



110 Riggs Road t 802 482-2255 www.renewableNRGsystems.com
Hinesburg, VT 05461 USA f 802 482-2272 info@renewableNRGsystems.com

Renewable NRG Systems, Inc.

Post Calibrating the NRG #40C Anemometer in the SOH Wind Engineering (SOH WE) Wind Tunnel

Steve Clark
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I. Executive Summary

Through October 2012, all NRG #40C non-MEASNET, initial production calibrations have been carried out in the Otech Engineering wind tunnels. Some users of NRG #40C Anemometers have had calibrations performed on these anemometers after field-deployment as a quality check. The calibrations performed after field-deployment are often referred to as “post-calibrations” and are typically performed in the same wind tunnel as the initial calibration (to remove tunnel-to-tunnel bias in the result).

At the end of October 2012, Otech Engineering closed its calibration facility in Davis, California. A new calibration facility, SOH Wind Engineering (SOH WE), located in Williston, Vermont, possesses a broader range of test capabilities and began anemometer calibrations on January 24, 2013.

The following white paper quantifies the additional systematic and random uncertainty associated with post calibrating an anemometer in a tunnel different than its initial calibration. The additional systematic and random uncertainty is quantified for the NRG #40C Anemometer for a 4-26 m/s wind speed calibration range (the range that all NRG #40C initial calibrations have been done in the Otech tunnel).

Two (2) procedures – one simplified, one rigorous – are provided in this white paper, defining the process of evaluating SOH WE post-calibrations of NRG #40C Anemometers initially calibrated at Otech. The Simplified Procedure is summarized below and again in Section IV. The Rigorous Procedure is included in Section IV of the report and followed by a numerical example in Section V.

A. Simplified Procedure

1. NRG #40C Anemometer is initially calibrated at Otech Engineering (NRG #40C Anemometers through S/N 212199).
2. After field-deployment, the NRG #40C Anemometer is post-calibrated over the 4-26 m/s wind speed range at the SOH WE wind tunnel.
3. For NRG #40C Anemometers initially calibrated after July 1, 2011 (serial numbers greater than 177000), an Adjustment Factor of 1.0086 (0.86%), representing the mean bias between the Otech and SOH WE wind tunnels, is applied to the SOH WE wind tunnel calibration results to ensure consistency with the Otech initial calibration. For NRG #40C Anemometers initially calibrated before July 1, 2011 (serial numbers less than 177000), it is not necessary to apply an Adjustment Factor.
4. The anemometer’s 10 Hz response between the initial and post calibrations are compared.
 - a. If the adjusted SOH WE nominal 10Hz response is within the range defined by the Otech nominal ± 0.15 m/s, the post calibration at SOH WE is consistent with and statistically indistinguishable from the initial calibration at Otech.
 - b. If the adjusted SOH WE nominal 10Hz response is outside the range defined by the Otech nominal ± 0.15 m/s, apply the Rigorous Procedure detailed in Section IV of the report.

It is typical to allow for some additional change in calibration from beginning to end of life of an anemometer. It is up to the analyst to determine how much additional difference between initial and post calibrations are acceptable and covered by the overall uncertainty analysis for the measurement campaign.

II. Introduction

The following white paper quantifies the additional systematic and random uncertainty associated with post calibrating an anemometer in a tunnel different than its initial calibration. The additional systematic and random uncertainty is quantified for the NRG #40C Anemometer for a 4-26 m/s wind speed calibration range (the range over which all Otech #40C initial calibrations have been performed).

Same-sensor calibration comparisons have been performed verifying excellent agreement between anemometers calibrated in the Otech and SOH Wind Engineering (SOH WE) tunnels, validating the applied SOH Adjustment Factor and additional standard uncertainty.

III. Uncertainty

Uncertainty is the range of possible values of a measurand bounding a measurement in which the true value is likely to reside. Uncertainty is comprised of systematic (or bias) errors and random (or precision) errors.

The additional uncertainty associated with post calibrating an anemometer in a tunnel different than its initial calibration is comprised of systematic and random errors. Both error sources are described and quantified in the following sections.

B. Systematic Uncertainty

The systematic bias associated with calibrating an anemometer in the SOH wind tunnel is quantified by comparing same-sensor calibrations in the Otech Engineering and SOH WE wind tunnels.

The following test protocol was utilized to quantify the systematic bias.

i. Test Protocol

Twenty five (25) NRG #40C anemometers were calibrated in the Otech and SOH WE wind tunnels. The systematic bias between the two wind tunnels is quantified by calculating the average mean bias between the two sets of calibrations.

The test calibration wind speed range is 4-26 m/s. Otech's calibration employed twelve (12) wind speed intervals (in order): 4, 8, 12, 16, 20, 24, 26, 22, 18, 14, 10, 6 m/s. SOH WE's calibration utilizes thirteen (13) wind speed intervals - the same 12 as Otech's plus one additional interval at 15 m/s at the end of the calibration.

Data recording time for the Otech and SOH WE wind tunnels was 30 sec at each interval following adequate time to reach steady state conditions.

The sensor was mounted in the same orientation for all calibrations such that the “tear drop” shape of the lower boot was downstream of the mount stem.

ii. Data Comparison Method

The selected comparison method presents the histogram of the 10 Hz (nominally 8 m/s) response of the NRG #40C anemometer.

Calibration data from the Otech Engineering wind tunnel includes a blockage factor of 1.00735 (0.735%). Otech Engineering’s blockage correction factor is based on the $\frac{1}{4}$ area ratio, defined as the ratio of the anemometer frontal area divided by the tunnel cross section, and was applied to all NRG #40C Anemometer calibrations as of July 1, 2011. In the case of SOH WE’s calibration, an Adjustment Factor is applied, derived by matching the mean 10 Hz response values from each of the calibration data sets. The Blockage Factor (in the case of the Otech tunnel) and Adjustment Factor (in the case of the SOH tunnel) increase the wind tunnel speed proportionally by the magnitude of the factor.

iii. Results of Systematic Bias Test

Figure 1 below is a plot of the histograms of the 10 Hz response of the 24¹ NRG #40C test anemometers measured at both the Otech and SOH WE wind tunnels. All initial calibrations were performed at Otech after July 1, 2011 and therefore include a Blockage Factor of 1.00735 (0.735%).

The plot shows the calibration results of 24 NRG #40C Anemometers from Otech (Green) and SOH WE (Blue). The adjusted SOH WE calibration results (using an Adjustment Factor of 1.0086 (0.86%)) are shown in yellow. An Adjustment Factor would not need to be applied if the initial Otech calibration had been performed prior to July 1, 2011.

As shown in Figure 1, excellent agreement between Otech and SOH WE is achieved using the 1.0086 (0.86%) Adjustment Factor applied to the SOH WE results.

¹ The population of test sensors consisted of 25 NRG #40C Anemometers. However, S/N 203174 was identified as an outlier using Chauvenet’s criteria and eliminated from the population, yielding 24 anemometers.

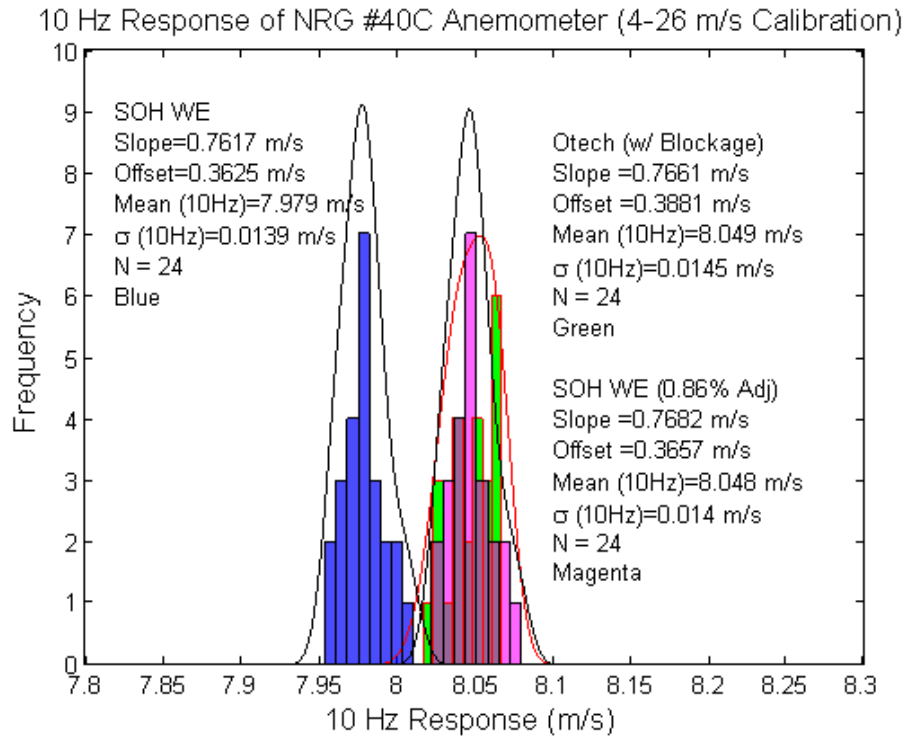


Figure 1 NRG #40C Anemometer 4-26 m/s Calibration Comparison

iv. Additional Uncertainty Associated with SOH Adjustment Factor

Per the IEC 61400-12-1 Standard for power performance measurements of electricity producing wind turbines (Annex F) (IEC, 2005), it is suggested that the standard uncertainty associated with a blockage factor be half the difference between the corrected and uncorrected value. Applying this method to the Adjustment Factor results in a bias of,

$$B_{AF} = \frac{1.0086 - 1.0}{2} = 0.0043$$

Based on the ISO Guide to the Expression of Uncertainty in Measurement (GUM) (ISO/IEC, GUIDE 98-3:2008(E)), the systematic uncertainty associated with the Adjustment Factor is then,

$$\frac{\partial V}{\partial k_{AF}} \times B_{AF}$$

Where $\frac{\partial V}{\partial k_{AF}}$ is the partial derivative of the wind tunnel velocity with respect to the Adjustment Factor, also known as the sensitivity coefficient. The sensitivity coefficient simplifies to $\frac{V}{k_{AF}}$ for a data reduction equation given by,

$$V = k_{AF} k_b \sqrt{\frac{2k_c \Delta p}{C_h \rho}}$$

The above referenced data reduction equation computes the tunnel reference wind speed as measured by a pitot probe.

The Adjustment Factor bias uncertainty equation ($\frac{\partial V}{\partial k_{AF}} \times B_{AF}$) results is an array of bias uncertainties, one number for each of the twelve (12) wind speeds used in the calibration. Table 1 below summarizes the average systematic uncertainty calculated from calibrations of the 24 NRG #40C Anemometer calibrated at SOH WE.

Table 1 Bias Uncertainty of SOH WE Adjustment Factor

Tunnel Wind Speed (m/s) Nominal	Bias Uncertainty of SOH Adjustment Factor
	$\frac{\partial V}{\partial k_{AF}} \times B_{AF}$ (m/s)
4	0.0172
8	0.0342
12	0.0514
16	0.0685
20	0.0856
24	0.1027
26	0.1113
22	0.0942
18	0.0770
14	0.0601
10	0.0426
6	0.0258
15	0.0637

Expressed as a relative (of tunnel wind speed) uncertainty, the bias uncertainty of the Adjustment Factor is 0.43%, derived as,

$$\frac{\frac{\partial V}{\partial k_{AF}} B_{AF}}{V} = \frac{\frac{V}{k_{AF}} B_{AF}}{V} = \frac{B_{AF}}{k_{AF}} = \frac{0.0043}{1.0086} = 0.0043 = 0.43\%$$

Table 1 is the additional bias uncertainty associated with the SOH Adjustment Factor and is added to the systematic uncertainty estimate of the tunnel wind speed to quantify the change between SOH WE post calibration results and Otech initial calibration results. This will be discussed in detail in Section III D.

C. Random Uncertainty

The random uncertainty is derived from the 24 NRG #40 Anemometer calibrations performed in the Otech and SOH WE wind tunnels.

For each of the data sets, as shown in Figure 1, the histogram of the 10 Hz response is plotted along with the mean and standard deviation of the 10 Hz response. The random uncertainty is quantified by combining the standard deviations of the calibration distributions from both the Otech and SOH WE wind tunnels.

As shown in Figure 1, the standard deviation of the Otech distribution of calibrations is 0.0145 m/s; for the SOH WE wind tunnel adjusted results, the standard deviation is 0.0140 m/s.

In Table 2, the standard deviations from the two calibration distributions are combined using the root sum-of-the-square (RSS). The combined standard deviation is 0.0202 m/s and represents the increase in random standard uncertainty associated with post calibrating an anemometer in a tunnel different from its initial calibration.

Table 2 Random Uncertainty of Otech and SOH WE Wind Tunnels

Anemometer	Otech (σ)	SOH WE (σ)	RSS (σ)
NRG #40C	0.0145	0.0140	$\sqrt{0.0145^2 + 0.0140^2} = 0.0202$

D. Random Plus Systematic Standard Uncertainty

The additional standard uncertainty applied to post calibrating an anemometer in the SOH wind tunnel, that was originally calibrated in the Otech wind tunnel is computed as the RSS of the systematic plus random uncertainty. Mathematically, the standard uncertainty is,

$$u = \sqrt{b^2 + s^2}$$

Where “u” denotes the standard uncertainty, “b” denotes the systematic bias and “s” denotes the random uncertainty. The resulting additional standard uncertainty is summarized in

Table 3. A coverage factor (i.e., confidence interval) has not yet been applied to the standard uncertainty. Expressed as a percent of the tunnel wind speed, the additional standard uncertainty is 0.47%.

Table 3 Additional Standard Uncertainty for Post-Calibrating NRG #40C in SOH WE Wind Tunnel

	Systematic Uncertainty (m/s)	Random Uncertainty (m/s)	Additional Standard Uncertainty (m/s) $u = \sqrt{b^2 + s^2}$	
Tunnel Wind Speed (m/s) Nominal	b	s	m/s	%

	Systematic Uncertainty (m/s)	Random Uncertainty (m/s)	Additional Standard Uncertainty (m/s) $u = \sqrt{b^2 + s^2}$	
4	0.0172	0.0202	0.0265	0.66%
8	0.0342		0.0397	0.50%
12	0.0514		0.0552	0.46%
16	0.0685		0.0714	0.45%
20	0.0856		0.0880	0.44%
24	0.1027		0.1047	0.44%
26	0.1113		0.1131	0.44%
22	0.0942		0.0963	0.44%
18	0.0770		0.0796	0.44%
14	0.0601		0.0634	0.45%
10	0.0426		0.0471	0.47%
6	0.0258		0.0328	0.55%
15	0.0637		0.0668	0.45%

IV. Post-Calibration Process

The following steps define the post-calibration process offered by NRG for #40C anemometers initially calibrated at Otech and post-calibrated at SOH WE. A numerical example follows in Section V.

A. Simplified Procedure

1. NRG #40C Anemometer is initially calibrated at Otech Engineering (NRG #40C Anemometers through S/N 212199).
2. After field-deployment, the NRG #40C Anemometer is post-calibrated over the 4-26 m/s wind speed range at the SOH WE wind tunnel.
3. For NRG #40C Anemometers initially calibrated after July 1, 2011 (serial numbers greater than 177000), an Adjustment Factor of 1.0086 (0.86%), representing the mean bias between the Otech and SOH WE wind tunnels, is applied to the SOH WE wind tunnel calibration results to ensure consistency with the Otech initial calibration. For NRG #40C Anemometers initially calibrated before July 1, 2011 (serial numbers less than 177000), it is not necessary to apply an Adjustment Factor.
4. The anemometer's 10 Hz response between the initial and post calibrations are compared.
 - a. If the adjusted SOH WE nominal 10Hz response is within the range defined by the Otech nominal ± 0.15 m/s, the post calibration at SOH WE is consistent with and statistically indistinguishable from the initial calibration at Otech.
 - b. If the adjusted SOH WE nominal 10Hz response is outside the range defined by the Otech nominal ± 0.15 m/s, apply the Rigorous Procedure detailed below.

B. Rigorous Procedure

1. NRG #40C Anemometer is initially calibrated at Otech Engineering (NRG #40C Anemometers through S/N 212199).

2. After field-deployment, the NRG #40C Anemometer is post-calibrated over the 4-26 m/s wind speed range at SOH WE wind tunnel.
3. For NRG #40C Anemometers initially calibrated after July 1, 2011 (serial numbers greater than 177000), an Adjustment Factor of 1.0086 (0.86%), representing the mean bias between the Otech and SOH WE wind tunnels, must be applied to the SOH WE wind tunnel calibration results to ensure consistency with the Otech initial calibration. For NRG #40C Anemometers initially calibrated before July 1, 2011 (serial numbers less than 177000), it is not necessary to apply an Adjustment Factor.
4. The anemometer's 10 Hz response between the initial and post calibrations are compared.
 - a. If the adjusted SOH WE nominal 10Hz response is within the range defined by the Otech nominal value plus/minus the uncertainty reported in column G of Table 7 in Section V, the Uncertainty Range Relative to the Initial Calibration, the post calibration at SOH WE is consistent with and statistically indistinguishable from the initial calibration at Otech. Graphically, this is shown in Figure 4 in Section V below.
 - b. If the adjusted SOH WE nominal 10Hz response is not within the range defined by the Otech nominal value plus/minus the uncertainty reported in column G of Table 7 in Section V, the post-calibration at SOH WE is inconsistent with and statistically distinguishable from the initial calibration at Otech.

V. An Example of the Post-Calibration Process

As an example, consider NRG #40C Anemometer S/N 203159 with the following Otech and SOH WE calibration data, hereby treated as a simulated initial and post calibration. Keep in mind, this anemometer was not field-deployed so the difference in response reflects (predominantly) tunnel variation. Had this NRG #40C Anemometer been field-deployed, the difference in anemometer response would likely have been greater than that reported in this example.

The Otech calibration certificate for S/N 203159 is shown in Figure 2. Also shown in Figure 2 is a fly-out highlighting the data table from the Otech calibration. The data table itself is included as Table 4 below.

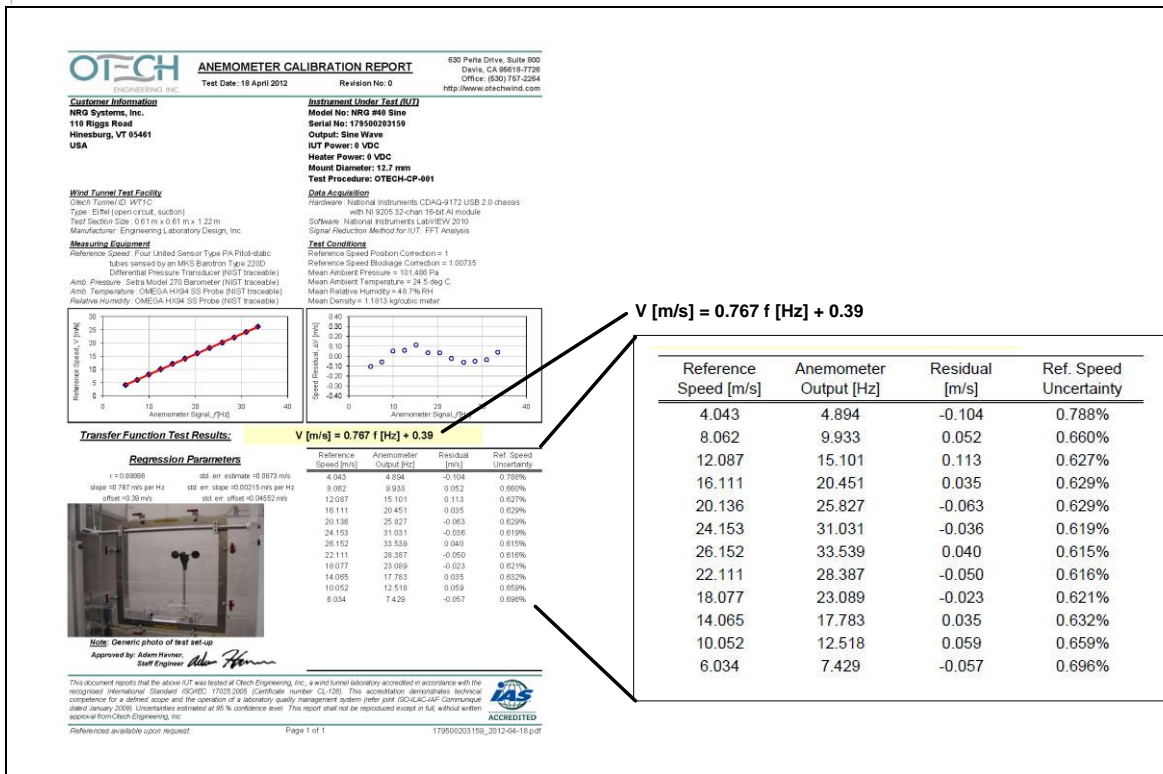


Figure 2 NRG #40C S/N 203159 Otech Calibration Certificate

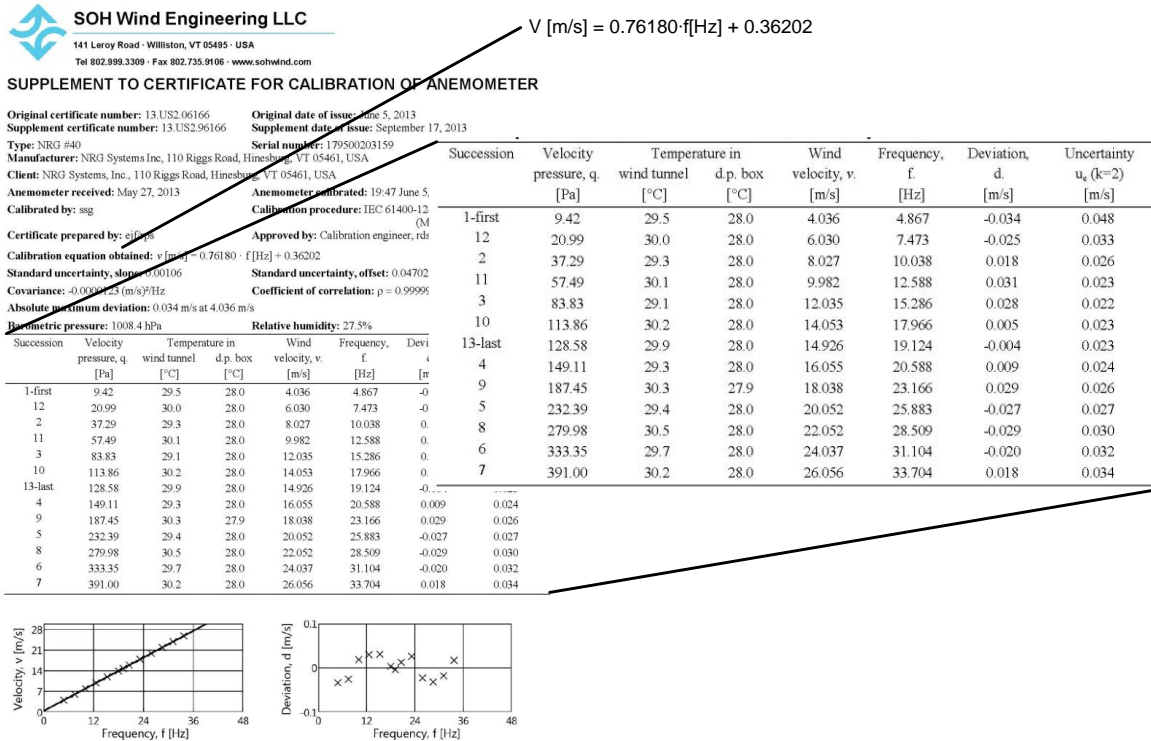
Table 4 NRG #40C S/N 203159 Otech Calibration Data Table

Reference Speed [m/s]	Anemometer Output [Hz]	Residual [m/s]	Ref. Speed Uncertainty
4.043	4.894	-0.104	0.788%
8.062	9.933	0.052	0.660%
12.087	15.101	0.113	0.627%
16.111	20.451	0.035	0.629%
20.136	25.827	-0.063	0.629%
24.153	31.031	-0.036	0.619%
26.152	33.539	0.040	0.615%
22.111	28.387	-0.050	0.616%
18.077	23.089	-0.023	0.621%
14.065	17.783	0.035	0.632%
10.052	12.518	0.059	0.659%
6.034	7.429	-0.057	0.696%

In Table 4, column 1 is the reference tunnel wind speed in meters per second (m/s) for each of the 12 wind speed intervals. Column 2 is the anemometer frequency output in hertz (Hz). Column 3 is the residual, defined as the difference in the wind speed predicted by the calibration transfer function

minus the reference tunnel wind speed, expressed in meters per second (m/s). Column 4 lists the uncertainty of the reference tunnel wind speed, as a percent of wind speed.

Similarly, the SOH WE calibration for S/N 203159 is shown in Figure 3, highlighting the calibration data table. The data table itself is included as Table 5 below.



AC-1746
Standard: ISO/IEC 17025

Figure 3 NRG #40C S/N 203159 SOH WE Calibration Certificate

Table 5 NRG #40C S/N 203159 SOH WE Calibration Data Table

Succession	Velocity Pressure, q [Pa]	Temperature in Control Room		Wind Velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty uc (k=2) [m/s]
		Wind Tunnel [°C]	d.p. box [°C]				
1-First	9.42	29.5	28.0	4.036	4.8668	-0.034	0.048
12	20.99	30.0	28.0	6.030	7.4729	-0.025	0.033
2	37.29	29.3	28.0	8.027	10.0383	0.018	0.026
11	57.49	30.1	28.0	9.982	12.5882	0.031	0.023
3	83.83	29.1	28.0	12.035	15.2861	0.028	0.022
10	113.86	30.2	28.0	14.053	17.966	0.005	0.023
13-last	128.58	29.9	28.0	14.926	19.1237	-0.004	0.023
4	149.11	29.3	28.0	16.055	15.917	0.009	0.024
9	187.45	30.3	27.9	18.038	17.877	0.029	0.026
5	232.39	29.4	28.0	20.052	19.879	-0.027	0.027
8	279.98	30.5	28.0	22.052	21.854	-0.029	0.030
6	333.35	29.7	28.0	24.037	23.827	-0.020	0.032
7	391.00	30.2	28.0	26.056	25.824	0.018	0.034

In Table 5, column 1 lists each of the 13 wind speed intervals², in random order. Column 5 is the reference tunnel wind speed in meters per second (m/s) for each of the 13 wind speed intervals. Column 6 is the anemometer frequency output in hertz (Hz). Column 7 is the residual, expressed in meters per second (m/s). Column 8 lists the uncertainty of the reference tunnel wind speed, expressed in meters per second (m/s).

The objective now is to compare NRG #40C anemometer S/N 203159 10 Hz response initial and post calibrations to determine if the calibrations are consistent and statistically indistinguishable.

Using the Otech calibration transfer function,

$$V \text{ [m/s]} = 0.767 f \text{ [Hz]} + 0.39$$

Substitute in 10 Hz from into the above equation,

$$V \text{ [m/s]} = 0.767 \times 10 \text{ [Hz]} + 0.39 = 8.06 \text{ m/s}$$

Repeat the process using the SOH WE's transfer function reported on the calibration certificate,

$$V \text{ [m/s]} = 0.76180 \times 10 \text{ [Hz]} + 0.36202 = 7.98 \text{ m/s}$$

Applying the 1.0086 (0.86%) Adjustment Factor yields,

$$V \text{ [m/s]} = 1.0086 \times [0.76180 \times 10 \text{ [Hz]} + 0.36202] = 8.05 \text{ m/s}$$

² Calibration intervals at the SOH WE wind tunnel include the 12 intervals of the Otech 4-26 m/s calibration plus an additional interval at 15 m/s, yielding a total of 13 intervals.

The results are summarized in Table 6 below.

Table 6 10Hz Response Comparison between Otech and SOH WE Wind Tunnels

NRG #40C Anemometer S/N 203159				
Wind Tunnel	Slope	Offset	10 Hz Response (m/s)	% Difference
Otech	0.767	0.39	8.06	0.12
SOH WE (Adjusted)	0.768	0.37	8.05	

Applying Step 4a of the Simplified Procedure (Section IV A), if the nominal 10Hz response of the NRG #40C Anemometer S/N 203159 is within the range defined by the Otech nominal ± 0.15 m/s, the post calibration is consistent with and statistically indistinguishable from the initial calibration at Otech. In our example problem, comparing the initial Otech calibration against the SOH WE post calibration for NRG #40C Anemometer S/N 203159, the SOH WE response of 8.05 m/s is well within the uncertainty range for calibration consistency ($8.06 \text{ m/s} \pm 0.015 \text{ m/s}$). As such, one would conclude the SOH WE post calibration is consistent with and statistically indistinguishable from its initial Otech calibration. If the SOH WE response was outside of the uncertainty range for calibration consistency, one would apply the Rigorous Procedure (applied below, as an example, even though the calibrations are consistent).

Applying Step 4a of the Rigorous Procedure (Section IV B), if the nominal 10Hz response of the NRG #40C Anemometer S/N 203159 is within the range defined by the Otech nominal value plus/minus the additional uncertainty relative to the initial calibration, the post calibration at SOH WE is consistent with and statistically indistinguishable from the initial calibration at Otech. Graphically, this expanded uncertainty range is shown in Figure 4 below.

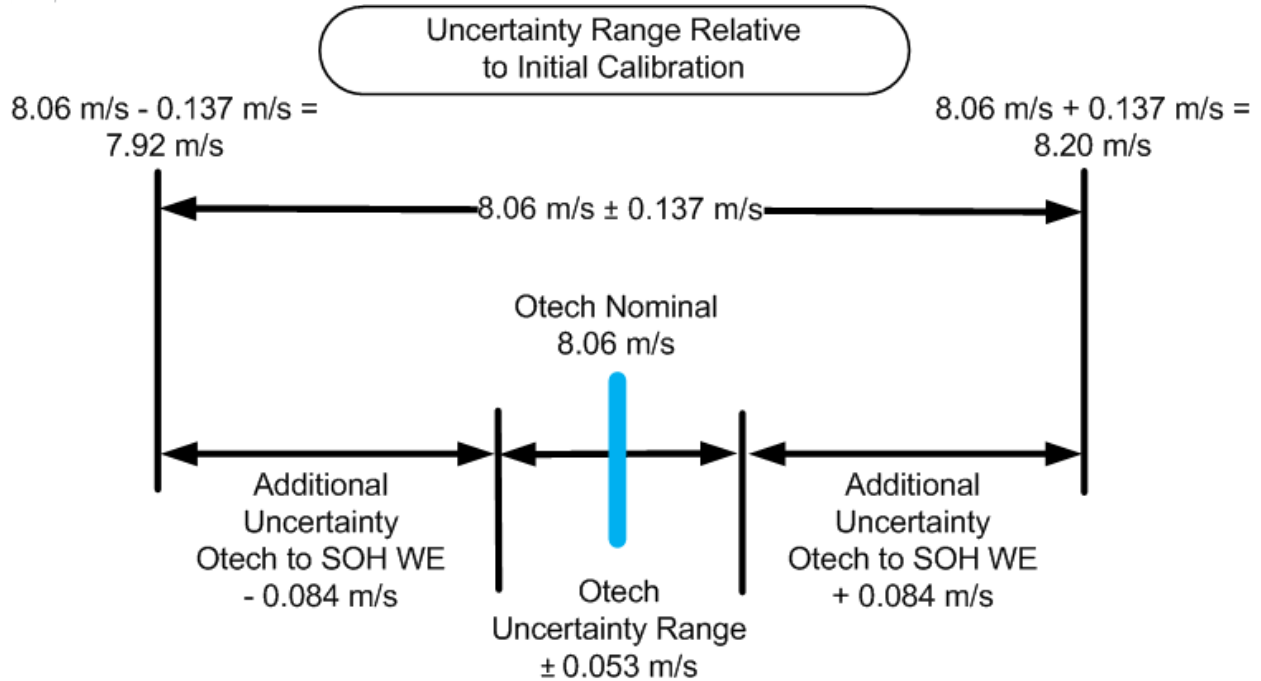


Figure 4 Graphic showing Uncertainty Range Relative to Initial Calibration for S/N 203159

The calculation of the uncertainty range relative to the initial calibration (shown in Figure 4) is derived in Table 7. The left-hand side of Table 7 includes the same SOH WE calibration data from Table 5, repeated here for clarity. The right-hand side of Table 7³ shows how the additional uncertainty (associated with calibrating an anemometer in a tunnel different than its initial calibration) is calculated and applied. As shown in Table 7, the combination of Otech’s uncertainty and the additional uncertainty is ±0.137 m/s at the nominal 8 m/s tunnel reference wind speed (corresponding to the 10 Hz response of the NRG #40C Anemometer).

³ In this example, the right-hand side of Table 7 is presented alongside SOH WE calibration data but is not part of the calibration certificate. It is presented alongside the calibration data for clarity.

Table 7 Calculation of Uncertainty Range for NRG #40C SN 203159

Succession	Velocity Pressure, q [Pa]	Temperature in Control Room		Wind Velocity, v. [m/s]	Frequency f. [Hz]	Deviation, d. [m/s]	Uncertainty uc (k=2) [m/s]
		Wind Tunnel	Control Room				
		[°C]	[°C]				
1-First	9.42	29.5	28.0	4.036	4.8668	-0.034	0.048
12	20.99	30.0	28.0	6.030	7.4729	-0.025	0.033
2	37.29	29.3	28.0	8.027	10.0383	0.018	0.026
11	57.49	30.1	28.0	9.982	12.5882	0.031	0.023
3	83.83	29.1	28.0	12.035	15.2861	0.028	0.022
10	113.86	30.2	28.0	14.053	17.9660	0.005	0.023
13-last	128.58	29.9	28.0	14.926	19.1237	-0.004	0.023
4	149.11	29.3	28.0	16.055	15.9170	0.009	0.024
9	187.45	30.3	27.9	18.038	17.8770	0.029	0.026
5	232.39	29.4	28.0	20.052	19.8790	-0.027	0.027
8	279.98	30.5	28.0	22.052	21.8540	-0.029	0.030
6	333.35	29.7	28.0	24.037	23.8270	-0.020	0.032
7	391.00	30.2	28.0	26.056	25.8240	0.018	0.034

D Additional Uncertainty Otech to SOH WE [m/s]	E Total Uncertainty uc (k=2) RSS of C & D [m/s]	F Otech Uncertainty at 10 Hz Response		G Uncertainty Range relative to Initial Calibration (E + F)	
		[%]	[m/s]	[%]	[m/s]
0.027	0.072				
0.033	0.073				
0.040	0.084	0.660	0.053	1.7	0.137
0.047	0.097				
0.055	0.113				
0.063	0.129				
0.067	0.136				
0.071	0.145				
0.080	0.161				
0.088	0.178				
0.096	0.195				
0.105	0.212				
0.113	0.226				

Additional uncertainty associated with post-calibrating an anemometer in a wind tunnel different from its initial calibration.

In our example problem, comparing the initial Otech calibration against the SOH WE post calibration for NRG #40C Anemometer S/N 203159, the SOH WE response of 8.05 m/s is well within the uncertainty range for calibration consistency⁴. As such, one would conclude the SOH WE post calibration is consistent with and statistically indistinguishable from its initial Otech calibration. If the SOH WE response was outside of the uncertainty range for calibration consistency, one would conclude the SOH WE post calibration is inconsistent with and statistically distinguishable from its initial Otech calibration.

Ultimately, however, it is up to the analyst to determine how much additional difference between initial and post calibrations are acceptable and covered by the overall uncertainty analysis for the measurement campaign.

In this example, the anemometer was not field-deployed so the difference in response reflects (predominantly) tunnel variation. Had this NRG #40C Anemometer been field-deployed, the difference in anemometer response would likely have been greater than that reported. It is typical to allow for some additional change in calibration from beginning to end of life of an anemometer. AWS Truepower analyzed calibration reports for 19 WindSensor P2546A anemometers, which had spent 155 to 1500 days in the field (Hale, 2010). The 10 Hz WindSensor responses were within $\pm 1\%$ of their initial calibration value. Therefore, it is entirely appropriate to factor in additional systematic bias due to sensor wear, the magnitude of which is left up to the analyst to determine.

VI. Conclusions

The additional systematic and random uncertainty associated with post-calibrating an NRG #40C Anemometer in a tunnel different than its initial calibration is quantified over a 4-26 m/s wind speed range. The paper defines the post-calibration process offered by Renewable NRG Systems for #40C Anemometers initially calibrated at Otech.

Calibration comparisons were performed over a wind speed range of 4-26 m/s using twenty four (24) NRG #40C Anemometers to quantify and verify the proposed SOH WE Adjustment Factor of 1.0086 (0.86%). Excellent agreement exists between test anemometers calibrated in the Otech and SOH WE wind tunnels using the proposed Adjustment Factor applied to the SOH WE calibration results and the expanded uncertainty range.

VII. Bibliography

Hale, E. e. (2010). *AN ANALYTICAL CORRECTION TO TREAT NRG #40 DATA AFFECTED BY DRY FRICTION WHIP*. Dallas, TX: AWEA WindPower Conference.

⁴ Applying this exercise to the twenty four (24) NRG #40C Anemometers, all SOH WE adjusted calibrations are within $\pm 0.5\%$ of the initial Otech calibration, well within the $\pm 1.7\%$ expanded uncertainty range.



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