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THE C3—AN ALTERNATIVE ANEMOMETER FOR RESOURCE ASSESSMENT

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Executive Summary.

Second Wind Inc. is pleased to offer a new standard anemometer for resource assessment that incorporates industry proven geometry and features. The new three-cup anemometer, the Second Wind Model C3, is physically similar to a popular anemometer designed by Maximum, Inc. and used in the wind industry for more than 30 years. However, the C3 employs more durable materials with high-quality manufacturing methods that make it an extremely reliable alternative for wind assessment.

Key benefits include:

- *A second source for the industry's most popular anemometer design*. This provides a new choice for customers.
- Choice of calibrated or uncalibrated units.
- *Confirmation from wind tunnel tests that there is no appreciable difference* in wind speed or energy measurement between the Second Wind-manufactured C3 and the Max/NRG# 40 manufactured by NRG Systems Inc.
- *Indications of slightly less product variability* than the Max/NRG#40, which was previously sold by Second Wind, based on the same wind-tunnel tests involving hundreds of units.
- *Confirmation that the C3's field performance is virtually identical* to the many thousands of similar units employed in the wind industry, based on data from hundreds of C3 prototypes in active use.
- *The use of tough polycarbonate and single-piece construction for all molded plastic*, in place of less-durable ABS employed in Second Wind's previous anemometer offering.

This paper provides background on the anemometer's development, then describes the testing of the C3 and presents the results.

Background on Second Wind's Anemometer Offerings

In 1980, Second Wind Inc. (SWI) designed a new system (the AL-2000) for wind resource assessment. Then as now such systems need wind speed and direction sensors. After an exhaustive search we selected the wind speed sensor designed and manufactured by Maximum, Inc., then of Natick, Massachusetts. The selection followed a design review at the Maximum factory with Mr. Gordon White, inventor of the anemometer. In addition, Second Wind tested several Model 40 cups in the wind tunnel at the University of Massachusetts at Amherst. We found them to be well suited to the field of wind resource assessment.

For many years Second Wind supplied these cups and, starting in 1993, offered a version calibrated in Massachusetts Institute of Technology's Wright Brothers wind tunnel. The calibration method and equipment were designed by a team including SWI President Walter Sass, MIT Professor Eugene E. Covert[1], and Wright Brothers tunnel operator Frank Durgin. By this time Maximum, Inc. had

[1] MIT Professor of Aeronautics and Astronautics, 1963 to 1985. Awarded the Daniel Guggenheim Medal in 2005.

appointed NRG Systems of Hinesburg, Vermont ("NRG") the sole distributor of the sensor to the wind energy industry.

Resolution of Apparent Calibration Discrepancy

Starting the late 1980's, Otech Engineering, a Davis, California, consulting and engineering firm ("Otech"), developed and offered a calibration service for the Max/NRG #40 cups based on open-air measurements made on a moving vehicle. By 1997, differences in the calibration results from the MIT tunnel and the Otech method prompted the intervention of National Renewable Energy Laboratory (NREL) to manage a technical resolution.

NREL (through its contractor AWS Scientific of Albany, New York), Otech, NRG, MIT, and SWI all worked with Tom Lockhart of the Meteorological Standards Institute to uncover the causes of the differences and find consensus. The fundamental results showed important differences in the tunnel tests versus the truck, and also that the vinyl boot, introduced to cover the wiring underneath the cup body, affects the wind flow around the sensor. The differences were resolved and consensus slope and offset in use since then were reported.[2] In October 2005, Otech Engineering switched to a new calibration method using an open circuit wind tunnel, resolving the calibration issue completely.

For decades the wind energy industry has relied on a single source for this low-cost highly durable and accurate 3-cup anemometer. Second Wind is pleased to offer a second source for this design that introduces improvements while preserving the essential accuracy and durability.

[2] Lockhart, T.J.; Bailey, B.H. "Maximum Type 40 Anemometer Calibration Project," Windpower '98 Proceedings of the Annual Conference & Exhibition of the American Wind Energy Association, 27 April-May1 1998, Bakersfield, CA, 1998: 361-368.

Features of the Model C3 Anemometer

The new anemometer's design has proven itself over years and years of service to the wind industry, beginning with the Maximum #40, continuing as the NRG #40, and now improved as the Model C3. In 2004, Second Wind decided to manufacture its own anemometers and began considering design improvements to the standard 3-cup product. Prototype Model C3 anemometers were tested and by first quarter of 2005 the first 200 sensors were installed in the field. These are still in operation with a total of 2,500 produced at the time of this writing.

The Model C3 includes improvements to materials and manufacturing designed to enhance reliability and usability of the units in the field. Key improvements include:

- A single-piece, injection molded base simplifies the design and ensures manufacturing uniformity. There are no fitted or glued parts in the base assembly.
- All molded plastic – made of tough UV-resistant black polycarbonate plastic, not ABS.
- Manufacturing is RoHS compliant. The product is lead free and does not incorporate any of the materials deemed toxic by the European RoHS directive, allowing EC customers to use it with confidence.

A summary of the important standard features of the Model C3 design are noted below:

- Conical cups measuring 51 mm (2 inches in diameter)
- Rotor diameter is 190 mm (7.5 inches)
- Standard AC output, frequency proportional to cup rotational speed
- Shielded AC pick-up coil, 4100 turns of #41 wire
- Four-pole Indox 1 magnet rotates with the cup assembly
- Fully hardened beryllium-copper shaft running in self-lubricating modified Teflon bearings.
- Rated bearing PV (pressure-velocity) factor is 20,000
    - At 15 mph PV is approx. 500
    - At 100 mph PV is approx. 2,000.
- Rotor assembly moment of inertia = 68×10^{-6} S-ft^2 (or 92.2×10^{-6} kg-m^2)
- Distance constant = 10 feet (3.0 meters)
- Distinctive Second Wind blue vinyl boot to protect wiring terminals

No Measurable Differences in Wind Tunnel Tests

From June 12 to June 14, 2007 SWI tested approximately 500 Max/NRG #40 cups purchased from NRG and 135 Model C3 anemometers at the MIT Wright Brothers facility.

Testing of the two groups of anemometer was done consecutively following the same procedures in use for many years that include the use of a NIST traceable reference wind sensor. The test fixtures and instrumentation was unchanged throughout. The results show that the Model C3 and the Max #40 have a virtually indistinguishable transfer functions. Figure 1 shows the transfer function results where each slope and offset is a single point on the X-Y graph. The Model C3 data points are yellow and the Max 40 are blue. Because the vast majority of the two populations intersect, it is apparent that the basic characteristics are the same.

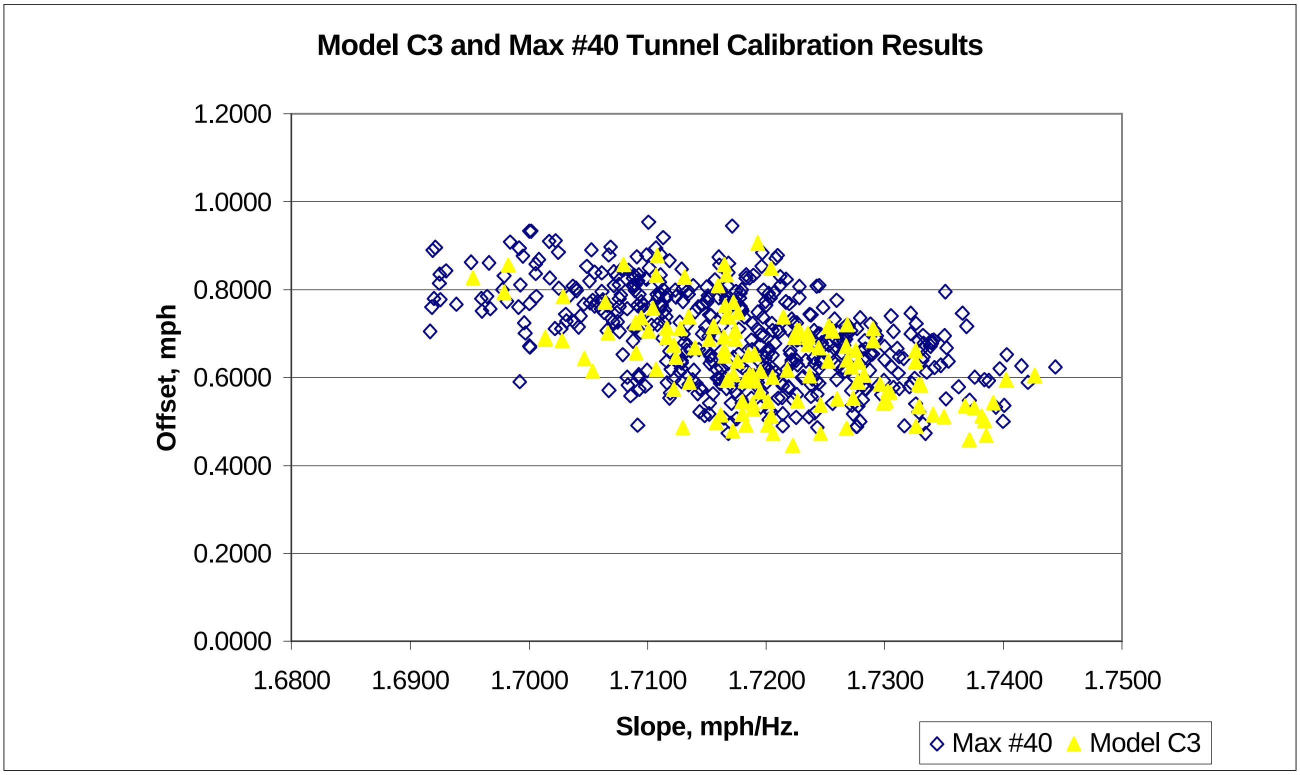

Figure 1

	Slope, mph/Hz	Std Dev	Offset, mph	Std Dev
Max 40	1.7174	0.0104	0.6961	0.1044
Model C3	1.7203	0.0096	0.6410	0.1053
Delta	-0.0029		0.0551	

Table 1

The averages and difference in slope and offset for the two populations is shown in Table 1. The MIT tunnel test results for the slope of the Max/NRG 40 cups are within about 0.37% of the consensus value in the Lockhart, et al work referenced above. This small difference (and the result for the NRG #40 offset) is well within expected experimental error. Since the Max #40 cup, now manufactured by NRG and sold as the NRG #40, has been demonstrated time and again to be consistently made, it reasonable to use our sample of 500 to calibrate the tunnel test itself. The important result is then the difference between the old cups and our new ones. The differences in Table 1 are applied to the consensus values for the old cups and Table 2 compares the two.

Comparison of slopes and offsets

	mph/Hz	mph
Max 40	**1.711**	**0.780**
Model C3	**1.714**	**0.725**
	m/s/Hz	**m/s**
Max 40	**0.765**	**0.350**
Model C3	**0.766**	**0.324**

Table 2

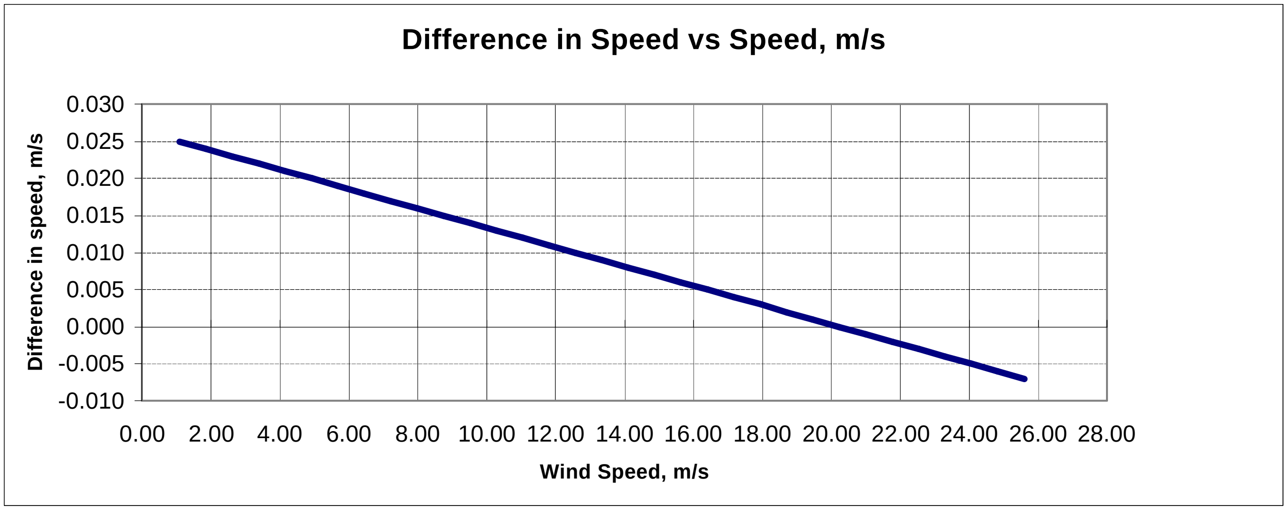

Figure 2

Figure 2 plots the differences in measured wind speed resulting from the small differences in the slopes and offsets in Table 2. The differences are small. They range from .025 m/s in almost no wind to no difference at 20 m/s. To determine the magnitude of the differences in a typical wind resource analysis, we applied the two calibrations to a measured wind distribution and calculated the theoretical energy output for a popular 1.5 MW low-wind regime turbine. The results are within 0.19% of each other. We conclude that the use of the new Model C3 will result in no appreciable error in wind speed or energy measurement even for the case where the Max/NRG #40 default slope and offset are used for the C3 or vice versa.

Quality Control Tests Indicate Less Product Variability

The Model C3 sensor is carefully assembled and each unit is fully tested before shipment. A useful and important measure of quality control is the variability in the wind tunnel test results. The variability in the slopes and offsets is a combination of both the tunnel test and the product.

Since the tunnel tests of the two anemometer models were run consecutively in the same facility, the contribution of test itself is comparable. Significant differences are thus likely to be from the product. We noted with interest that the standard deviation of slopes for the Model C3 was about 8% less than for the Max/NRG #40. The C3 standard deviation of the offsets was slightly higher (about 1%). From this we conclude that the Model C3 has equivalent or slightly less product variability than the original design.

An automated multi-point test of bearing and generator performance is done to each Model C3 anemometer prior to serialization. This test is a “spin-down” test. The anemometer rotor is spun up and then allowed to spin down. The output is measured and recorded using a computerized test fixture. The rate of spin down is an effective mechanical test of bearing and shaft alignment. The electrical output is checked for signal strength, an effective test of the magnet and coil quality. The computer test program measures the output for each sensor and compares these to known pass/fail values. By this means, defects in mechanical or electrical performance are found and these units are eliminated.

Conclusion

The new Second Wind Model C3 anemometer provides the industry a reliable alternate source for the most commonly used product for wind assessment. Improvements to materials and manufacturing are designed to make the product more reliable and usable for customers worldwide; tests indicate slightly less product variability, while in performance measures the transfer functions (slope and offset) of the Model C3 and the Max/NRG #40 are virtually indistinguishable.