To: Professor Ali Hamed
Union College Professor
From: Roderick Landreth

Date: September 26, 2018
Subject: **Wind Tunnel Flow Speed Calibration**

This document will summarize the calibration of a frequency controlled wind tunnel. The result displayed in Figure 1 is described by the equation $U(m/s) = 0.842 * f(Hz)$, converting the fan frequency into the centerline wind speed.

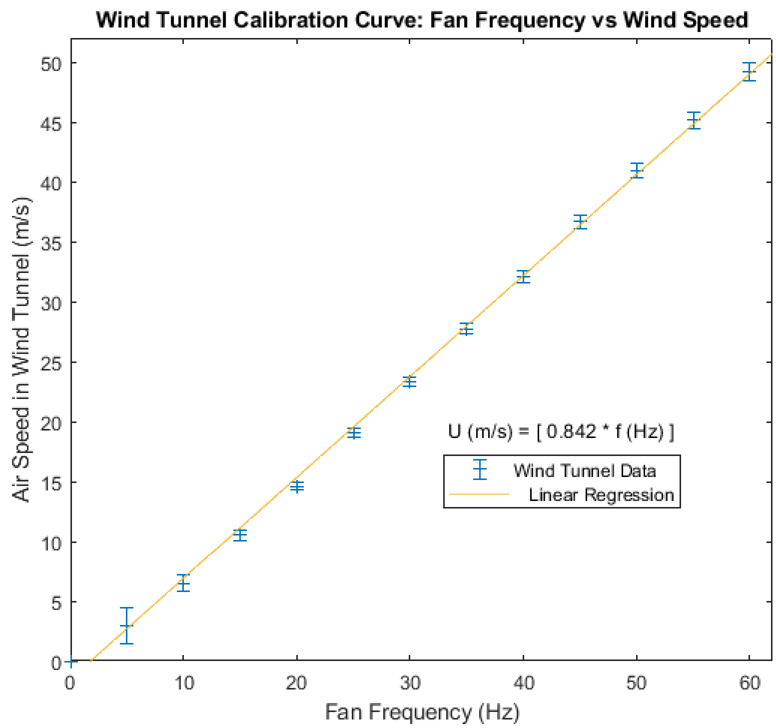

Figure 1: Final Calibration Curve including error bars, values in Table 1 attached.

Procedure Synopsis

The pressure difference measured by the Pitot tube was converted into a voltage for each tested fan frequency. The Pressure Transducer Calibration section details another calibration curve created to convert from voltage to pressure, comprising data points taken from a manometer. This equation was then applied to the voltage from each Pitot-Static tube reading, producing a pressure difference as detailed in the section Calculating Wind Speed from Pressure Chance. Using the Bernoulli equation, a speed can be calculated for each test, making possible a calibration curve directly relating fan rotation frequency to wind speed.

Calculating Wind Speed from Pressure Change

Each of 13 data sets at different frequencies, including one baseline test at 0 Hz, provided an average voltage. The calibration curve relating voltage to pressure detailed in the Pressure Transducer Calculation section allowed each average voltage to be converted to a pressure difference. Using the Bernoulli equation and neglecting temperature change, gas elevation, and initial velocity outside the fan yields the relationship:

$$U = \sqrt{\frac{2(\Delta P)}{\rho}} \tag{1}$$

The density of air calculated from the ideal gas law with temperature and pressure taken inside the room was $1.203 \pm 0.036 kg/m^3$. For each frequency tested, the pressure difference and density of static air produced a wind speed in m/s. Plotted together as seen in Figure 1, a linear calibration curve relates fan frequency to wind speed (equation 2). This relationship is linear because it encapsulates the relationships of Figures 4, 5, and 6 (Attachment B). Where Figure 4 has a quadratic relationship relating frequency to voltage, equation 1 produces a radical relationship in Figure 6. Experimental setup is detailed in Attachment A.

$$U(m/s) = 0.842 * f(Hz) \tag{2}$$

Pressure Transducer Calibration

Figure 5 in Attachment B shows the linear relationship of an equation relating voltage with pressure:

$$\Delta P('' H_2O) = (2.028 * V) + C \ \ (\pm 0.0205). \tag{3}$$

A pressure transducer measured pressure in terms of voltage 100 times for each of 18 trials. A micro-manometer experienced the same pressure to read the pressure in $'' H_2O$. Table 2 (Attachment C) shows the used data of the averaged voltages of each trial and the pressure the micro-manometer read. There were 13 successive tests in the wind tunnel; the baseline test ran without the fan turning and the rest incremented by 5Hz to 60Hz (Raw data in Attachment C). The baseline test contained a voltage for a wind speed of zero, setting the constant in the above formula. Each test measured 100 voltage readings for that fan frequency, and the average for each test was converted into a pressure difference using this regression.

Uncertainty in Air Density, Pressure Change, and Wind Speed

In Attachment C is the uncertainty analysis and the values it produced in Table 1. Due to variations of static conditions, measurement precision, and noise in voltage measurements, uncertainty averaged around 6%. Compared to identical tests completed at similar times, static conditions fluctuated throughout the day due to increasing temperature and atmospheric conditions. The other main source of error was noise in voltage measurements. Total uncertainty was greatest in the low frequency tests similar to a reciprocal or rational function, decreasing from ±50% at the first non-zero speed, to ±1.5% after a few tests.

The calibration of the wind tunnel revealed a linear relationship that can be used in future wind tunnel testing for maximum velocity within the tunnel. If assistance is needed, don't hesitate to ask.

Attachment A: Experimental Setup

The wind tunnel testing comprised 13 trials of pressure difference recorded as voltage by the Pitot-Static tube. The Pitot-Static tube (Figure 3) was held stationary in the centerline of the tunnel (Figure 2) facing the incoming air. Readings started after waiting 30 seconds for the flow within the wind tunnel to stabilize. The pressure read was produced by the air hitting the very end of the tube compared with the static reading perpendicular to the flow. Each trial recorded 100 values over 20 seconds of voltage to be averaged, reducing the effect of error.

Pressure transducer testing recorded 18 trials with the same pressure effecting a micro manometer, producing the voltage and pressure difference for each trial. Again, each test consisted of 100 values over 20 seconds to be averaged, limiting the effect of error.

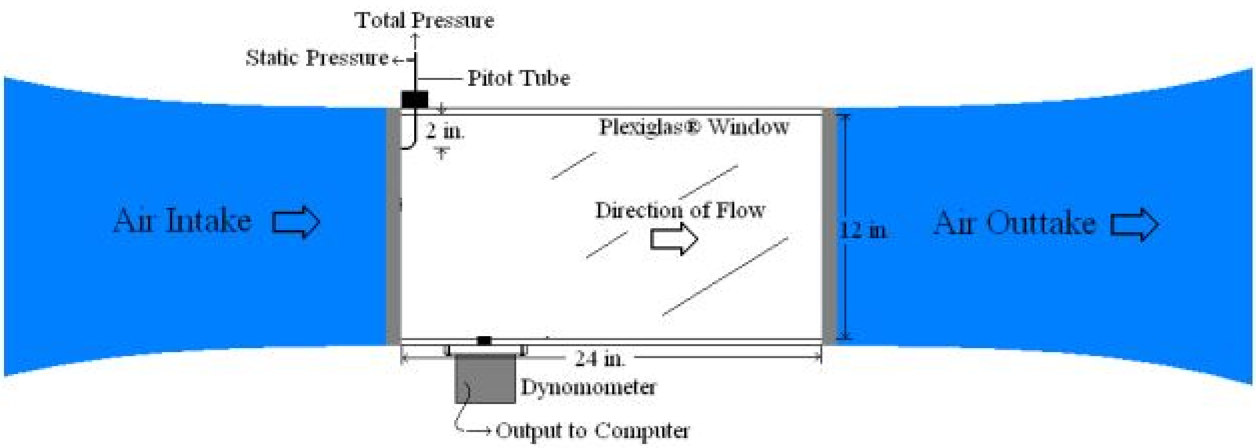

Figure 2: Wind tunnel configuration at time of testing, Pitot in centerline of "12 x "12 tunnel

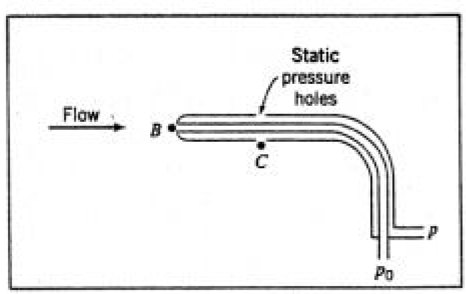

Figure 3: Pitot-Static arrangement within rind tunnel used to measure pressure differences

Attachment B: Data Plots

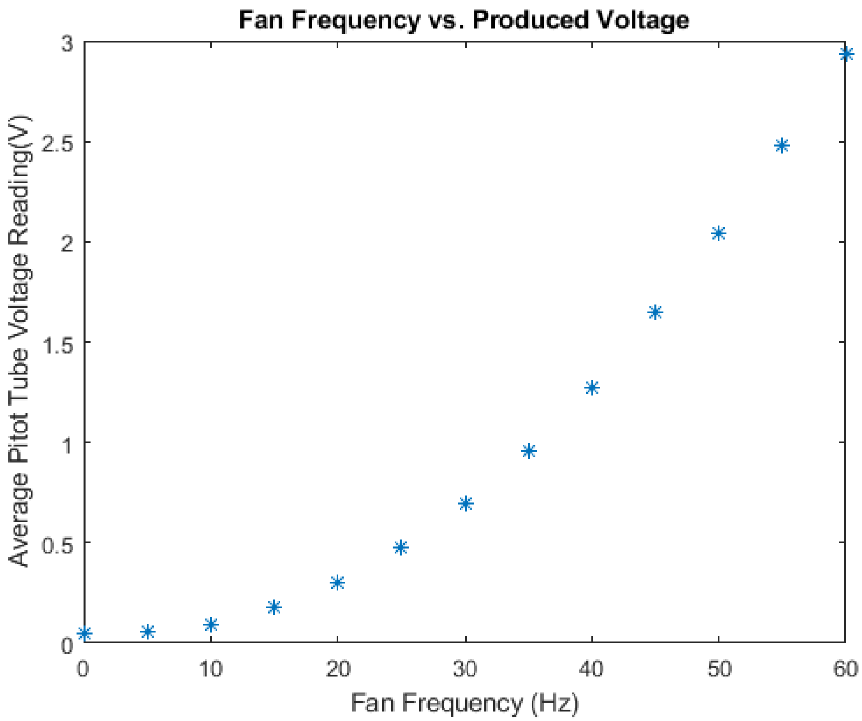

Figure 4: Voltage measurements read by Pitot tube shows a polynomial relationship with frequency.

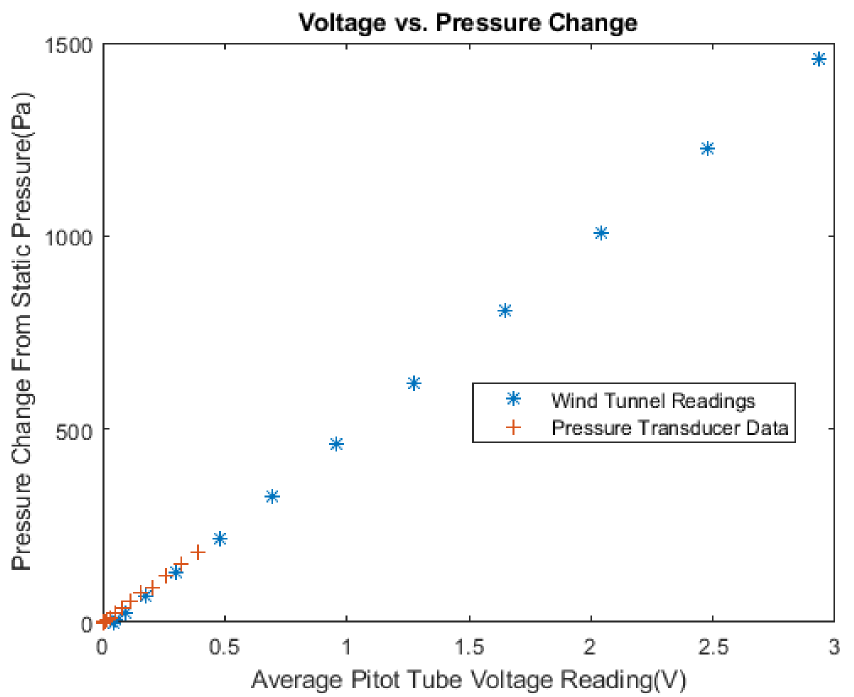

Figure 5: Red(+) data supplied by pressure transducer to make a calibration curve, used by Wind Tunnel Data(*)

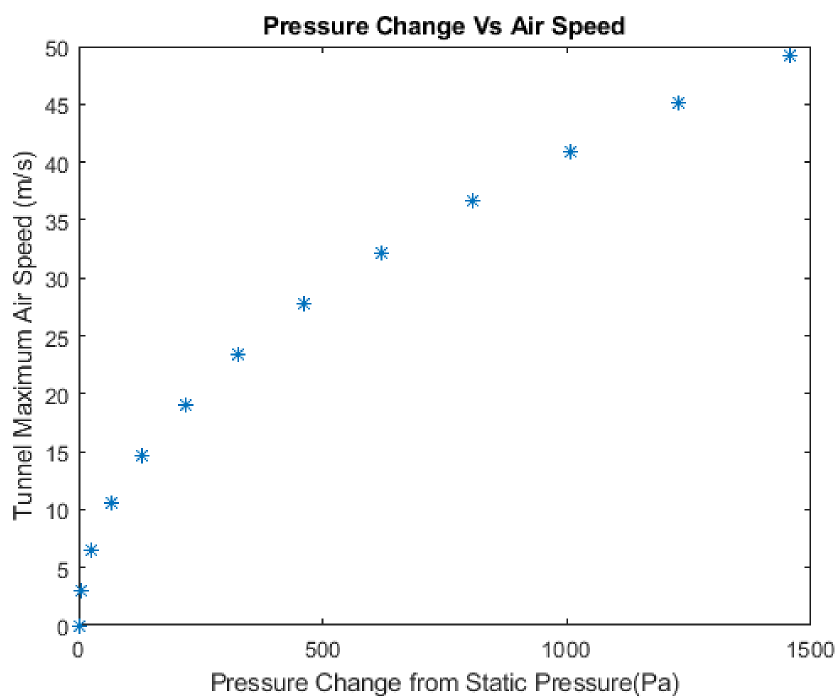

Figure 6: Bernoulli Equation produces a Radical Relationship (equation 1)

Attachment C: Raw Data and Experimental Uncertainty

Frequency (Hz)	**Average Voltage** (V)	**Pressure Change** (Pa)	**Wind Speed (m/s)**	**Wind Speed Uncertainty** (m/s)	**Percent Uncertainty**
0	0.045	0	0	0	0
5	0.055	5.198	2.940	1.45	49.3%
10	0.095	25.244	6.478	0.66	10.2%
15	0.178	66.830	10.540	0.43	4.1%
20	0.300	128.635	14.623	0.36	2.5%
25	0.478	218.297	19.050	0.36	1.9%
30	0.695	327.698	23.340	0.40	1.7%
35	0.960	461.458	27.697	0.44	1.6%
40	1.275	620.258	32.111	0.50	1.6%
45	1.647	808.034	36.651	0.56	1.5%
50	2.041	1006.726	40.909	0.62	1.5%
55	2.478	1227.572	45.174	0.69	1.5%
60	2.935	1457.739	49.227	0.74	1.5%

Table 1: Wind Tunnel Calibration Data with Uncertainty (1in $H_2O = 248.8$Pa)

E Ave, (V)	**E Stdev,** (V)	ΔP ($''H_2O$)
0.0057	0.00106	0
0.0052	0.00122	0.002
0.0081	0.00097	0.005
0.0166	0.00130	0.020
0.0297	0.00101	0.046
0.0496	0.00087	0.093
0.0773	0.00195	0.150
0.1130	0.00326	0.220
0.1537	0.00178	0.300
0.2028	0.00143	0.368
0.2575	0.00137	0.488
0.3193	0.00156	0.604
0.3877	0.00349	0.724
0.4601	0.00272	0.948
0.5456	0.00410	1.082
0.6345	0.00309	1.284
0.7279	0.00184	1.472
0.8294	0.0043	1.668

Table 2: Calibration Data for N007 Wind Tunnel Pressure Transducer

Reflection:

When I submitted this assignment, I felt I had covered everything required and would receive an A- or B+, depending on what mistakes I had made; I instead received a B-. I understand why, and looking back it makes sense to include the major pieces that I missed. Since I had never done a memo before, I followed the instructions as well as I could, and didn't ask questions because I thought there were none to ask, or didn't know what to ask. I know I'm not the best writer, and saw that last lab the majority of my problems were paying attention to detail and going by the suggested format. I thought that just being more careful would help. I realize this is a mistake, and even if I don't have questions will probably bring in future labs to ask for feedback.

I finished the data analysis the day after the lab, Wednesday. The tables and figures I competed Friday, though I forgot to add error lines on figure 1 until the day of submission. I didn't have a full draft done until Saturday because of other time consuming work. I revised this draft majorly twice. I was not confused on any aspect of the lab or memo because I had the written format in attachment F of the lab handout, asked questions in lab, and the example in class written by Prof. Hodgson to follow. Similarly, I didn't have format questions because I didn't quite know what to ask, and assumed the suggested format would be specific enough as to how much I had to convey and how to do so in this new type of report. In total I spent about 12-15 hours on this assignment. Time probably would have been saved if I had brought in the lab and asked for advice, but I was busy during the weekend and thought I knew what I was doing otherwise. I changed the introduction entirely, shortening it to two sentences. I edited a few simple mistakes on figures and equations to increase clarity. The Pressure Transducer Calibration section was heavily edited, including information on the experiment, how the data was measured, and used. More raw data was included for both the wind tunnel testing and the pressure transducer calculation, and the uncertainty analysis was included. I added more detail to the section regarding uncertainty in measurements, reorganized the attachments thoroughly.