Contemporary Problems in Appropriate Technology

Residential Wind Turbines and Noise Emissions

By

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Chapter 1: Introduction

The science of using the wind as a source of energy is not a new technology. In fact, the human race has been using the power of the wind for centuries. The first uses for wind energy were primarily for two purposes: turning a mill for grinding grain and for pumping water. The earliest known designs were vertical-axis machines used in Persia around 500-800 A.D., although there is a widespread belief that windmills were used in China as long as 2000 yeas ago (Darrell Dodge, 1996). Western Europe had embraced the technology by the late 14th. century in the form of horizontal axis machines usually set into a building. By the 19th. century American farmers were using windmills and in the early 20th. century, at the dawn of the industrial revolution, the first multiblade turbines were producing electricity.

It is the residential-scale electricity-producing wind turbine I will be focusing on in this research project. These come in two basic categories: residential and commercial wind turbines. In just the past 30 years, the technology and efficiency of both kinds have advanced very rapidly, in some cases bringing the cost of producing electricity down to 4-5 cents a kilowatt hour (NREL, 1997). For the commercial turbines to gain acceptance, it was necessary to address the issue of noise. Great strides have been made in this area through the use of gearing; this enables the blades to turn relatively slowly and still produce power cleanly and efficiently. In the case of residential turbines, however, this is not really an option due to the small generators used and the weight, cost, and size restrictions needed to be practical on a residential scale. Another factor is that the more complicated the machine, the more chance of breakdown, resulting in costly repairs. Manufacturers are working to lessen the noise emissions of small turbines through better use of materials and design, many times in the area of turbine blades. Other problems with small wind turbines can be maintenance issues, siting problems and the possible complaints from area residents, locations of the turbines and their fall zones which could result in damage to surrounding structures as well as the turbines themselves, and the noise emitted by small wind turbines. This project will focus in detail on the noise emissions of small wind turbines, through testing, statistics and experiences from manufacturers and installers in the field, and personal interviews with residents living nearby the SWI research facility.

Problem

There are some major complaints when it comes to wind turbines: site pollution, TV interference, and noise pollution(awea, small wind documents). As residential scale turbines gain popularity, the issue of noise is coming to the forefront. There are many types and sizes of residential machines, and all produce different levels and pitches of noise. The main problems become: how much noise is acceptable? How does one balance their desire for clean energy with respecting their neighbors? How much area is needed for a specific machine to negate sound as an issue for the owner as well as the surrounding homes? And, getting down to specifics, what pitches and tones are more or less detectable and irritating to the human ear? In short, which turbines are the least, and most, annoying, respectively?

Purpose

The purpose of this project is to scientifically address the problem of noise emissions related to residential scale wind turbines. This will hopefully be accomplished in three areas: research, testing, and interviews. The purpose of the research phase is familiarizing the reader as well as myself with how this problem has been addressed to this point. This will include the studies done so far, manufacturers specs and claims for their individual turbines, and experiences with these turbines from experts in the field, such as Mick Sagrillo and Paul Gipe, as well as others who work with these machines on a daily basis. To me these testimonials are a key element because these are the folks who have installed them and watched them in the field under real world conditions. The testing will be a continuation of the work started by Adam Sacora last semester using a sophisticated decibel meter. This device is also a data logger, and can be connected to a laptop to insure all noise testing is saved as it is conducted. This is probably the toughest phase due to the large amount of variables. These include wind speed, distance, and orientation to the machine in question. This entails not only east west, etc... But whether you are downwind or upwind of the turbine correlated with the wind direction and speed at that time. Another hurdle to deal with is the *type* of noise you are recording: Ambient noise (the wind itself, any naturally occurring noise in the area), background (cars, noise from homes or anything mechanical) and the actual turbine emissions. Separating these will be a challenge indeed. Finally, I will be conducting interviews with residents in the immediate area of the SWI research facility. Hopefully I will also be able to conduct some sound testing from these residences as well, depending on their cooperation and weather conditions (open window testing, etc...). I am optimistic that by making the local residents a part of the research process, they will be open to giving their opinions and concerns and/or inquiries of the wind turbines currently in use. Hopefully, all these areas will result in a well rounded research project that can be a tool for the awareness and understanding of the relationship between residential wind turbines and the noise they generate.

Chapter 2
Literature Review

Noise in General

To study the relationship between noise and small wind turbines, we must first define the difference between sound and noise, and what types of noise we will be dealing with. Webster’s dictionary defines sound in several ways, The most relevant to this study being “mechanical radiant energy that is transmitted by longitudinal pressure waves in a material medium (as air) and is the objective cause of hearing” (Webster’s, 2005). The two most relative definitions of noise are: A) “**SOUND**; *especially* **:** one that lacks agreeable musical quality or is noticeably unpleasant” and B) “any sound that is undesired or interferes with one's hearing of something” (Webster’s, 2005). That being said, noise can be very subjective. The same sounds may be pleasing to one person while come across as totally annoying to another. As one wind expert puts it “ noise is a very subjective topic with people. Sounds that are soothing to one person may make another crazy” (sagrillo, 1997). Adverse or unwanted noise can have many ill effects on humans, including deafness, annoyance, sleep fatigue, decreased work efficiency, as well as increased blood pressure and cardiovascular problems (Tripathi).

Intensity and Measurement

The intensity in sound depends on two things: power and distance from the source. The formula for sound intensity is defined as:

$$\text{Intensity} = \frac{\text{energy / time}}{\text{area}}$$

$$= \frac{\text{power}}{\text{area}}$$

(sasked.gov).

As sound waves travel through a medium (air as it pertains to small wind turbines) the intensity decreases with distance from the source of the sound wave. This is because the sound wave is spread over a larger area as it travels away from the source. This is usually called the inverse square law. This law can be applied to sound as well as gravity, light, and electric fields; figure 1 illustrates the inverse square law of sound (R. Nave).

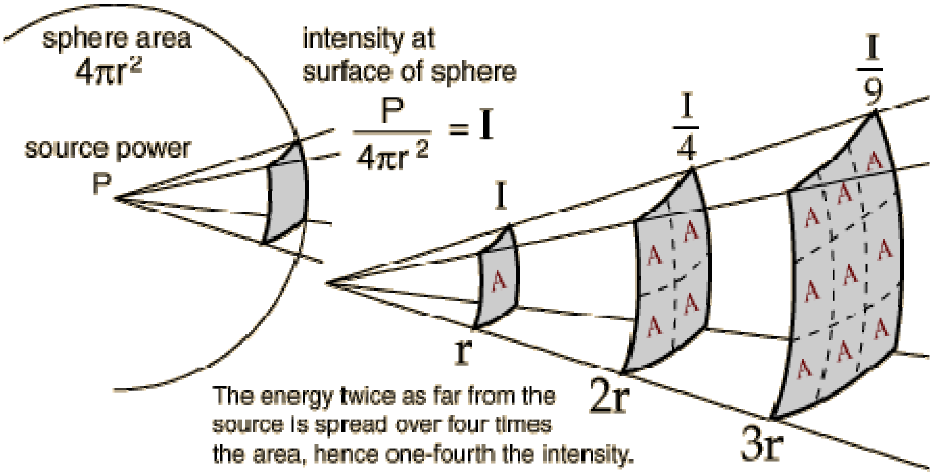
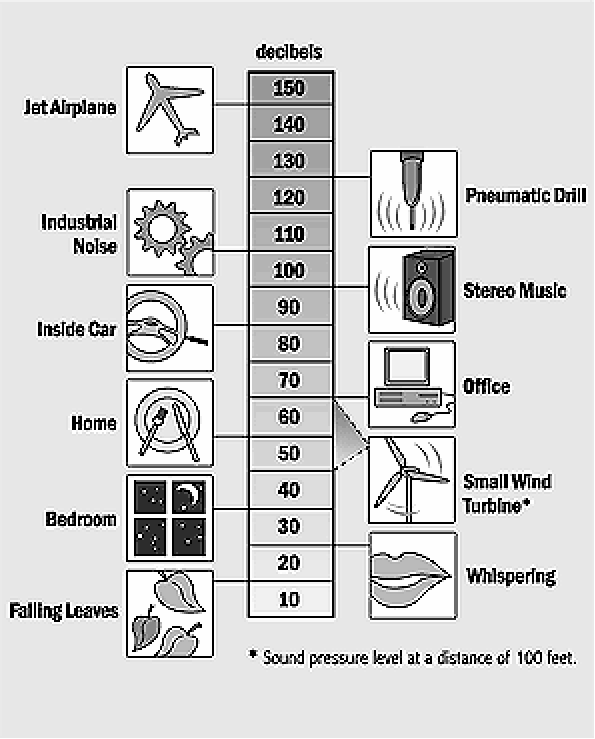


Figure 1: inverse square law of sound

Special units called bels and decibels have been developed to measure this intensity. A Decibel is actually a measurement of power, watts/square meter. The threshold of pain in the human ear is 1 watt/sq. meter, or 120 decibels, while the point at which humans can perceive sound is 1 decibel, or 0.000000000001 watt/sq. meter (Elsea, 1996). The formula for this calculation is $\text{Power difference in dB} = 10 \log \frac{\text{power A}}{\text{power B}}$. Most electronic decibel meters, however, use voltage to determine decibels using a formula to convert the voltage difference to sound pressure intensity, or dB rating. This dB formula is: $\text{Power difference in dB} = 20 \log \frac{\text{Voltage A}}{\text{Voltage B}}$ (Elsea, 1996). An example of dB ratings of some common noise pollutants, including small wind turbines, is given in figure 2 (awea).



http://www.awea.org/faq/noisefaq.html

<u>Figure 2 decibel measurements of noise pollution</u>

Types of noise associated with small wind turbines

When testing for noise levels in small wind turbines, one must realize the different types of noise. These are ambient, or background noise, mechanical noise, and aerodynamic noise.

Background noise consists of any and all noises in area not associated with a residential wind turbine. Some examples are the wind itself and the interaction with leaves or buildings, traffic noises, animals, and any other mechanical or insect noises in the area. In one example, background noise levels where measured at a high school in Hull, Massachusetts. The background noise had a range of 42-48 dB with a wind speed variation from 5-9 mph (RERL, 2002).In my testing, I have found background noises at the SWI research facility to be in this range as well with very few exceptions.

Mechanical noise is the noise caused by the motor and in the case of commercial turbines the gearbox and nacelles as well. Residential turbines do not use a gearbox and therefore have less moving parts than their commercial counterparts (Jim Green, 2004). Typically the only moving mechanical parts are the generator, the yaw motion, which sets the turbine into the wind, and the furling mechanism. The result of this is twofold: the lack of a gearbox means less mechanical noise. However, this makes residential turbines variable speed devices, resulting in higher blade speeds and more aerodynamic noise (Sagrillo, 1997).

Aerodynamic noise is the noise caused by the flow of air around the wind turbine blades (RERL, 2002). This is shown in figure 3 (RERL, 2002).

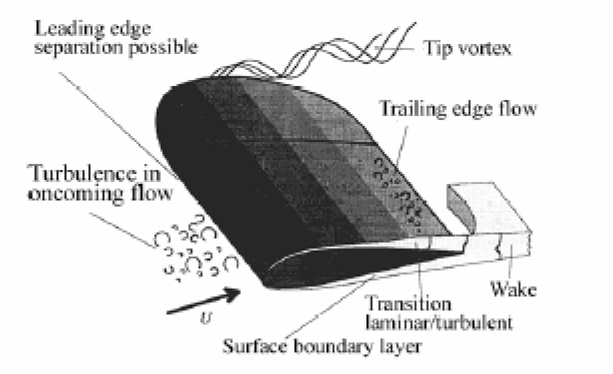


Figure 3: Aerodynamic wind noise

As stated before, because of the lack of a gearbox resulting in higher rotational blade speeds, the main source of noise in small wind turbines comes from aerodynamic noise(Sagrillo, 1997). Another reason for the additional noise levels from small wind turbines, as noted by the American Wind Energy Association, is that much more research money, from both government and private industry, has been spent to reduce noise from large scale wind turbines than on residential scale turbines (AWEA, 2001). As wind speeds increase, the frequency of the noise from smaller wind turbines also changes as blade speed increases. Thus aerodynamic wind noise can be distinguishable from ambient noise even though they are not louder (sagrillo, 1997). Additionally, when smaller wind turbines are in the process of furling or unfurling, sound levels can momentarily spike dramatically. This is especially true of the Air-x model, which uses blade flutter as over-speed protection. I have encountered this phenomena in my testing on both the bergey excel-1 and the Southwest air-x turbine. Although I was unsuccessful in finding a reference to this in the case of the Bergey Excel-1, tests conducted by National Renewable Energy Laboratory on a Southwest Air-403 , a similar model to the Air-x, show significantly increased noise levels due to ‘blade flutter’, as shown in figure 4 (NREL, 2003).

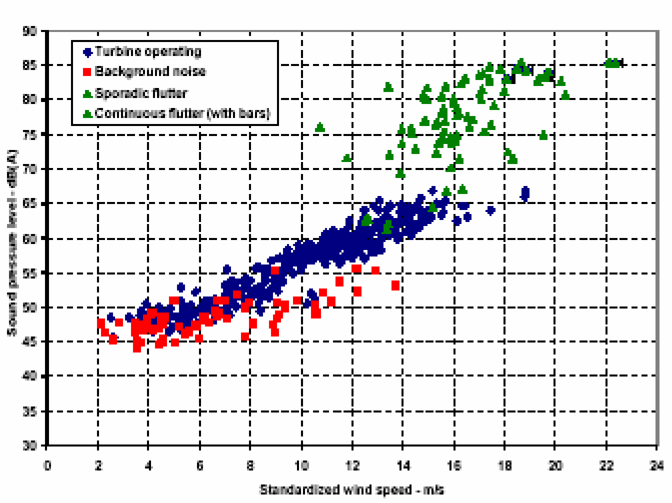


Figure 4: Air-403 sound testing

I will be going into this aspect of the small wind turbines in more detail in my data analysis.

Testing standards and noise regulations

The nationally recognized standard for the testing of the relationship between wind turbines and acoustics was set by the International Electrotechnical Commission in 1984. The most recent version was published in 1994 (IEC, 1994). The technical name for this document is IEC 61400-11. It is a very detailed document on every aspect of standards and procedures for acoustical testing. The AWEA set its own standard for testing, but this has recently been absorbed by the IEC to avoid confusion (AWEA, 2002). Adam Sacora and I are following the IEC standard as closely as we can; however budget restraints make it impossible to adhere to all the equipment standards.

In recent years, noise regulation standards are being set both internationally and nationally focused directly on wind turbine noise. This is a trend that will hopefully continue and legitimate noise testing will be a valuable asset to this trend. Internationally, many European countries have discussed adopting or have adopted noise guidelines. The following guidelines are from a summary of an International Energy Agency (IEA) expert meeting on noise emission. France's regulation calls for a maximum of 5 dB above background noise during the day, 3 dB at night. Holland has directly linked their regulation to background noise and wind speed; the limit is to start at 40 dB at night at 1 m/s wind speed (2.2 mph) and increase to 50 dB at 12 m/s (26.8 mph). Greece has an indoor limit of 45 dB for nearby dwellings with open windows and an outdoor residential limit of 50 dB(Johansson, 2000).

Domestically, regulations are popping up on several levels, from state wide to county and individual cities. California recently proposed noise regulations for wind turbines in residential areas (AWEA). AWEA also provides a model zoning ordinance for residential turbines which states, in part: " For wind speeds in the range of 0-25 mph, small wind turbines shall not cause a sound pressure level in excess of 60 dB, or in excess of 5dB above the background noise, whichever is greater, as measured at the nearest neighboring inhabited dwelling" (AWEA). In Oregon, a noise regulation is in place that requires a maximum nighttime noise level of 50 dB. In addition wind facilities (in this case large scale turbines) must not increase ambient, or background, noise by more than 10 dB in any one hour(oregon.gov). Saratoga, Ca has ordinance 209, which pertains to small wind energy systems. Section 15-52.080, part d states: " Except during short-term events including utility outages and severe wind storms, a small wind energy system shall be designed, installed, and operated so that noise generated by the system shall not exceed the 60 dB as measured at the closest inhabited dwelling" (Saratoga city council, 2002).

The adoption of noise regulations, to me seems to go hand in hand with the need for more standardized noise testing of residential wind turbines. With sufficient research, manufacturers as well as installers will be able to give reasonable and truthful parameters for siting and installing wind turbines of various sizes in various areas. In a 4 acre are, for instance, one would be able to eliminate trouble areas for a specific turbine in relation to neighbors as well in relation to the owners dwelling. This would clarify what size turbine a resident could install and still not create an unnecessary noise disturbance.

Chapter 3
Methodology

Goals

For my research project I have a set of goals I feel are realistically obtainable by the end of the semester. Testing is of course the primary goal. Because of time constraints I have decided to focus on 3-4 of the 6 turbines for the time being. These are: the bergey xl-1, the AWP 3.6, the Southwest AirX, and the Southwest Whisper 175. Each turbine will be tested from at least two specific distances and three wind orientations (upwind, downwind, and perpendicular to the wind direction) (IEC, p.13). The formula to determine these distances is explained in detail in this chapter. New developments in the last week have not only clarified the testing procedure, but have also made it very easy to fluidly continue research and testing on the remaining machines in the future. I will describe these further in the testing procedures section.

The secondary goal which I hope to accomplish is interviews with residents in the immediate vicinity of the research facility. I feel this can be an integral part of our understanding of how the sound levels and type of sound emitted by residential wind turbines are received, and perceived, by the general population. Having said that, I will make sound testing a priority for the duration of this project. I hope to continue working on this after May, so if I do not conduct the interviews before then, I will not consider this project a failure. Luckily Adam Sacora and Brian Raichle have been and will continue to be a great asset in the area of testing. Their help with integrating the Campbell data logger with the Extech decibel meter has accelerated and improved the testing time significantly.

Testing Standards

In testing the relationship between residential wind turbines and sound, I will conform to the standards laid out by the IEC as closely as possible. This is an internationally accepted standard for acoustic testing. Part 11 of the IEC standards, titled "Acoustic noise measurements techniques" is the most relevant part of the document where testing at the SWI facility is concerned. After weighing some options for standard distance, I decided to adhere with the formula outlined in the IEC standards (fig. 4). I will detail the actual procedures in this paper after describing the equipment and materials to be used.

Materials

There are quite a few materials needed to conduct testing in a professional and consistent manner. The most important of these is a sound meter. I will be using an Extech 407764 type II sound meter. This model was purchased in the fall of 2004 by the ASU technology department at a cost of about $599.00, before taxes. This sound meter is adequate, although a type I meter is preferred by the IEC standards. Unfortunately a type I meter ranges in cost from 2500-3000 dollars, which is not a realistic cost for this research project. This meter also comes with software for downloading and analyzing data on a PC or laptop computer. It has range options of 30-130db, as well as the ability to record sound captured in 1-second increments, and the option to feed directly into a computer. A modification to this dB meter is suggested by the IEC and was performed. This was a secondary windscreen placed around the stock windscreen on the microphone; specifically a second piece of open-cell foam similar to the one already covering the microphone and is basically to beef up the immunity to wind disturbances from the immediate area around the microphone (IEC, p.11).

Each wind turbine to be studied has 2 anemometers on their towers. For the scope of this study will be testing from only the top anemometer on each turbine to be tested. This will be done, at least initially, with a Campbell 21X Scientific data logger. Campbell Scientific makes the data loggers that will be used for the anemometers on a permanent basis at the SWI wind site. The 21X is a portable datalogger and will be connected directly to a laptop as data is being logged, with the Extech dB meter, model #407764, connected to the portable datalogger. A wind vane, which uses the same data logger as the anemometer being monitored, will also be checked periodically to maintain consistent downwind/upwind positions.

A soundboard is the third direct piece of equipment needed. This is a 1 meter round section of plywood placed under the Extech sound meter, and is also required by IEC standards (IEC, p. 11). Thickness is ¾”. The purpose of this is to eliminate interference in the direct vicinity of the microphone and windscreen. If simply placed on the ground the small amount of noise from the wind blowing through the grass would dominate the decibel readings due to its proximity to the microphone(fig.3).

Fig. 5 soundboard (IEC, p.27).

Testing procedures

As I said, the testing will conform as closely as possible to IEC standards, with the main difference being the sound meter. Some initial testing has been performed on the Bergey wind turbine as well as the Southwest Whisper 175. These were conducted with Adam Sacora and Dr. Dennis Scanlin, respectively. In each case the process went as follows. An NRG data logger was connected to the upper anemometer, to be monitored by one individual inside. This person (to be called T1) would constantly monitor the data logger as well as record the data collected on a graph. For the Bergey the tower distance was 100ft. so this was the ground distance away from the turbine where the sound meter was placed. A second person would be monitoring the sound meter (T2). The first tests were downwind testing. I will explain the procedure for consistent distances with towers of different heights momentarily. Using 2 way radios, T2 would give a decibel reading every10 seconds to T1. T1 would correlate that number on a chart with Y being decibels and X being wind speed and make a mark in the appropriate place. Since both readings are constantly fluctuating, if T1 is unsure at all of accuracy, that reading shall be disregarded. For the same reason it is crucial that a substantial amount of readings are recorded so a pattern may be established and accuracy can be analyzed easily. In our first tests, the chart resembled a scatterplot and significant grouping of decibels/wind speeds was evident. It was also easy to spot suspicious anomalies in the readings, such as a very high wind speed and an unusually low sound reading. Provided enough data is collected, I believe the margin of error is acceptable and anomalies can be easily spotted.

Although the aforementioned process has been tried and would be adequate, I have been able to implement a much better system for testing, with Adam and Dr. Raichles' help. Dr. Raichle has modified the programming in a Campbell scientific 21X data logger to record at 1 second intervals, the same interval as the Extech decibel meter. The Extech is plugged into one port on the Campbell, the appropriate anemometer into a second port. In this new system the Campbell logger is connected to a laptop which is powered through a small inverter plugged into a vehicles dc power. The vehicle is parked at the base of the tower being tested to cut down on long runs of wire being used. The wind speeds and noise levels are recorded as pulses, which are converted into wind speed and DB's respectively by an adjustment factor entered in the software. Our first test run was better than we expected, with readouts for DB's and wind speeds synchronized completely. This detail is validated by pulling up the laptops clock and date window while the datalogger's window is recording, insuring the sound and wind measurements are timed accurately. By splicing into each anemometer with a permanent secondary jack, we can wire the sound meter and anemometer into the data logger at the correct distance and eliminate human error and manual recording lag. It is crucial that the data logger's clock be synched up with a computer clock prior to testing. This assures the data from all sources can be verified and compared. The one drawback to the Campbell data logger is a malfunctioning battery box; unfortunately a new battery would get drained and be useless as well since the problem lies in the recharging function of the Campbell logger. An external power source (a vehicle is most practical) must be wired to the logger from time synch until testing is complete. The best part about this is that Campbell is the permanent data logger for all the data devices at the site, so the software is integrated for all data received, whether outside or from the electronics center inside.

The issue of a standard distance from hub height to sound meter came up during the 175 tests. If one stood at a distance from the tower equal to its height, the distance from sound meter to hub would be different for each turbine, resulting in flawed testing and making comparisons between turbines and the noise they emit unreliable. To resolve this Dr. Scanlin used the Pythagorean Theorem as a way to calculate a standard for distances from each turbine ($a^2+b^2=c^2$). The initial distance from the bergey was 100 ft as well as tower height so $100^2$2 +$200^2$2=20,000. Taking the square root of that=141.42, the height from the tower hub to the sound meter. This became the standard distance we would use. This is very crucial to the legitimacy of this type of testing because without a standard distance, the data recorded is irrevocably flawed. For the 175, which had a tower height of 60 ft. the appropriate distance was found to be 122.88 ft from the tower base.

At Dr. Scanlins suggestion, I checked the IEC standards and found they have a formula that achieves the same standardized distance measuring (fig. 5). This formula is R0= h + d/2. R0 is the required distance from the turbine base to the dB meter, H is the height of the turbine, while d designates the rotor diameter. This insures a consistent relative distance from hub height to the source of sound measurement, or R1 (IEC, p. 29). While both methods resulted in a constant distance for testing, I think it is best to adhere to IEC standards whenever possible.

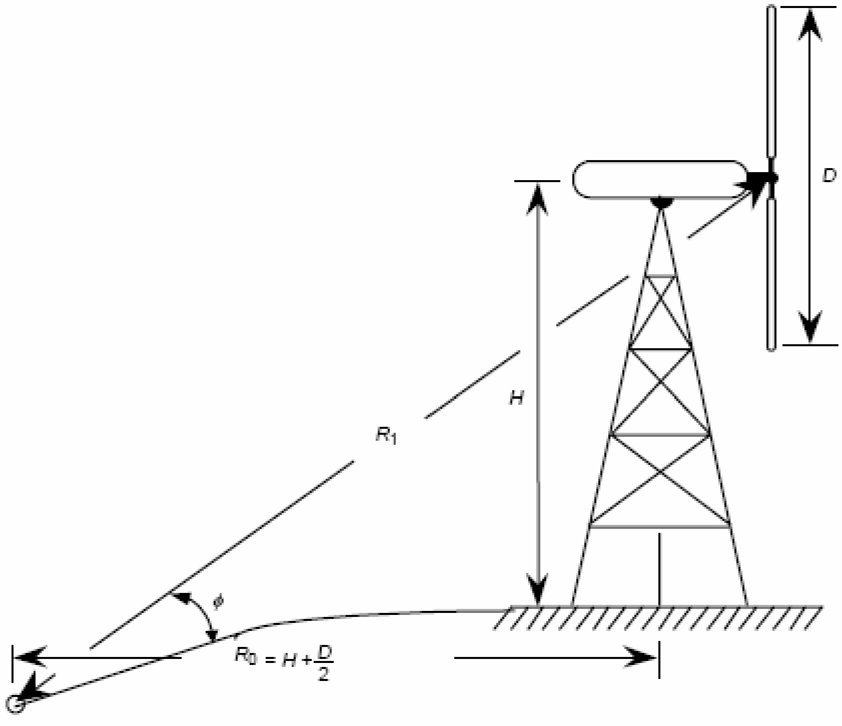


Figure 4a – Horizontal axis turbine

Another element not to be missed is the need for sound testing with no turbines in use. These tests would be conducted at the same locations at various wind speeds to determine the level of ambient and naturally occurring background noise at the site. In an informal test, I found the ambient noise levels to be only 10-20 decibels less than the noise level with 1 turbine running at 25-30 mph. This will be an integral part of the research, because it has been documented that the pitch, and not just volume, is one way the human ear differentiates sounds. Simply put, a turbine may be at the same sound level as the wind rustling through trees, but the pitch is different, allowing someone to notice it easily. The IEC has very detailed guidelines for measuring techniques involving pitch and frequency testing, such as high band and low band noise, but in the interest of time and money I believe this was more involved than we would be able to do any still see results in a timely fashion.

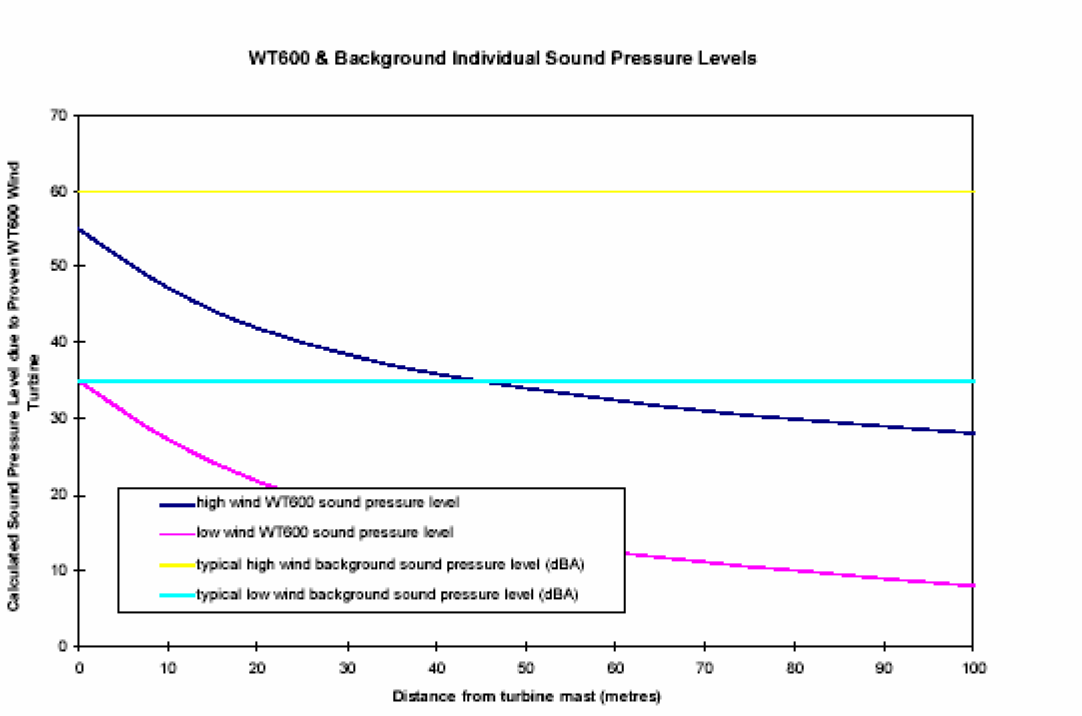
After the data is collected It can be analyzed and graphed on a turbine-by-turbine basis, as well as a comparative analysis. This comparative analysis will be a great tool for comparing and contrasting different machines and the possible annoyance factor of owning or living near one. It will be much easier to determine how much land is recommended for a specific turbine as well as a good distance to install these machines from dwellings or other public places. In an effort to be as thorough as possible, I will include all pertinent data on each turbine including: brand and model with a detailed description of turbine type, rotor diameter, power curve, and any other relevant details.

There are many other variables that can and do come into play in testing such as this. Some examples are air density, temperature, and the pitch of wind turbine noise vs. ambient or background noise, etc. These variables should be explored; however in the interest of time my focus for this semester will be to collect as much reliable data as possible and to record and organize that data in a professional and organized manner so it can be a useful tool for not just the facility at ASU but the entire wind community, both business and residential. The more truthful and accurate information we can provide on the issues associated with residential scale wind turbines and the sound levels they generate, the more acceptance this technology will enjoy.

Wind & Sound

WIND & SOUND: Portable Weather Station, Decibel Meter

Site #	Wind Direction (° from N)	Wind Speed (mph)	Decibel (dB)
01	134	7-10	48-62
02	140-260	1-6	46-50
03	270	0-2	40-42
04	140	5-12	58-68
05	200	3-5	42-50
06	no wind	0	47-48
07	no wind	0	52



Chapter 4
Data Analysis

Data collected

If I could state in one word how much data to collect it would be: MORE. The more data you have the more accurately you can analyze and understand this data and the trends it represents. Unfortunately, the time spent on how to better collect data was significant through trial and error and working the bugs out of the Campbell datalogger. As a result we did not collect as much data as we would have liked; having said that, I think we are heading in the right direction and can definitely see some patterns emerging. I have also learned the hard way that the correlation between background and turbine data can be a problem, specifically in the case of the AWP data. I will go into more detail on this in the following section on that turbine. For each of the turbines, background data was collected with all turbines shut down from a distance and heading (downwind upwind or perpendicular) determined by the IEC standards. Following testing was conducted with only the turbine being tested turned on at the same location. The distances were basically called tower height and 2X tower height, although technically half of the turbine's rotor diameter was added to the tower height, per IEC standards (IEC, p. 11). Unfortunately testing on all six locations was not completed on the four turbines we concentrated on, and in the case of the Whisper 175, some data was deemed useless.

One other thing to mention: the Campbell scientific automatically puts the wind speeds into bins. These are in increments of 1.71 MPH. This definitely does not affect the data's validity, only it's precision. It should be possible in the future to adjust the

Campbell’s programming to a more precise measurement level, as the time interval of data recording was adjusted to 1 second increments. By using a D average formula in Microsoft excel, every datapoint collected at each wind bin is averaged. This reiterates the need for as much data as possible, because this will result in much more accurate dB averages at every wind speed. At this point we have *some* downwind, upwind and perpendicular data from all 4 turbines, at both the original tower height distances as well as twice the distances. However, I was unable to analyze all the data in time for this report. For this reason I narrowed the scope of the data analysis, using the methods I described earlier, to downwind locations only. Wherever possible I analyzed both tower height and 2X tower height data.

Whisper 175

The Whisper 175 is a 3.0 Kw upwind turbine. This is the only 2-bladed machine at the SWI testing facility. It has a 15 ft. rotor diameter. This was probably the biggest setback in the data collection process. A great deal of data was collected from almost both the initial distance and twice the distance at all locations. However when we looked at the data, we were getting 2 ranges of dB’s at virtually every wind speed. For example, at 25 mph there were significant dB readings ranging from 40-50 dB, with a second set of data ranges in the 65-80 dB range. When graphed in a scatterplot, this resulted in a ‘forked tongue’ appearance. Only when a short was discovered did we realize that the 175 was partially unloaded during virtually ever test session. Specifically, a wire had been rubbing against the turbine housing and had worn the insulation on one of the voltage wires down. This resulted in the turbine unloading whenever this wire touched the housing. Once that happened, the turbine would freewheel, resulting in much higher blade speeds and subsequently much higher noise levels.

We did manage to obtain some data once the turbine was repaired, although the wind speeds are in a lower range than the previous tests, from 4-23 MPH. At both the initial tower height and twice the tower height, the increased noise is both the most consistent and the largest of all the turbines tested. Once data is collected at higher wind speeds, we can determine if the background noise will eventually close the dB gap, as it appears to on both the Bergey XL-1 and the Air-X.. Also of note is the effect doubling the distance has on total noise(see graphs below). I should explain that the yellow ‘turbine’ line on the legend represents the difference, or additional, noise level of the test turbine over the background noise. In the interest of continuity in this section, all data sheets and accompanying graphs can be found in the appendix, in the order of the turbines presented here. Although much more data is needed, the 175 has so far proven have the biggest disparity between background and turbine noise at low to medium wind speeds. However, even at 20-23 MPH, the total noise level rarely climbed above 60 dB, which is rapidly being accepted as a noise regulation standard for small wind.

Bergey XL-1

The Bergey XL-1 is a 1 Kw upwind machine with a rotor diameter of 8.2 ft. The bergey data represents the broadest range of wind speeds collected, from 2-40 MPH. The disparity between background and turbine noise is very steady from startup speed, around 8 MPH, until right at 40 MPH when the gap narrows slightly. The additional turbine noise ranged from around 6.8 dB above ambient to 7.9 above, at a distance of 104’. Total noise exceeded 60 dB at 33 MPH. At more realistic windspeeds, for instance 16 MPH, total noise levels averaged just less than 49 dB. Although I don’t have the finished data for the longer distance, the raw data suggests a good drop in total noise when you move to the second distance of 216 ft.

African Windpower-AWP 3.6

The AWP 3.6 is also an upwind turbine at the SWI facility, and generally considered to be the quietest. When analyzing this data, we learned the hard way the value of following background testing with turbine testing immediately, as opposed to using background levels recorded on a different day, Normally this would not be of great concern, but the initial readings were showing that the noise levels where significantly less with the turbine on than with it off. As you will see in the Air-x data, it is possible at very high wind speeds for ambient noise to actually drown out the wind turbine, but not at the entire range of wind speeds, as the AWP data suggests. Adam Sacora conducted the background tests in question, and it had been snowing that day. After much consideration, it was determined that the physical contact of the snow hitting the microphone artificially increased the ambient noise levels. The data conducted with the turbine on is still valid; the differential between background noise and total noise cannot be used, as even the quietest wind turbines cannot *bring down* the noise levels when running. As I said, the total noise figures (turbine with background) are valid, since that is one set of data recording, while the background noise was a different set of data taken on a different occasion. And even at 31.5 MPH and at a 106 ft distance, the decibel level barely exceeded 54 dB. At 16 MPH, the dB levels were barely above 45 dB; other background tests from different locations brought us levels anywhere from 35-45 dB. In short the data affirms what people visiting and working at the site have noticed; this is a very quiet machine. The longer background distance was conducted on the same snowy day, and the exaggeration in ambient noise is even worse. However the total noise for the AWP taken from both distances was taken on the same clear day. The drop in noise level when moving twice as far away is the least of all turbines tested. My personal theory is that this is because this is an upwind machine, causing a different dynamic for noise traveling from the wind turbine. I would be very interested in examining this possibility in more detail.

Air-X

The Air-X is a 400 watt downwind turbine which sits on the shortest tower at the facility at 42 ft. This is the most complete data we have from the downwind position, at both the tower height and double the height. One thing a person notices when in the presence of the Air- x while running is the higher pitch; this is because the blade speed on this machine is so much higher than the other turbines in use. This high pitch makes it easier for the human ear to differentiate the sound of the turbine from background noise. Another important point is these tests were done from distances relative to tower height, resulting in data collection from only 44 ft. and 88 ft. away. Even with that, the noise levels only exceeded 60 dB at a wind speed greater than 26 MPH from 44 ft. and 28 MPH from 88 ft. This is very encouraging and I look forward to testing from 200 ft. or more away to see what the levels are. Also, at higher wind speeds the gap between background and turbine noise closes considerably, and over 40 MPH the background noise exceeded the turbine noise. One thing to note is the giant spike in dB at 41.84 MPH from the 44 ft. distance. Once in a great while, and always at very high wind speeds, wind turbulence causes the Air-x to do a sort of backwards 360 momentarily. This is accompanied by a very loud high pitched ‘bark’ of sorts. The dB reading of 97.70 is actually the only reading at the wind speed 41.84. So that is actually a 1 second phenomenon and not an average; however, I felt it was necessary to leave it in because of the uniqueness of its occurrence and the fact that it does not skew any other averages.

Lastly, I did a comparison of the noise level above background with the 175, the Bergey, and the Air-x. I left out the AWP because of the flawed background data. According to this analysis, at 12 MPH the 175 is by far the loudest machine, which is consistent with the opinion of most everyone I have talked to. The Air-x and the Bergey are almost the same, yet after 13-14 MPH the difference in noise with the Air-x starts to quiet down considerably, while the Bergey maintains a fairly consistent noise differential. From what I have gathered so far, I believe a 60 dB regulation would allow these turbines to be installed on plots of land of at least an acre with no problems or complaints, as long as the distance from neighboring houses was at least 100ft.

Chapter 5
Conclusions and recommendations

In analyzing the data that Adam Sacora and I were able to collect, it is obvious that noise can be a very big issue with residential scale wind. The good news is that from the testing we were able to complete, it appears noise from these turbines dissipates rapidly as the distance from the turbine is increased. As contentious as this issue can be, common sense seems to win out: obviously there are space limits associated with these machines. Installed in too small an area, they can be a source of annoyance and aggravation to the owner as well as the surrounding neighbors. But that doesn’t mean you need 5 acres of land before you can start using this valuable resource while still keeping noise at acceptable levels. A hypothetical regulation I see would be a 60 dB max. at the nearest property line, coupled with a minimum distance of 100 ft. from the property line, more if the fall zone exceeds that. Further testing is obviously needed, but from the tests we have performed so far, every turbine at the SWI facility would be in compliance with such a regulation.

My main recommendation is more testing. It was a disappointment that we were not able to do more testing, yet the time spent on perfecting the testing methods and equipment was completely necessary to validate this study. It is ongoing, and I hope to test from all locations and distances mentioned. In addition I would like to determine the distance at which each turbine falls under 60 dB at speeds up to 40 MPH. This would go a long way in establishing a set of standards for minimum area needed for specific turbines. Also, it is crucial that background and turbine testing on a specific machine are performed consecutively on the same day. This will ensure that the background levels of noise are consistent with no discernible difference in variables such as humidity, pressure, and weather conditions in general. This has been a great learning experience, and some things can only be learned through trial and error, as has been the case several times this semester.

I have talked to several area residents about interviews and am scheduled to meet with one of them on or around may 10, 2005. It is my hope that I can eventually interview at least 5 area residents and do some interior sound testing as well. In closing, I think this project has taught me a great deal about data collection and analysis as well as the state of residential wind today, and I hope our results can help pave the way for a realistic and universal standard on the issue of wind turbines and noise.

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