MONTANA STATE UNIVERSITY
WIND APPLICATION CENTER

Wind Tunnel Construction

KidWind Competition Test Tunnel

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Introduction

In an effort to provide a means of promoting Wind Energy Education in Montana schools, the Wind Application Center (based at Montana State University) has undertaken to create a performance test tunnel to be made available for a competition called the KidWind Challenge. This competition began when a sixth grade teacher from California, Michael Arquin, decided to create his own wind energy curriculum and has since expanded into a national competition for 6th through 12th grade students. The KidWind Challenge is a design/build competition with a primary focus on learning. Kids may be drawn in by the element of competition, but essentially we at the Wind Application Center hope for it to be used as a tool to establish an interest in wind energy applications.

The Tunnel Design Problem

Most wind tunnels are designed for a very precise purpose, be it aerodynamics studies of automobiles or supersonic applications in aerospace. In the design of the KidWind tunnel, there were some very practical limitations and design parameters. The first of these was to accurately mimic the wind speed conditions an actual wind turbine in the field would experience. A second, and very important aspect, was user-friendliness. In order to use the device for learning, it had to be sturdy and easy enough to use for a number of conditions and allow maximum hands-on experience for kids participating in the competitions. Third, we decided to design the tunnel to be collapsible and capable of being easily transported in a pick-up or trailer. Due to the rural nature of many Montana schools, the possibility of transporting the KidWind test tunnel to regional competitions around the state is very real. Compact storage was also an impetus for this design parameter. All sections of the tunnel should be detachable in at least a 5' x 3' section that is fairly lightweight. Ideally one person could set-up or break-down the tunnel if needed.

Building the Tunnel

In order to incorporate all the design specifications above, WAC interns spent some time brainstorming and researching sub-sonic wind tunnel applications. A preliminary fluid flow analysis was done both by hand and by using a SolidWorks fluid flow application- SolidWorks Flow Simulation 2010. A basic 3-D model was built in SolidWorks and tested in order to better understand the losses which would potentially be experienced in a tunnel of this size and geometry. This was essential because the fans which would provide the "wind" in the tunnel had to provide enough flow to achieve between 5 and 15 meters per second (10 to 30 miles per hour) wind velocity. These numbers were set as minimum and maximum flow parameters because they mimic actual flow conditions in which wind turbines generate power.

At the invitation of Dr. Doug Cairns, MSU professor of aerospace design and materials, WAC interns toured a facility which manufactures atmospheric sensor equipment in order to learn about the built-on-site wind tunnel they use for testing their equipment. This facility incorporated inexpensive materials available locally to construct a low-cost, high-performance tunnel. With this experience to build on, our design was finalized with the exception of choosing a fan.

After the initial brainstorming phase, it was determined that fans which would provide enough flow was of utmost importance. Four 24 inch industrial blower fans rated at 8,575 cubic feet per minute[1] (maximum) would potentially provide this flow even with losses. After these fans were purchased, design was altered to incorporate a large fan bank. This meant that there would have to be a contraction section leading into the actual test section of the tunnel. With the idea of minimizing losses, the effects of Venturi flow in a pipe (our tunnel) were modeled. The Venturi effect is basically what happens when flow is constricted. As the cross-sectional area of the pipe decreases, the velocity of the flow increases and pressure in the flow decreases. The equation for continuity of flow we used in our "back of the envelope" calculation is:

$Q = (VA)_1 = (VA)_2$

V = flow velocity, A = cross sectional area, and Q = volumetric flow rate
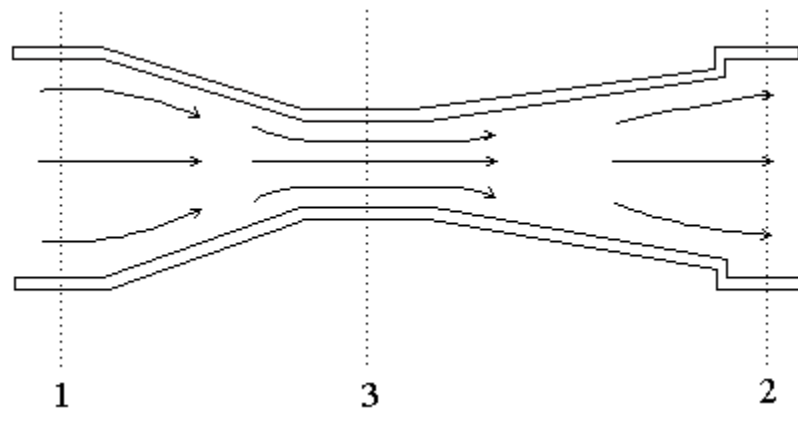
Figure 1: In this model of Venturi flow, the flow velocity at 3 is higher and pressure is lower than at 1 or 2 because of the decreased cross-section. [4]

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[1] Global Industrial Product Specifications Sheet

It is therefore advantageous in a wind tunnel to incorporate this contraction, but the angle of contraction had to be minimized in order to minimize losses. An ideal angle would be less than 9.5 degrees. Considering this ideal angle restriction in light of our cost restrictions, it was determined that it would be possible to get very close to this angle and use as little materials as possible. The angle of the finalized design is approximately 10 degrees.

Areas of intense cost and performance analysis were materials and fasteners. The material which was decided on for constructing the fan bank and the contraction region was ½ inch CDX plywood because it is available locally at an inexpensive cost and was easy to work with. This material was optimized for air flow by sanding to remove excess roughness and painting all surfaces. In an effort to the number of sheets of plywood purchased, the layout for each side of the contraction section of the wind tunnel was as follows. This allowed three of the half-sides to be cut out of each 4'x8' sheet of CDX. Configuration of this section with respect to the rest of the tunnel can be seen in the SolidWorks model (Figure 4) in the Appendix.
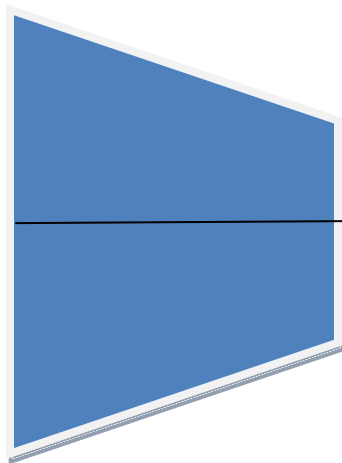
The black line divides the top section from the bottom section of each side of the contraction region of the tunnel. Hinges hold them together so that they are simple and collapsible. See Figure 4 in Appendix.

Figure 2: Diagram of contraction region of KidWind Challenge wind tunnel.

To allow maximum visual access for spectators in the KidWind competition the entire test section with the exception of the floor was constructed of acrylic Plexiglas. Aluminum extrusions and epoxy were used in conjunction with the Plexiglas for structural and aesthetic reasons. The aluminum angles were used as channels and trim pieces elsewhere in the tunnel on the wood parts to provide aesthetic continuity and serve as connectors.

Design of the fan bank was crucial. The fans needed to be easily removable and the whole section had to break down into pieces which could be handled easily and stacked up for storage. The final design included making small framing sections covered with plywood exterior. The bottom and top section had flat sides and circular cut-outs to hold the fans while the center section continued the circular cutouts

necessary to encase all four fans in a square pattern (Figure 4).   All sections latch together on the outside with draw latches to improve stability and speed of assembly.

Testing and Flow Characterization

In order to understand flow and boundary layer effects within the test section of the tunnel, some testing was completed using an NRG #40 3-cup-type rotating anemometer and National Instruments Data Acquisition System fed into LabView code written by the Wind Application Center (WAC) interns. The floor of the test section of the tunnel was marked out in a grid of 1 foot by 1 foot dimensions and labeled 1 through 16. (Figure 11) The anemometer was placed in the center of the grid square and data was collected for 60 second duration at 1 second intervals. This data was written to a text file and averaged for each square. This procedure was repeated for all sixteen grid squares at heights of 14 inches, 28 inches and 40 inches. Data was then processed using Microsoft Excel and plotted in Figures 3a, 3b.

Figure 3a shows Uncorrected Average Wind speed Values. Uncorrected refers to the limitations in configuration of the anemometer. Figure 11 shows that for the test, the central axis was positioned at the center of each square. In the squares near the walls of the tunnel, the wind speed at the right side of the anemometer is different than at the left side due to the boundary layer effects which occur when a fluid such as air moves over a flat surface such as the wall of a wind tunnel.   Especially near the entrance of the tunnel the wind speed can vary significantly over a small distance. Because of this effect and the symmetry of the tunnel it was determined that symmetric flow through the test section could be assumed. Figure 3b shows this symmetry of flow as Corrected Average Wind Speed Values.

The data is output from the anemometer as a voltage. In order to get wind speed data from this output the linear relationship between frequency and wind speed from the calibration of the anemometer by the manufacturer was used. This relationship is V_{wind} = .765x(f) + .35, where f is frequency of the rotation of the anemometer.

Results of Flow Characterization Plotted vs. Position in the Test Section
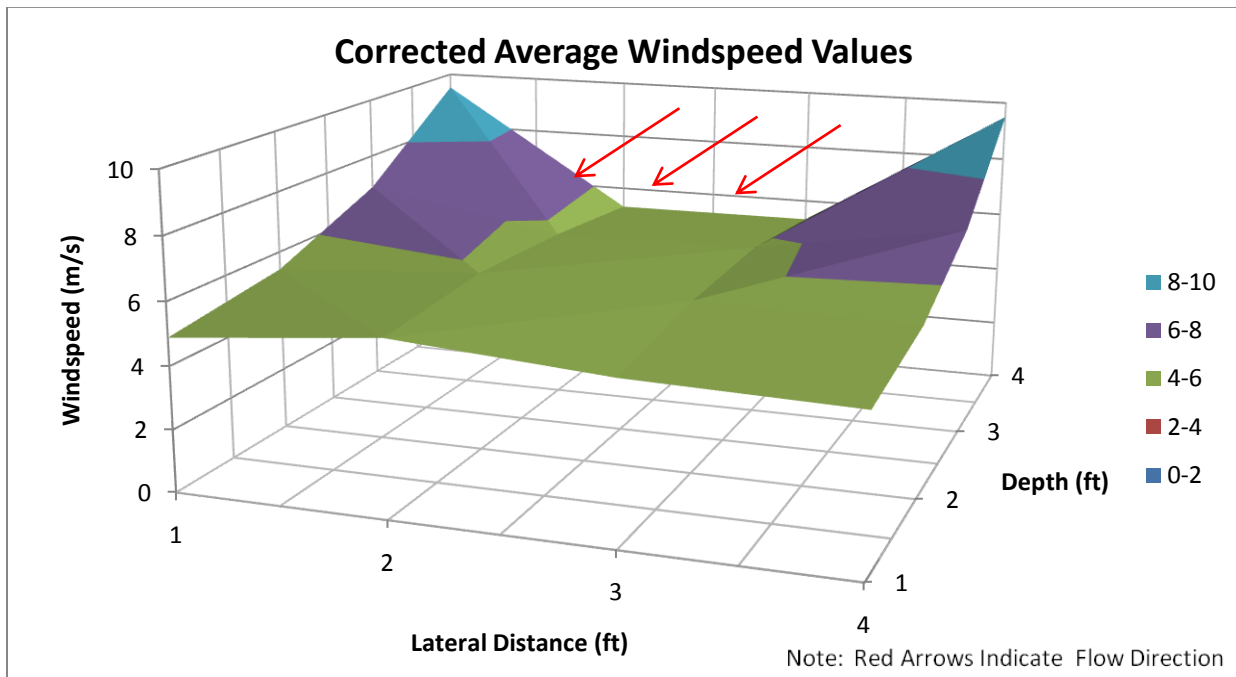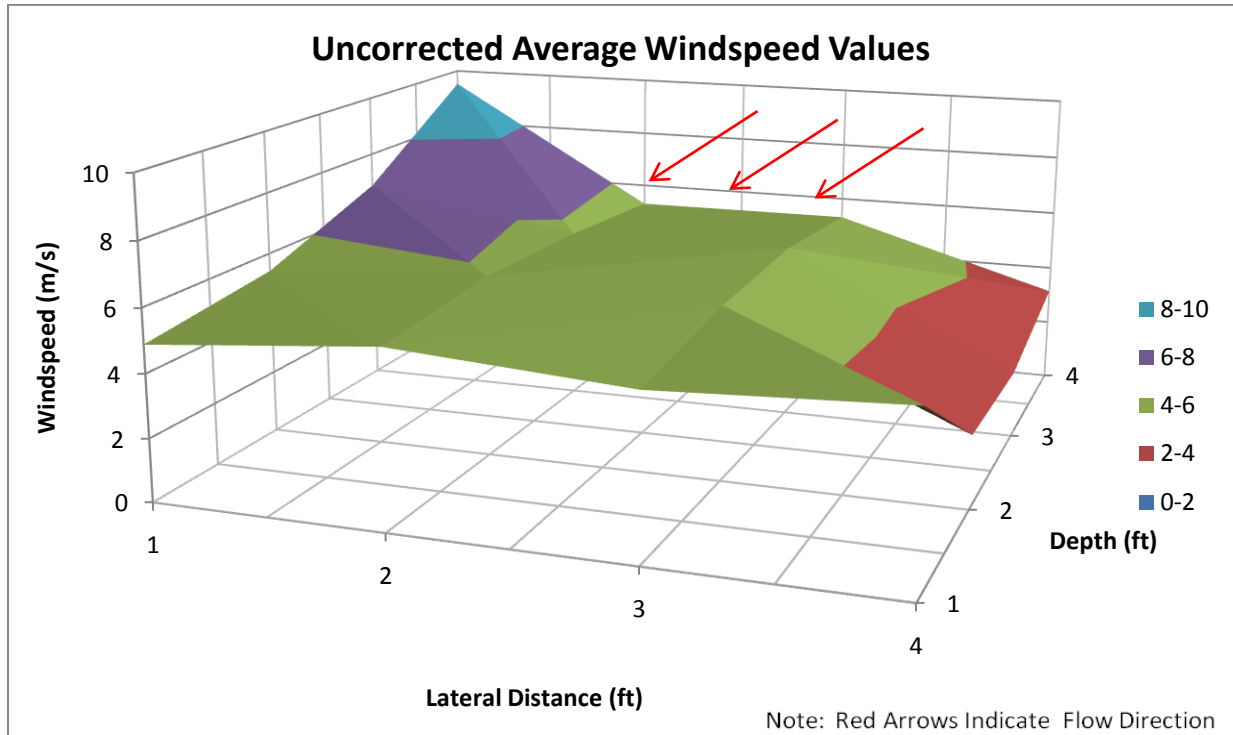
Figure 3a, 3b: Uncorrected Average Wind Speed Values, and Corrected Average Wind Speed Values
due to Anemometer Geometry Respectively

Anemometer Interference in Turbine Power Output

To mimic an actual wind turbine as accurately as possible it is desirable to have real time wind speed data measurements. However, the implementation of a cup-type anemometer into the wind tunnel changes the flow stream characteristics, and it was unknown how severely this would affect turbine power outputs. To this end, a series of tests were performed to determine the placement of the anemometer that minimized the anemometer's influence on turbine power output.

Three locations were examined in this experiment along with a control run without the anemometer present; directly upstream of the turbine, to the side of the wind turbine, and directly downstream of the turbine. Ten tests were performed at each location, to determine the one miliwatt-minute[2] average power generation.   The upstream location provided very uniform wind speeds, but also contributed to a loss of almost 5% power output when compared with the test run without the anemometer. The downstream location provided no significant losses in power output, but the variation in wind speed data collected in this configuration was problematic. Only five tests were performed at the downstream location due to the extreme variance in wind speed data in an effort to conserve time and energy. The best location proved to be in plane with the turbine hub and to the side of the turbine. Wind speed values remained consistent, and the power output of the turbine actually increased about 3% relative to the control test run.

Conclusions and Recommendations

The main challenges and requirements for the low speed wind tunnel were largely dependent on initial budget available for the project. An initial budget of $1000.00 (one-thousand dollars) was given as a relatively flexible but good guideline to use for pricing. However after substantial research the WAC interns found this dollar value to be too low to adequately meet both the wind speed, and portability requirements. To keep production costs at a minimum, some sacrifice in wind speed and portability was deemed necessary.   A minimum wind speed was achieved which was within a very acceptable range to meet KidWind challenge criteria. The tunnel is still very portable, but construction time therefore increased with the purchase of cheaper more labor intensive materials. Also during construction the need to add further structural support for the wind tunnel increased construction time.

The addition of a more permanent structure for the base portion of the wind tunnel is highly recommended to allow for the wind tunnel to gain portability once constructed. Additionally the tunnel was designed to make use of a cart system for further support and access for instrumentation and would receive great functionality gains if implemented. The cart would allow for the tunnel to be movable on casters and allow for a shorter set up time due to the support gains provided.

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[2] A milliwatt-minute is the amount of power produced in 60 seconds. The generator on the KidWind Turbines produces a very small amount of power and therefore the more familiar watt or kilowatt are not reasonable to use.