 2003. These results are representative of test results gathered from the other operational sites. The data for this analysis was separated into periods when rain (RA) was occurring and periods when there was no precipitation (NP). In each of the following figures, the text box on the lower left represents the total number of minutes of data in each category. The box on the lower right represents the average of the differences and the standard deviation respectively.

4.3.1 Wind Speed Differences

Test results are displayed in figure 9 showing average speed differences in intervals of one knot (x-axis). Agreement in wind speed between the two sensors were within ± 2 knots 100% of the time. The average of the differences were ½ knot with a bias toward slightly higher speeds reported by the Belfort.

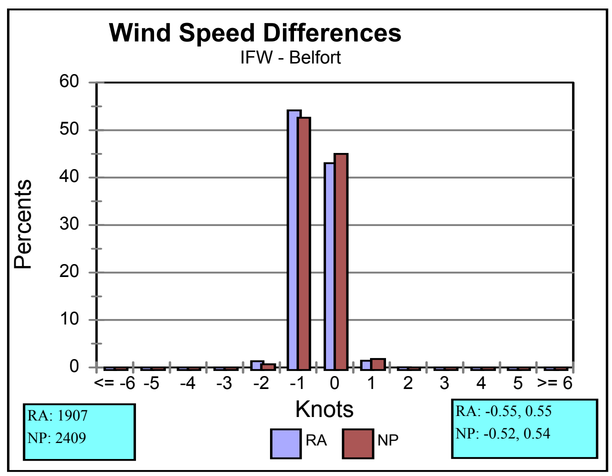

Figure 9 . Average speed difference histogram in all wind speeds.

4.3.2 Wind Direction Differences

Test results are displayed in figure 10 showing average direction differences in intervals of one degree (x-axis). Agreement in wind direction between the two sensors were within ± 4° 99.1% of the time in rain and 99.3% of the time in no precipitation.

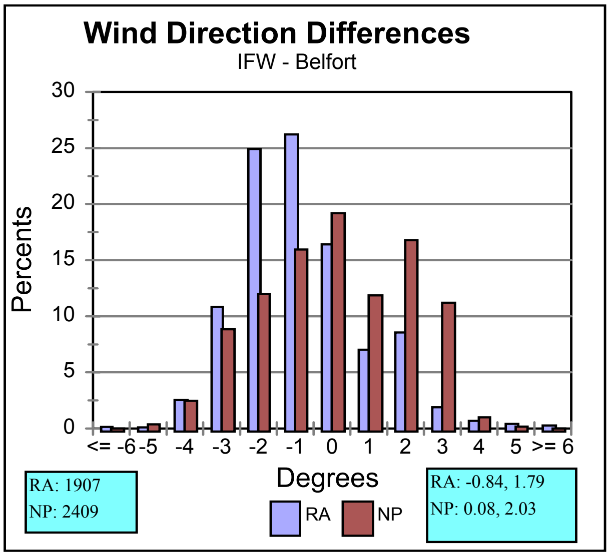

Figure 10. Average direction difference histogram in all wind speeds.

4.3.3 Peak Wind Speed Differences

Test results are displayed in figure 11 showing average speed differences in intervals of one knot (x-axis). Agreement in wind speed between the two sensors were within ± 2 knots 99.6% of the time in rain and 99.4% of the time in no precipitation. Again, as noted in section 4.1, there is a slight tendency for the sonic to report higher peak winds than the cup and vane. Also contributing to this is the fact that the cup and vane peak wind in ASOS is based on a 5-second block average while the sonic speed is a 3-second running average.

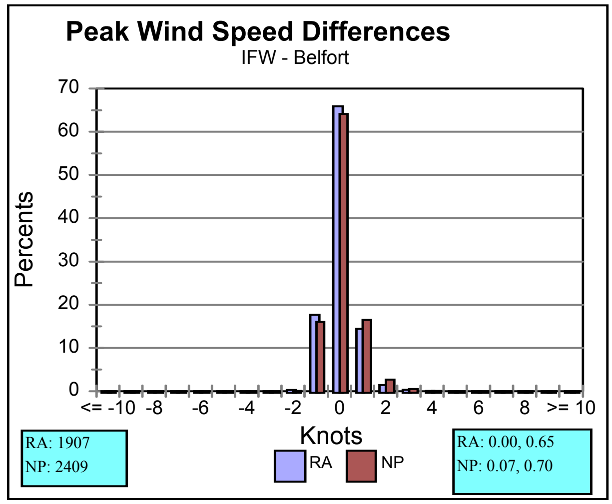

Figure 11. Peak wind speed difference histogram in all wind speeds.

4.3.4 Peak Wind Direction Differences

Test results are displayed in figure 12 showing average direction differences in intervals of one degree (x-axis). Agreement in wind direction were within ± 4° 70% of the time and ± 10° 95% of the time.

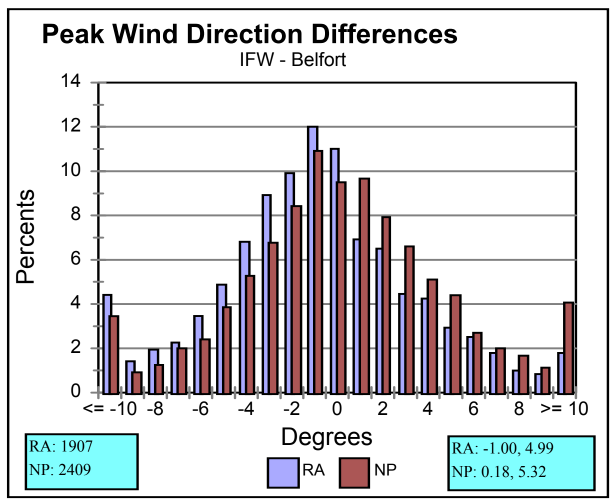

Figure 12. Peak wind direction difference histogram in all wind speeds.

5. CONCLUSIONS

The field and operational test demonstrated the high degree of comparability between mechanical anemometers and sonic anemometers. Specifically, with respect to ASOS, the switch from the cup and vane technology currently in use to sonic anemometers will be transparent to most users. However, it is clear that, because sonic anemometers are nearly instantaneous in their response to rapidly changing wind speed, there will be occasions when the wind gusts and peak winds reported by ASOS will be higher due to the change from cup and vane to sonic anemometer. While there is no reason to doubt the accuracy of the sonic measured wind speed, it is important that climatologists be aware of the change in anemometer technologies and the resulting increase in gust speeds and the possibility of new station peak wind records.

ACKNOWLEDGMENT

The authors are grateful to Michael Sturgeon of NWS for contributions in all phases of this effort as well as his primary role in the development and implementation of sonic anemometers for ASOS.

REFERENCES

Childs, B. and R. Lewis,2001: Investigating the impact of changing the ASOS wind gust averaging period from five to three seconds; 11th Symp. on Meteorological Observations and Instrumentation, January 14-18, Albuquerque, NM, Amer. Meteor. Soc., Boston, MA, 46-49.

Schrenk, O., 1929: Errors due to inertia with cup anemometers in fluctuating wind. Z. Tech. Phys., **10**, 57-77.

Winans, L.J. and R. Lewis, 1999: Gust measurements: cup and vane vs. sonic anemometer; 15th International Conference on Interactive Information and Processing Systems, January 10-15, Dallas, TX, Amer. Meteor. Soc., Boston, MA, 201-204.