Wind Tunnel Tests of Some Low-Cost Sonic Anemometers

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Abstract
Sonic anemometers for meteorological measurements have been around since the early 1970s. The early sonic anemometers were very expensive and did not have the high reliability, low-cost electronic components now available. Thus, early sonic anemometers had poor reliability and were mainly used for scientific research. In the last several years, manufacturers have started offering lower-cost sonic anemometers suitable for general meteorological use. The low maintenance and low electrical power requirements of these current sonic anemometers make them good candidates for remote sensing applications with solar panels. This paper presents test data for several available low-cost sonic anemometers using wind tunnel test method ISO 16622 *Meteorology – Sonic anemometers / thermometers - Acceptance test methods for mean wind measurements*. The measurement performance differences of sonic anemometers and rotating anemometers are discussed in this paper.

1. Background
A new generation of low cost, high performance sonic anemometers has come into the market place in the past 10 years. Prices of the latest sonic anemometers are significantly less, and the prices are now comparable to high quality cup and propeller anemometers. As an added advantage, sonic anemometers require almost no periodic maintenance since there are no moving parts to wear out. The starting threshold and response time, for both wind speed and direction, are essentially zero. These two characteristics make the sonic anemometer a good candidate for air pollution, dispersion models and other applications requiring high accuracy at very low wind speeds.

2. Anemometers Tested
The sonic anemometers tested were: 1) Gill WindSonic - UK; 2) R. M. Young 85000 - USA; 3) Vaisala WS425A - Finland; 4) Vaisala WXT510 - Finland. All the sensors tested were two-dimensional sonic anemometers. The Gill WindSonic and R. M. Young 85000 have a four-transducer configuration while both Vaisala sonic anemometers utilize a three-transducer configuration. All test anemometers were configured with an RS-232 serial interface and required an external dc power supply. The wind tunnel tests were conducted in the polled RS-232 mode for all the test anemometers.

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3. Test Method [1]

The tests were conducted in the NWS Sterling Wind Tunnel. The wind tunnel test section is 1.3 m x 1.3 m x 2 m long. The maximum speed of the wind tunnel is 68 m/s. The reference wind tunnel air speed measurements were made with a pitot-static tube mounted in the test section. Ambient temperature, relative humidity, and barometric pressure measurements were taken in the wind tunnel test section. These measurements were used to correct the air density in the wind tunnel test section to standard conditions of dry air at 15 ºC and 1013.25 hPa. This air density correction is then applied to the pitot-static tube pressure measurement. The pitot-static tube has been calibrated at the United States' national laboratory: National Institute of Standards and Technology (NIST). All wind tunnel parameters are sampled at a 6-hertz rate and recorded in 30-second intervals, time synchronized with the test anemometer data. The wind tunnel air speed measurement uncertainty was verified by the use of a transfer standard anemometer (R. M. Young 27106DR), which had been previously calibrated at NIST. The calibration verification test was conducted over the air speed range of 6.8 to 66 m/s in approximate 8 m/s increments. Two 30-second data points were taken at each speed. The wind tunnel air speed measurement uncertainty, with a coverage factor of k=2, was 0.09 m/s over the full air speed range.

Sonic anemometers often exhibit measurement perturbations in response to the incident wind direction. These measurement perturbations are caused by the wind turbulence created by the support structure and/or the transducers themselves. A rigorous test requires that the sonic anemometer be rotated over the full 360-degree azimuth and data taken at a sufficient number of points to define the speed and direction performance characteristics. Generally, for most sonic anemometers, there seems to be little effect of the wind direction on sonic anemometer performance at speeds below 15 m/s, but as the air speed increases the performance issues often occur in the form of both wind speed and wind direction measurement accuracy.

The wind tunnel tests were conducted in accordance with section 8.3.1 of ISO16622 *Meteorology - Sonic anemometers/thermometers – Acceptance test methods for mean wind measurements*[2]. The test speeds were calculated as specified in ISO 16622. The sonic anemometers were tested at constant wind tunnel air speeds of 6, 11, 20, 36, and the maximum operational speed (U_{max}) of the particular sonic anemometer. At each constant test speed, the sonic anemometer was rotated in five-degree increments from 0 to 360 degrees. Data was taken from the anemometer for 30 seconds at each five-degree increment. Both the wind speed and direction are averaged over the thirty-second sampling interval.

The wind direction alignment procedure was performed in two steps:

1) An initial visual static alignment of the test sonic anemometer to wind tunnel centerline is performed with a straight edge ruler. This results in an initial sensor alignment to within ±1 degree.
2) A dynamic alignment of the sonic anemometer is performed with the wind tunnel propeller speed set to 200 rpm (~13.5 m/s) to eliminate any offset from step 1. This offset value is then entered in the rotator table controller program. This offset is then used for all wind tunnel test runs at the selected test speeds.

4. Test Results

The test results and manufacturers' stated specifications are summarized in Table 1. For the wind tunnel tests, all anemometers were configured to provide wind speed data in knots. The wind speed data was converted in post processing to m/s.

Manufacturer Model	Sensor Firmware Version	Vendor's Stated Current Draw @ 12.0 vdc[1]	Measured Current Draw @ 12.0 vdc[2]	Manufacturer's Stated Wind Speed Accuracy	Test Results Wind Speed Accuracy	Manufacturer's Stated Maximum Operational Speed, U_{max}	Manufacturer's Stated Wind Direction Accuracy	Test Results Wind Direction Accuracy
Gill WindSonic sn 043116	2162-400	40 ma[3]	17 ma	±2% @ 12 m/s	+1% to +5% @ 11 m/s Overall: 0^-% to +7%	60 m/s[4] (117 knots)	±3 degrees @ 20 m/s	±2 degrees @ 20 m/s Overall: ±4 degrees
RM Young 85000 sn 00211	1.2.00	40 ma	31 ma average	±0.1 m/s (@ 3.3 m/s max) or ±3% whichever is greater	No test data at this speed[5] *0^+ to* *+0.3 m/s* *@ 6 m/s* -1% to +5%	60 m/s (117 knots)	±3 degrees	-1 to +2 degrees
Vaisala WS425A sn Y1020010	6.04	25 ma	14 ma average	±0.135 m/s (@ 4.5 m/s max) or ±3% whichever is greater	No test data at this speed[5] *-0.1 to* *+0.2 m/s* *@ 6 m/s* -5% to +4%	65 m/s (126 knots)	±2 degrees @ wind speeds greater than 1 m/s	-2 to +1 degrees
Vaisala WXT510 sn Z441004	1.03	0.07 to 13 ma 3 ma typical	4 ma average wind message only[6]	±0.3 m/s (@ 15 m/s max) or ±2% whichever is greater	-0.2 m/s to +0.4 m/s @ 11m/s -4% to +7%	60 m/s (117 knots)	±2 degrees	-4 to +8 degrees[7]

Table 1 - Summary of sonic anemometer wind tunnel test results and manufacturers' specifications – see notes in Appendix A

Gill WindSonic

The measured sonic path length for the Gill WindSonic is approximately 100 mm. The WindSonic had a rather unique sonic path configuration with the sonic signals reflected off a top horizontal plate. The anemometer provided a one-second averaging time and was running at an internal sensor-sampling rate of one hertz. The one-second-averaging time is not adjustable. The Gill WindSonic User Manual accuracy statements were: ±3 degrees at 20 m/s for wind direction and ±2% at 12 m/s for wind speed. The Gill WindSonic technical brochure had the same accuracy statements (±3 degrees / ±2%) with no wind speed qualification statement. The WindSonic demonstrated a positive wind speed measurement bias of approximately 3 to 5% at the nominal test air speeds. The WindSonic did not reach its manufacturer's stated maximum operational speed (U_{max}) of 60 m/s at all orientations. At an air speed of 60 m/s, the WindSonic experienced missing or anomalous data at ten azimuths: 55, 60, 65, 70, 155, 240, 245, 310, 330 and 335 degrees.

Summary of Gill WindSonic Wind Direction Performance

Nominal Test Speed	Manufacturer's Stated Accuracy*	Results As Tested
6 m/s		±2 degrees
11 m/s		±2 degrees
20 m/s	±3 degrees	±2 degrees
36 m/s		-2 to +1degree
60 m/s		±4degrees (Missing Data)

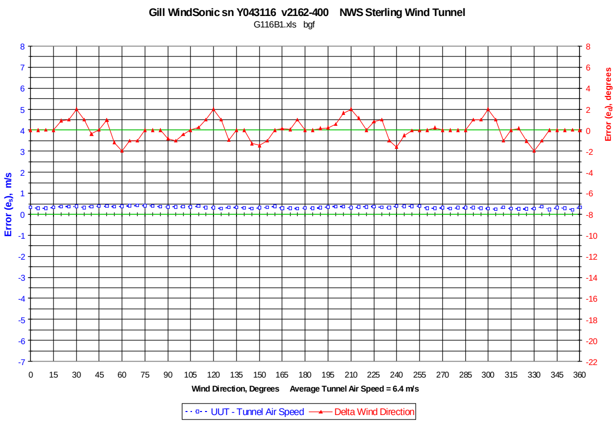
*Manufacturer's stated accuracy is: ±3 degrees at 20 m/s.

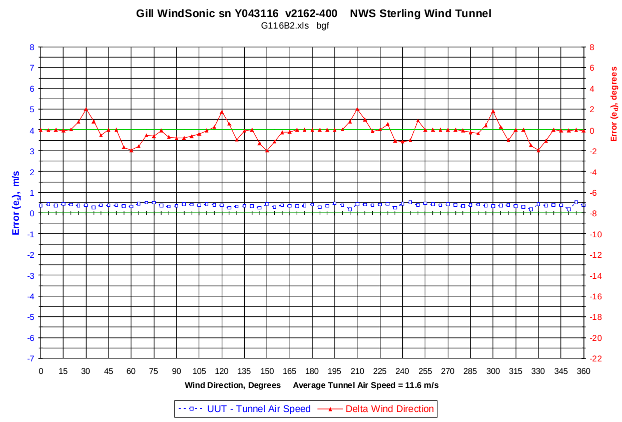
Summary of Gill WindSonic Wind Speed Performance

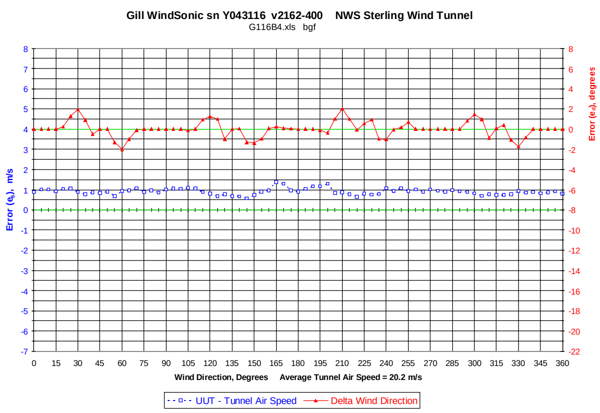
The Gill WindSonic had missing data at its stated maximum operational speed (U_{max}) of 60 m/s.

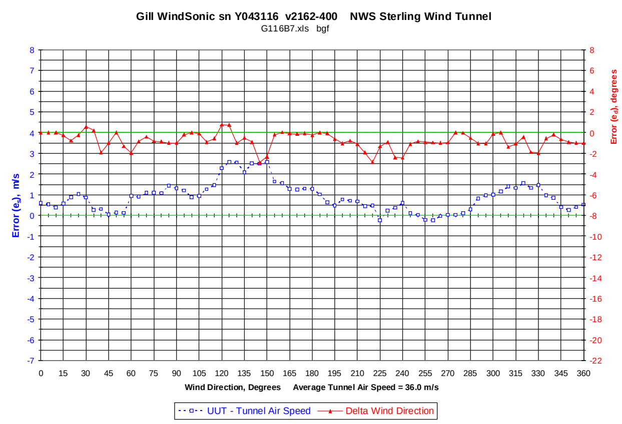
Nominal Test Speed	Manufacturer's Stated Accuracy*	Results As Tested
6 m/s		+3 to+7 %
11 m/s	±2 %	+1 to +5 %
20 m/s		+3 to +7 %
36 m/s		+1 to +7 %
60 m/s		0^- to +6 % (Missing Data)

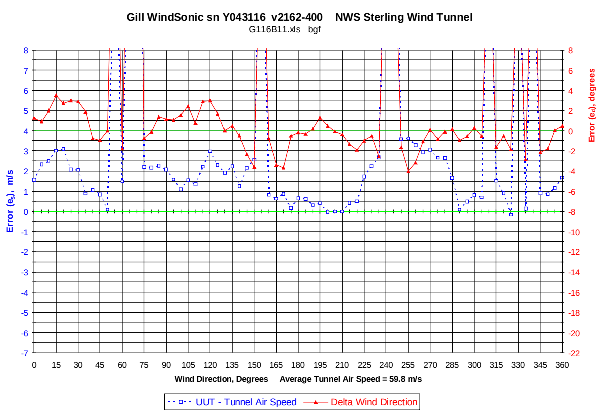
*Manufacturer's stated accuracy is: ±2 % at 12 m/s.











Gill WindSonic wind tunnel test graphs

R. M. Young 85000

The measured sonic path length for the R. M. Young 85000 is 141 mm. The R. M. Young 85000 was configured in software to provide three-second average wind direction and wind speed data and was running at an internal sensor-sampling rate of one hertz. The R. M. Young 85000 met the manufacturer's stated wind direction accuracy through 60 m/s. The R. M. Young 85000 demonstrated a slight positive wind speed measurement bias at all the nominal test air speeds. The average bias was approximately 1.5 %. The R. M. Young 85000 had no missing data at its stated maximum operational speed (U_{max}) of 60 m/s.

Summary of R. M. Young 85000 Wind Direction Performance

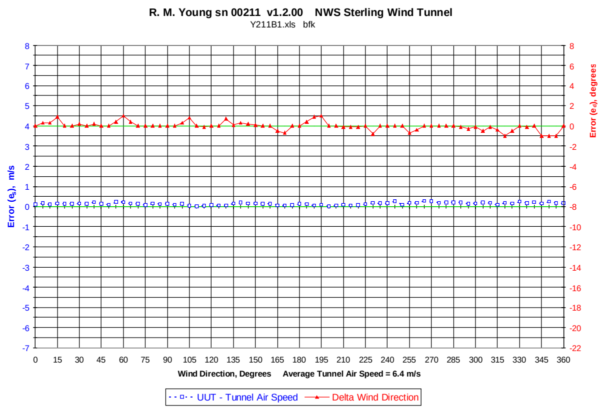
Nominal Test Speed	Manufacturer's Stated Accuracy	Results As Tested
6 m/s	±3 degrees	±1 degree
11 m/s		±1 degree
20 m/s		±1 degree
36 m/s		±1 degree
60 m/s		-1 to +2 degrees

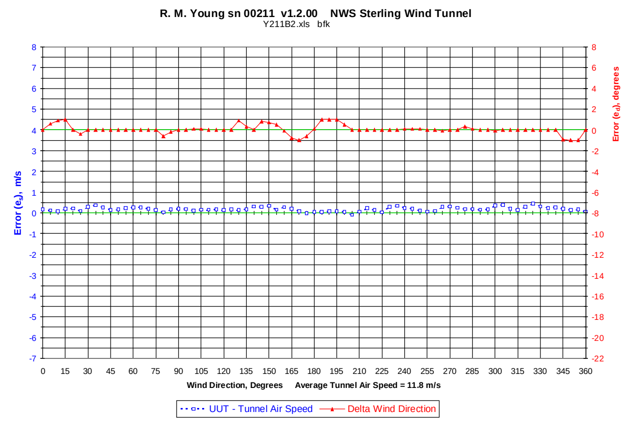
Summary of R. M. Young 85000 Wind Speed Performance

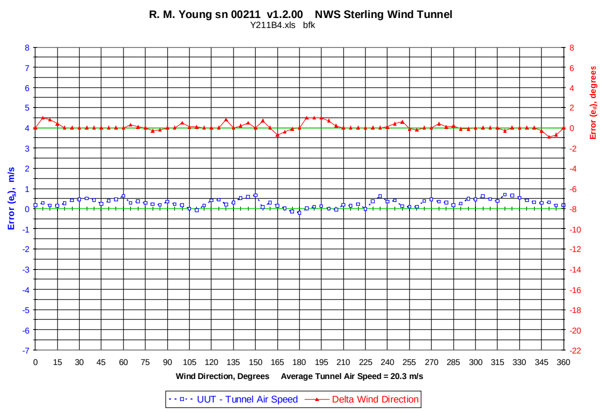
The R. M. Young had no missing data at its stated maximum operational speed (U_{max}) of 60 m/s.

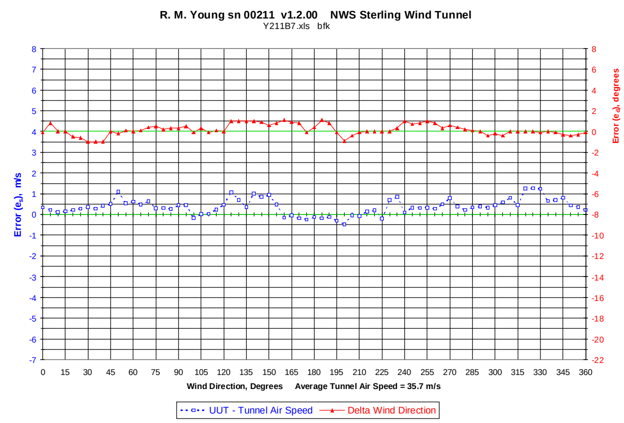
Nominal Test Speed	Manufacturer's Stated Accuracy*	Results As Tested
6 m/s	±3 %	0^+ to +5 %
11 m/s		-1 to +4 %
20 m/s		-1 to +3 %
36 m/s		-1 to +4 %
60 m/s		-1 to +5 %

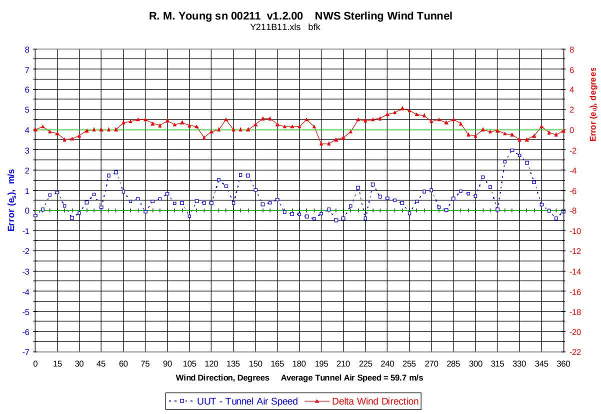
*Manufacturer's stated accuracy is: ±0.1 m/s or ±3 %, whichever is greater.











R. M. Young 85000 wind tunnel test graphs

Vaisala WS425A

The measured sonic path length for the Vaisala WS425A is 217 mm. The WS425A was configured via software commands to provide three-second average wind speed and direction values and was polled every three seconds for data. With the omni-directional sonic pattern from the round transducers, it was necessary to mount the WS425A with an eight-degree side tilt in the wind tunnel to prevent disturbances in the received sonic signal due to sonic reflections off the wind tunnel sidewalls. The WS425A met the manufacturer's stated wind direction accuracy. The WS425A met the manufacturer's stated wind speed accuracy through 60 m/s but not 65 m/s.

Summary of Vaisala WS425A Wind Direction Performance

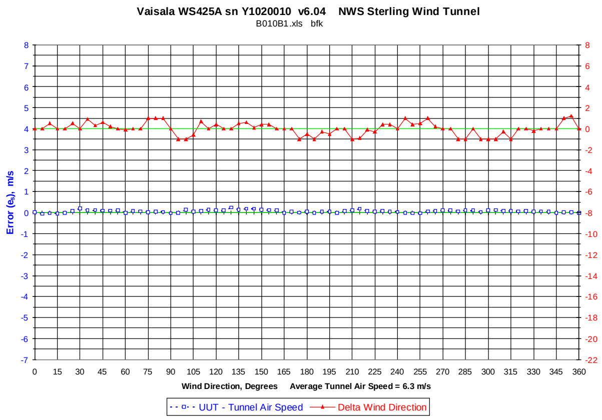
Nominal Test Speed	Manufacturer's Stated Accuracy	Results As Tested
6 m/s	±2 degrees	±1degree
11 m/s		±1degree
20 m/s		±1degree
36 m/s		±1degree
60 m/s		±1degree
65 m/s		-2 to 0 degrees

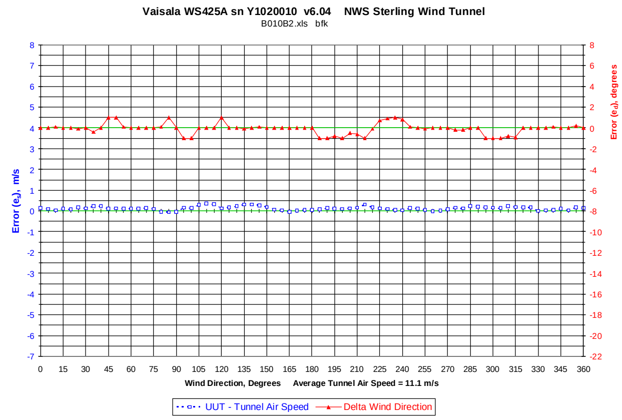
Summary of Vaisala WS425A Wind Speed Performance

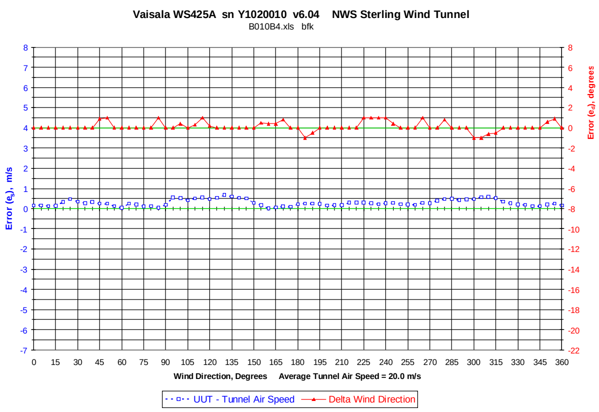
The Vaisala WS425A had no missing data at its stated maximum operational speed (U_{max}) of 65 m/s.

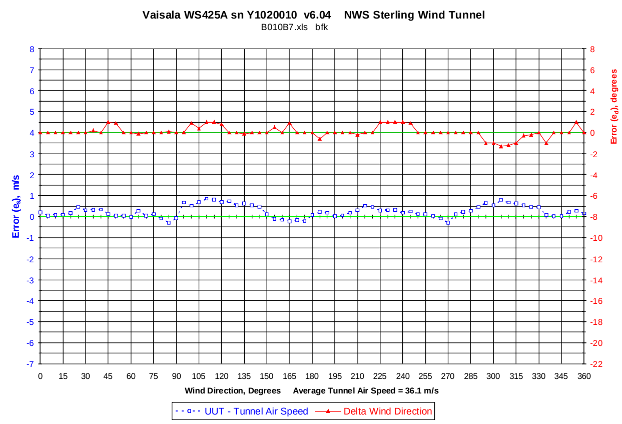
Nominal Test Speed	Manufacturer's Stated Accuracy*	Results As Tested
6 m/s	±3 %	-1 to + 4 %
11 m/s		-1 to +3 %
20 m/s		0^- to +3 %
36 m/s		-1 to +2 %
60 m/s		-3 to +2 %
65 m/s		-5 to +1 %

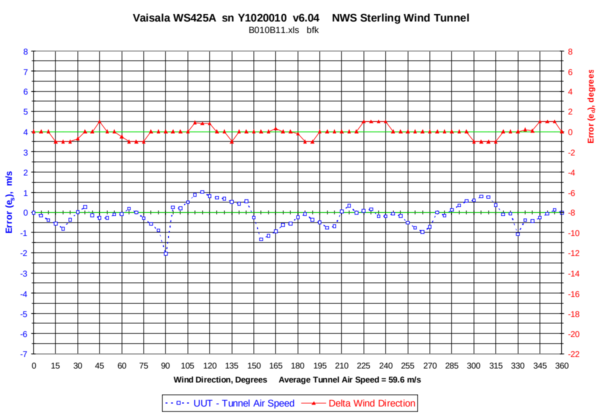
*Manufacturer's stated accuracy is: ±0.135 m/s or ±3 %, whichever is greater.

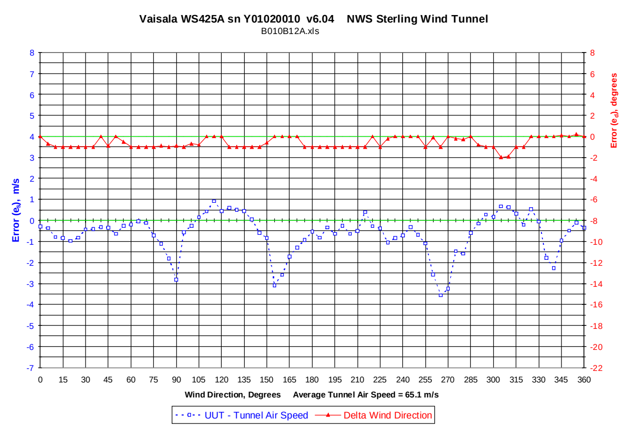












Vaisala WS425 Wind tunnel test graphs

Vaisala WXT510

The measured sonic path length for the Vaisala WXT510 was 88 mm. The Vaisala WXT510 was configured via software commands to provide three-second average wind speed and direction values updated once per second. At zero degrees, the Vaisala WXT510 produced random anomalous wind direction readings of 120 and 240 degrees at all wind speeds. During some 30-second samples at zero degrees, all wind direction values were zero degrees. During other 30-second sample intervals there would be one or more anomalous wind direction values. This anomalous wind direction pattern did not occur at azimuths of 120 or 240 degrees, suggesting that the problem could be a wind direction algorithm malfunction at zero degrees.

Summary of Vaisala WXT510 Wind Direction Performance

Nominal Test Speed	Manufacturer's Stated Accuracy	Results As Tested
6 m/s	±2 degrees	±3 degrees
11 m/s		-2 to +5 degrees
20 m/s		-2 to +4 degrees
36 m/s		-3 to +8 degrees
60 m/s		-4 to +6 degrees

Summary of Vaisala WXT510 Wind Speed Performance

The Vaisala WXT510 had no missing data at its stated maximum operational speed (U_{max}) of 60 m/s.

Nominal Test Speed	Manufacturer's Stated Accuracy*	Results As Tested
6 m/s	±0.3 m/s	±0.2 m/s
11 m/s		-0.2 to +0.4 m/s
20 m/s	±2 %	-2 to +4 %
36 m/s		-4 to +7 %
60 m/s		-3 to +7 %

*Manufacturer's stated accuracy is: ±0.3 m/s or ±2 %, whichever is greater.

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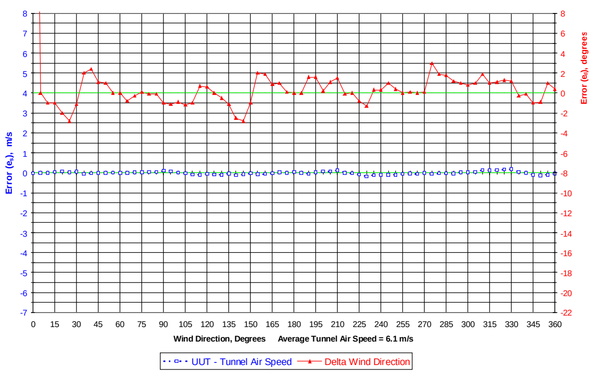

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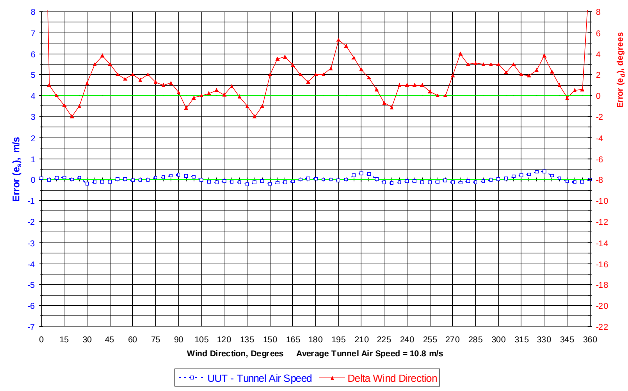

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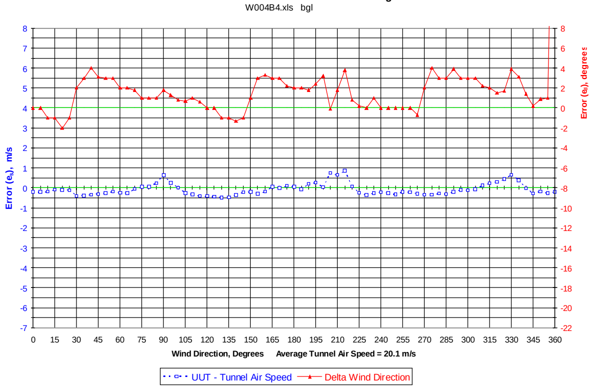

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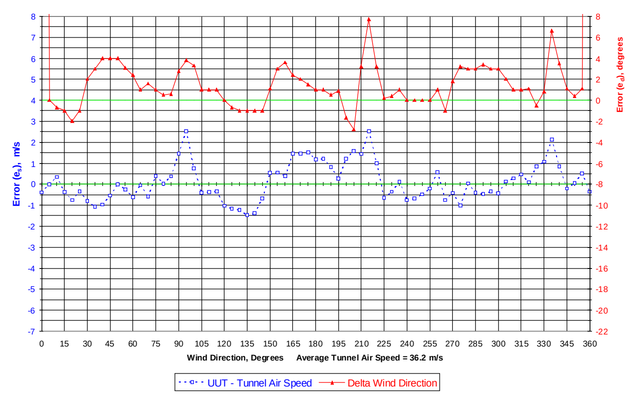

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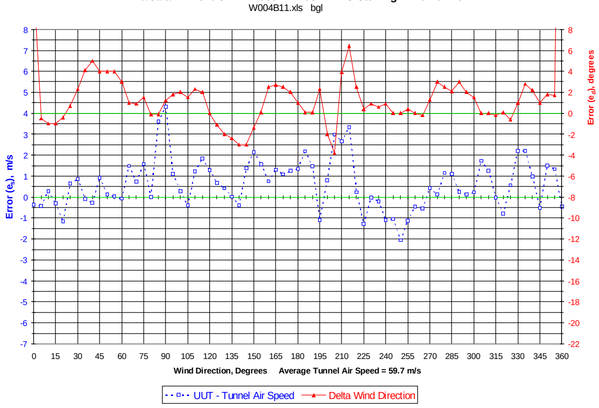
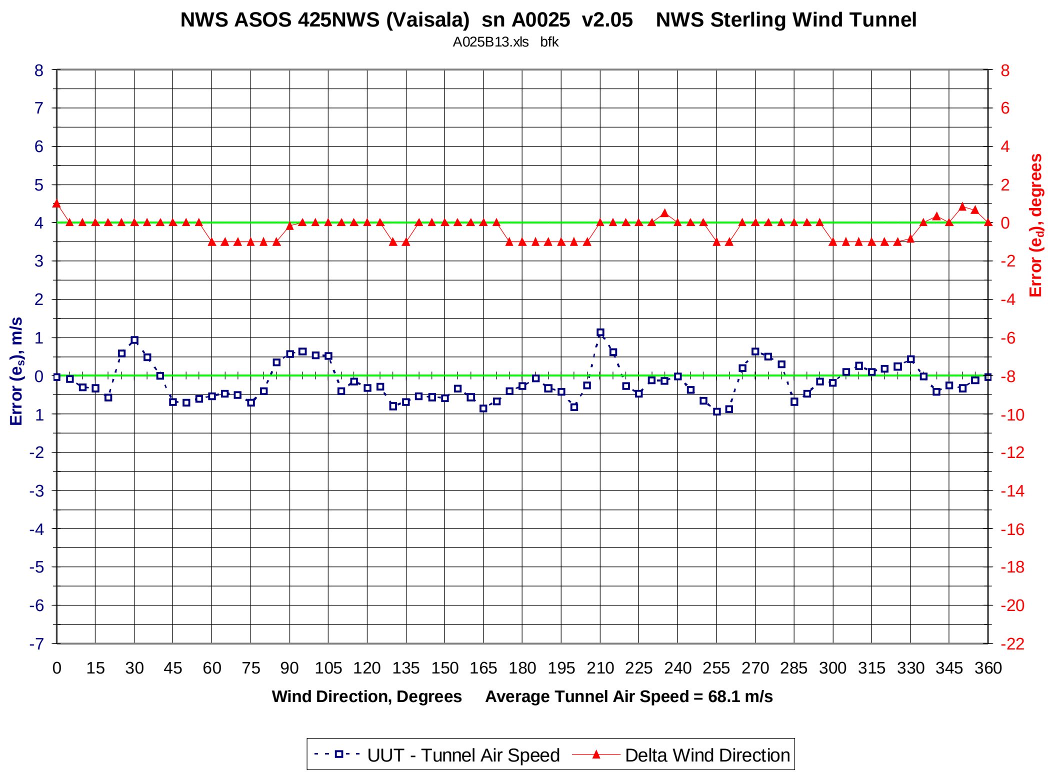


Vaisala WXT510 wind tunnel test graphs

5. Conclusions

Two of the sonic anemometers, the R. M. Young 85000 and the Vaisala WS425A, met the manufacturer's stated wind direction accuracy over the full operational speed range of the anemometer.

None of the sonic anemometers met the manufacturer's stated wind speed accuracy over the full operational speed range of the anemometer. It's the author's opinion that some fine-tuning of the internal speed correction tables could improve the wind speed accuracy of these low-cost sonic anemometers to 65 m/s and beyond. The wind tunnel performance of a NWS ASOS 425NWS sonic anemometer at 68 m/s is shown below. This anemometer is not a low-cost sonic anemometer but is shown as a performance benchmark. This sonic anemometer is a modified version of the COTS Vaisala WS425A. The ASOS 425NWS wind speed accuracy was –1.4 % to +1.7 % at 68 m/s in the wind tunnel.



NWS ASOS 425NWS sonic anemometer at 68 m/s

The author has made several observations over years concerning sonic anemometers. Is there a need to specify wind direction accuracy any better than ±3 degrees? It's the author's opinion that a wind direction accuracy of ±3 degrees is adequate for many applications that report wind direction to the nearest 10 degrees. In most cases, with an error allowance of ±1degree for a precision north alignment, a sensor accuracy of ±3 would provide the same 10-degree wind direction-reporting bin in the database. Sonic anemometers have a definite U_{max} when the transmitted sonic signal can no longer be discerned due to the noise created by the air turbulence of wind flowing over the transducers and support structures at high wind speeds. The analog interface on sonic anemometers may not provide the same accuracy as the digital interface. Also, the end user should test the sonic anemometer with the measurement units (knots, m/s, etc.) that are to be used in the particular application to ensure that there are no errors in the unit conversion or the internal sensor correction tables. To summarize: Test the exact model of the sonic anemometer with the sensor firmware version, interface, and with the measurement units to be used in the particular application.

Bibliography

[1] Sturgeon, M. C., *A Wind Tunnel Acceptance Test Method For Sonic Anemometers*, presented at the 15th International Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology at the 79th annual meeting of the American Meteorological Society at Dallas Texas on January 12, 1999.

[2] ISO16622: 2002, *Meteorology - Sonic anemometers/thermometers – Acceptance test methods for mean wind measurements*

Appendix A

Notes to Table 1

[1]Manufacturer's stated supply voltage range:

Gill WindSonic	9 to 30 vdc
RM Young 85000	9 to 16 vdc
Vaisala WS425A	10 to 15 vdc
Vaisala WXT510	5.5 to 30 vdc

All wind tunnel tests, except for the Vaisala WS425A sonic anemometer, were conducted at 12.05±0.05 vdc. The power source used was a Tenma laboratory power supply model 72-110, sn 8705697. For the Vaisala WS425, a Vaisala model 4257006 power supply, sn 168, was used. The supply voltage was 12.15 vdc. The load current was measured with a Fluke Model 87-III True RMS multimeter, sn 69820005.

[2]Current draw shown for theRS-232 interface. RS-422, RS485, SDI-12, and analog interfaces are either available as a standard feature or an option depending on the particular model anemometer.

[3]With the newest version of sensor firmware, the manufacture's stated current draw is 14 ma @ 12 vdc.

[4]Missing data errors occurred at 60 m/s.

[5]No data was taken at the specified speed. Data shown is for closest test speed for comparison only.

[6]The heaters were not used during the wind tunnel tests. The heaters supply lines were jumpered at the sensor terminal board to the 12 vdc power supply ground. The sensor heaters were not energized during these wind tunnel tests. The heater supply (+) and heater supply (-) were jumpered to the power supply ground (-) terminal at the internal sensor terminal strip.

[7]Anomalous wind direction readings of 120 and 240 degrees occurred at zero degrees at all wind speeds.

Acknowledgements

This paper is dedicated to the memory of Thomas J. Lockhart, whose mentoring for quality in meteorological measurements has inspired many during his lifetime.

A special thanks to: Michael Salyards, NWS, for technical suggestions and editorial review of this paper.

Disclaimer

The opinions expressed in this paper are solely those of the author and do not represent any official position of the United States National Weather Service.