

Building a Wind Tunnel: It Will Blow Your Mind

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“While great advances in theoretical and computational methods have been made in recent years, low-speed wind tunnel testing remains essential for obtaining the full range of data needed to guide detailed design decisions for many practical engineering problems” (Rae 2).

Introduction:

You may be wondering why we choose this nontraditional approach of building a wind tunnel. Or better yet, why a wind tunnel at all? In a society that is growing dependent on computers and always moving towards new technologies, the use of wind tunnels to solve aerodynamic problems may seem obsolete. However, as we believe and hope to prove through this journal, the use of wind tunnels to solve both basic and complex aerodynamic problems is still needed today. With growing fuel costs comes the desperate need to improve efficiency in both general transportation and the airline industry. Unlike computers which produce mostly quantitative data, wind tunnels provide unique flow visualization that can find critical problems and solutions not seen in the pure numbers. With their ability to combine both types of data, wind tunnels are a critical instrument in the quick and thorough design process of anything that involves fluid dynamics. In addition to gaining a further understanding of aerodynamics and the importance of wind tunnels, the main objective of our project is to help us learn the process that engineers go through to research, test, analyze and ultimately rectify scientific and mathematical problems in our society.

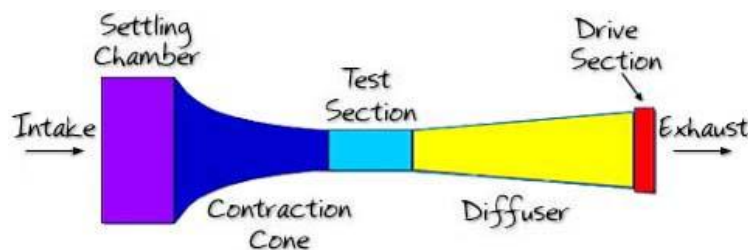
A common hobby of ours has been building and flying small remote control airplanes and helicopters. Without knowing much about aerodynamics, we would experiment with design aspects when making different planes in an attempt to change flight characteristics or to see if the planes would even fly at all. Through building a wind tunnel we hope to learn about aerodynamics, and, more generally, about the process that engineers go through in the real world to test hypotheses and solve problems. A common interest in flight has led both of us to this project where we plan to explore the complex field of aeronautical engineering and have some fun in the process, ultimately preparing us for future studies, jobs and real-life situations.

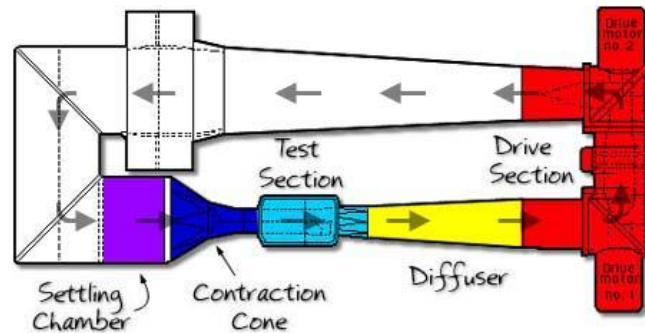
Building a Wind Tunnel

One of the most important parts of a wind tunnel is the flow visualization it provides. Sure lift, drag and efficiency can all be calculated with complex equations. However, it is the visual aspect of a wind tunnel and the controllable environment it provides that allows you to physically see what will happen in multiple real life situations. You can create an environment where you can see how a plane will react when it is taking off, cruising and landing all in the confines of a test lab. Then, with the same machine, you can see how air flows over the body of a racecar when it is zooming around a track to maximize its efficiency. The versatility and tangibility of a wind tunnel is what makes it such an important part of aerodynamic research.

Being such an important part of aerodynamic research, it is important to continue to promote wind tunnel testing. In this project, the ultimate goal is to research, design, build and test objects in a real wind tunnel in order to more fully understand basic concepts of aerodynamics and recognize the capabilities and importance of wind tunnels in solving practical engineering problems.

There are two main types of wind tunnel, open loop and closed loop. In an open loop wind tunnel, there is an intake and an exhaust. In a closed loop wind tunnel, the air is recirculated to improve efficiency for high speed testing.

Open Loop Wind Tunnel

Closed Loop Wind Tunnel

(Flights of Inspiration- Make a Simple Wind Tunnel)

In either case, there are 5 main components to the wind tunnel. There's the settling chamber, the contraction cone, the test section, the diffuser and the drive section. The settling chamber usually contains a honeycomb material to straighten airflow. The spinning fan creates a swirling motion in the air that produces an undesirable effect in the test section. The honeycomb eliminates this uneven air flow. The contraction cone increases the velocity of the air in the test section without creating turbulence in the airflow. The test section is where objects are placed and analyzed. The diffuser connects the test section to the fan and slows the airflow down, again without disturbing airflow. The drive section is the source of the wind and is chosen to produce the desired velocity in the test section.

For our project, we will be constructing an open loop wind tunnel, for its ease and cost of construction. In this type of wind tunnel, it will be easier to manipulate variables since we are designing the tunnel ourselves and it will be a trial and error type of process.

In the following journal entries, we will describe how we went about designing, building and testing our open loop wind tunnel.

March 15, 2008:

After basic research the early development of our wind tunnel seems to break down into five major components. These consist of the settling chamber, compression cone, test section, diffuser, and power source or fan. Most sources indicate that the test section is the most important part of the wind tunnel and should be designed first, based on specific needs and Reynolds numbers, so that the rest of the wind tunnel can be constructed accordingly to meet the specifications determined by the test section.

Before designing the test section we considered its purpose and what we planned on testing. Wing shapes and specific airfoils were the main priority decided, however, to accommodate scale models as well, a test section of 20in by 20in was chosen. A length selection of 30in seemed like it would fit most model airplanes and also provide extra space for a means of mounting a model, as well as some way to implement flow visualization. In our research, three main means of flow visualization have surfaced. Smoke, French Chalk and String Tufts. Each of these has their pros and cons. A smoke flow would be ideal, but the most difficult to implement. "Smoke is used to visualize streamlines and flowfields about the model. White smoke produced by burning a kerosene / oil mixture is delivered through a wand" (Testing Information). This method would be ideal as it would demonstrate the best laminar flow over an airfoil as indicated on the website of the Low Speed Wind Tunnel Testing site in San Diego. Also on this website, it explains the French Chalk and string tuft methods of flow visualization. "French chalk (a liquid mixture of kerosene, talc, and oil) can be used to visualize flow patterns on the surface of a model. Tufts can be used to visualize flow patterns near the surface of the model. The tufts are made using black or white yarn (depending on the model color) and are attached to the surface of the model using tape." At this point, string tufts seem to be the easiest option, but we will definitely explore the others as we progress in the project. Plexiglass was the

material selected for this section because it would make a good viewing window, and the square shape design was meant for easy access to the model.

A second critical component for the wind tunnel is the settling chamber, most often the placed at the entrance of the contraction cone. This piece of the wind tunnel is best described on the 'Flight of Inspiration' website. "The settling chamber straightens the airflow. Uneven turbulent flows can cause unpredictable forces to be experienced and measured in the test section. The less turbulence there is, the better the wind tunnel will simulate actual flying conditions. The settling chamber usually includes a honeycomb flow straightener and wire mesh smoothing screens that produce a smooth airflow" (Flights of Inspiration- Make a Simple Wind Tunnel). The honeycomb material they discuss can be made of hexagonal cells, like normal honeycomb, but it can also be circular or square cells. Not much of this aspect as been thought through in the design process yet. However, one idea is to use a square fluorescent light diffuser section to straighten the airflow. Research shows that the length should 6-8 times the cell diameter. Stacking the diffuser panels could meet this requirement. So far this seems to be the best low cost solution for honeycomb, and a good alternative to the real hexagonal cells; which are shown to be slightly better at reducing turbulent air.

The next component following the air through the tunnel is the contraction, most often referred to as the contraction cone. The purpose of this section is to compress the air to form a higher velocity in the test section. As discussed above the settling chamber is normally placed at the very beginning of the wind tunnel; making up the front part of the contraction cone. This is because the honeycomb is more effective when the air is at a lower velocity. Because the contraction cone starts off as a large area it allows the honeycomb to be placed in an area where the air is more static, before contracting to the operating air velocity. The major design issue with this aspect of the wind tunnel is its unique wavy shape; commonly a

cubic function or a combination of radiuses. On NASA's website, 'Wandering Wind tunnel', they discuss some of the issues they had regarding shape and material of this section. Most notably, they recommended the use of the cubic function and 14 gauge sheet metal as a material. With regard to these issues, scale paper models have been constructed to verify a few design ideas and confirm that it can be constructed from flat pieces of sheet metal. Although research has shown this specific shape to be important, it is also recognized that the specific shape of the curve is not as critical in the design of small wind tunnels. Also, for ease of construction, straight walls that form a trapezoid are being considered. As noted in a similar project to our own done by the University of Colorado; "Despite what all the references say about having a curved compressor, a flat one was chosen instead to allow for ease of construction. Because of this, a small settling chamber (hexagonal honeycomb) will be added just in front of the test section to renormalize the flow" (Zollars 17).

Following the air through the test section the next large component required is the diffuser section. This connects the end of the test section with the fan and goes from a smaller area to a slightly bigger one. Research has noted that the angle of expansion should not be more than 5 degrees, which fits the 4.3 degrees in the current design (Rae 41). Although the shape of this section is best when square is blended with a circle it is very difficult to construct. For something that is more easily built the square attaches to 4 triangles, whose tips connect to the fan shroud. (seen in the picture of the current design). The gaps are filled in with curved sheet metal for a generally smooth shape to connect the fan to the test section.

The fan, or power source, is the final critical component in the design of our low speed wind tunnel. An industrial fan was selected, and acquired, to meet specifications made by the test section. With a 25in. diameter and max rate of 8100cfm it can pull enough air to reach speeds in the test section of up to 70 mph. A dimmer switch is being considering allowing for a free range of wind velocities. One of the problems

with the fan that was noted is that the switch box is mounted on the side that the air is sucked from. In many attempts to try to switch the direction of the wind being pushed we; swapped over the fan blade, individually rotated each blade of the fan, and tried combinations of the two. However, nothing reversed the flow.

Overall the basic design of our wind tunnel is complete and many materials have been selected. The most current design calls for $\frac{1}{4}$ plywood, Plexiglass, thin flexible sheet metal, a large metal screen, fluorescent light diffuser panels, an industrial fan, 2x4s, and miscellaneous mounting hardware. Some materials have already been obtained such as the fan, and most of the wood needed for construction; although a few key design characteristics need finalizing before we can continue onto construction.

March 29, 2008:

Over the past two weeks, significant progress has been made in the design and construction of our wind tunnel. Each section of the wind tunnel has been planned out and finalized to some degree and some parts are currently under construction. The details of the plan, which will be discussed below, follow some original thoughts but also include some significant design changes to minimize cost and maximize performance. Although this is the most current design there is still some future planning required and thus it is always subject to change.

One of the larger and more critical aspects of the wind tunnel is the contraction cone. The most difficult part about this section is deciding what shape to make it. There were two main options we had. First, there was the more traditional approach of a curved contraction; a profile with an 'S' shape to it. The other option was to make flat walls in the shape of a trapezoid, which would serve the same purpose. The underlying goal of the contraction cone is to transfer from a larger area to the smaller area of the test

section; in a sense a large square to a smaller square. The contraction cone serves many purposes in the overall scheme of the wind tunnel. The contraction cone increases the efficiency of the system by giving the fan a larger pool to pull air from it is easier to pull air through the tunnel. Also by starting off at a larger area the velocity of the air is much lower and more ideal for the use of screens and honeycomb to straighten the airflow. Problems that can occur in this section include separation of air and an increased boundary layer. All of these factors were considered in making the final design; however, it was ease of construction, and total cost that also played a large factor in the final decision. A curved contraction cone would be much harder to construct, so the flat design was chosen for its ease of construction. The advantages of a curved contraction cone were not seen to be necessary and are compensated for elsewhere in the design. In our research, this flat design was found to cause a greater chance of separation and possible problems at the boundary layer. However, sources also show that by increasing the length of the contraction you can minimize both of these issues. "It is also possible to avoid separation in the contraction by making it very long, but this results in an increase of tunnel length, cost, and exit boundary layer thickness"(Lindgren 488). As stated, the trade offs are cost, size, and thickness of boundary layer; however these factors are far less significant for our specific wind tunnel. Since it was easier to make it longer than to make a curved shape, a length of 40 in was chosen as it is 30% longer than the general recommended length. The final aspect of this part of the wind tunnel is the contraction ratio or difference in areas. Although this ratio was not found to be very critical, sources showed that a minimum ratio of 5:1 is ideal. By making the opening a 30x30 in square and contraction down to the test section with an area of 13.75x13.75 in we were able to achieve a similar ratio while keeping the overall size reasonable. The only other aspect of this section is the settling chamber, which is normally placed at the beginning of the contraction cone.

Our research has proven that the use of honeycomb settling chamber as a flow straightener is most effective in areas of low velocity, and thus should be placed in the entrance of the contraction cone. It was

also found that the reasoning for this was that the efficiency is drastically reduced when the honeycomb settling chamber is placed in an area of higher velocity. Efficiency, however, is not of utmost importance to us. Having found this, it is easier and more economical to place the honeycomb towards the end, right before the test section. After researching different honeycomb materials, the lowest cost honeycomb (commonly used in small low speed wind tunnels) was found to be plastic drinking straws. However, the problem becomes not only buying thousands of straws in bulk, but the complexity involved in cutting thousands of straws to the correct length and stacking them together. Because of the much larger area at the beginning of the wind tunnel, it would cause much more straws to be used and add to the overall complexity. To reduce this issue without eliminating the necessary use of honeycomb we decided to place the settling chamber (honeycomb) at the end of the contraction cone which is right before the test section. The advantage of this is that it is over a much smaller area and would cost less while being easier to construct. The other major factor in this decision relates to the flat design of the contraction cone. One disadvantage in that design is that it makes the flow more likely to separate, or in other words can create more turbulent air. By placing the honeycomb at the end of the contraction cone it can renormalize the air right before the test section as seen by Independent Study: Wind Tunnel. In their wind tunnel, they have a flat contraction cone and describe its effects and what they did to compensate. "Despite what all the references say about having a curved compressor, a flat one was chosen instead to allow for ease of construction. Because of this, a small settling chamber (hexagonal honeycomb) will be added just in front of the test section to renormalize the flow" (Zollars 17). Downsides to this design were found to reduce efficiency, possibly making the fan work harder. Because our fan motor is already overpowered this was not seen to be an issue and was another reason to place the honeycomb right before the test section. The last aspect of the settling chamber is screens, normally combined with honeycomb to reduce turbulence.

Currently the thinking is to place one screen in the very front and others where it is seen to be needed. A window screen was chosen because it is easy to use and was the most cost effective.

The next section of the wind tunnel is the test section. This mainly consists of two wooden frames connected by a clear material. A test section area of 13.75x13.75 in. was chosen because it allowed a wide range of wind velocities, and it was also convenient to the length of wood we had on hand. By cutting each piece at 45 degrees, pre-drilling each hole, and screwing them together; we were able to make two identical square frames. The only other part of the test section is the Plexiglass or clear material needed to view the experiment. It is common to make all four sides of the square out of Plexiglass, however, we are now thinking about only using one or two sides of Plexiglass to minimize cost. No research or sources have indicated anything about this part of the test section, however, a few things are being considered in the decision. The only purpose of the Plexiglass is to view the object, so it would seem reasonable that only one side is needed to look in. However, other considerations such as the amount of light that will then get in or the background in viewing smoke needs to be looked into. Other low-cost clear materials are also being considered as a means of reducing cost; but no final decision has been made.

The pieces after the test section are somewhat less significant because the air is already through the test section; although separation of air is still an important factor. The diffuser, or part that connects the fan to the test section, has been designed based mostly on fixed dimensions such as the diameter of fan and cross section of the test section. Although research does not note on the length of this section, it has shown that a slope of 5-10 degrees is desirable, and at about 6 degrees meets our criteria. With the final dimensions set for both the diffuser and contraction cone, the plans have been sent out to be made from sheet metal; used for its light weight and low cost.

The final aspect in our wind tunnel design and construction is the fan. As previously mentioned we have decided on and purchased an industrial strength fan that can push up to 8400 cubic feet per minute. However, most experiments require a wide range of wind velocities; so the need to control a wide range of speeds is very important. The idea is to use a dimmer switch to interrupt the power leg to the fan motor and thus control its speed. However, after dissecting the electronics of the fan we found that a capacitor was wired into a 3 position switch; somehow making a high, low and off setting. After preliminary research, we found that using a classic style dimmer switch could not be used on an AC fan motor because the voltage required had to be at certain frequencies. Not fully convinced of this, we did small scale testing with a classic style one pole dimmer switch on a small inexpensive AC fan. Without replacing the existing high, low, off switch we wired the dimmer switch into the wire with power. This worked out very well and produced fine adjustments in the speed of the fan. More importantly, though, it produced no signs of damage to the motor or switch. Despite this promising small scale test, the potential risk to the large fan motor prevented us from dimming the real fan as of today. More research is being done to see the dangers, if any, of dimming an AC motor. Other options, such as dimmers designed for AC motors (although more expensive) are also being considered.

The details discussed above are the most current and final designs although they are subject to change. One thing we have found through all the research is that for every design option, there are tradeoffs. Most often between cost, performance, and ease of construction; this current design balances these things to make a wind tunnel that is not only functional and low cost but also reasonable to build.

April 5, 2008:

The biggest sections of the wind tunnel have recently been completed and are beginning to come together. There is finally some resemblance to a complete wind tunnel. Some of the major successes have

included wiring the fan to be variable speed, building the contraction cone, diffuser and test section.

However, there is still a fair amount of work that needs to be done to connect all of these pieces to make a functional wind tunnel.

After we designed the contraction cone and diffuser on the computer, we sent the plans to a professional ductwork company that put these pieces together for us as a donation. Although the pieces were not exactly constructed to our specifications, they should still be functional. The contraction cone goes from a 13.75" square to a circle 32" in diameter (see picture #1:Contraction Cone). Since we had already decided to straighten the airflow at the end contraction cone, the shape the contraction cone itself is not critical because if the air is somehow disturbed by this particular shape, it will be re-straightened by the honeycomb straightener which we are going to put right before the test section as we discussed in the previous journal entry. As Flights of Inspiration stated, "The contraction cone's purpose is to take a large volume of low-velocity air and reduce it to a small volume of high-velocity air"(Flights of Inspiration- Make a Simple Wind Tunnel 7). The contraction cone will serve this purpose just fine, again, considering we will be straightening the air flow just prior to the air entering the test section. The biggest problem that could arise from using this shape will be separation at the boundary layer but this will hopefully be renormalized by the straightener. The contraction ratio is the other important aspect of this section. The target contraction ratio was 5:1 and with our current section, it is approximately 4.8:1 which is very close to our target ratio.

The honeycomb straightener that we will use will be constructed of plastic drinking straws that are 1/4" in diameter and approximately 3" long. They will be placed together in a square frame and covered with screen door mesh to eliminate any eddies that may have formed in our obscurely shaped contraction cone. Even though we are trying to keep this project low-cost, many other small, low-speed wind tunnels

use this straw method as well. A research project at MIT used it for many of the same reasons we chose to use this method.

“Accordingly, the honeycomb is constructed of approximately 130,000 plastic soda straws, 3/16 inches in diameter and 10 ½ inches in length, carefully stacked in a hexagonal close-packed configuration and held in place fore and aft by 18-mesh screening. The whole process results in seamless construction and clean-cut ends. The whole section proved to be quite inexpensive and relatively easy to construct.” (Hanson 3)

MythBusters used it in one of their episodes, *Concrete Glider*, to test the aerodynamics of a train.

As in both of these cases, we will also place the frame at the end of the contraction cone and it will be right in front of the test section to produce a laminar flow.

The test section is the latest sub-project we have worked on. We bought .080” Plexiglass at Lowe’s and made a rectangular prism out of it using the square frames (see picture #2: Test Section frames) we previously constructed. The Plexiglass was cut using a table saw (see picture #3: Cutting Plexiglass) and was glued together using a special Loctite adhesive that cures using UV radiation (see picture #4: Gluing). We will also be running a bead of silicon along the corners to produce a smooth, filleted corner to reduce interference with the air. The final dimensions of the test section are 13.75” x 24” (see picture #5,6,7: Test Section). One other thing we still have to do on the test section is to construct something to hold the test pieces in place. One idea we had is to drill a hole to allow a wooden dowel to fit inside to mount airfoils. This has to be done very carefully so the Plexiglass does not crack. Also, flow visualization is going to be very important in the test section. Once the tunnel is done, we can experiment with the various methods that have been previously described in past journal entries. However, one of the methods would require a mounting setup right behind the test object. This method is the low-density string method that would show the vortices produced behind the airfoils. This would eventually need to be incorporated into the test section and/or airfoil. One of the shapes that will be interesting to test with this method is a triangular

shaped wing because these wings have distinct vortices that are produced and should be easy to see with the low-density string method of flow visualization.

The diffuser we have was built exactly to the specifications of the plans. It is a square-to-round transition with a 25" diameter circle for the fan attachment and the square is 13.75" to fit the test section (see picture #8: Diffuser). This piece was less critical in the design because its main purpose is to connect the fan to the rest of the tunnel and since it is after the test section, boundary separation and turbulence becomes less important.

As mentioned before, the fan has been wired so that it has a variable speed control which is a lot easier said than done. Having talked with an electrical engineer, getting recommendations from an electrician, doing small scale testing and spending about 10 hours of time, we were finally able to get the desired results. This process will be described in a more detailed journal entry. We will now be able to run the wind tunnel at air speeds ranging from 0-20 m/s. Once the wind tunnel has been completed, we will calibrate the dimmer switch so we know the airspeed at varying positions. We will do this by putting an anemometer in the wind tunnel and running the wind tunnel at the various speeds and then recording the position on the convenient control box we made that has all of the necessary switches, remote from the fan.

Again, there is still a substantial amount of work to do connecting all of these individual pieces but so far, the project has been going very smoothly. We are only about a week behind as it does not look like the whole tunnel will be done by May 2nd, however it should be completely shortly after that date.

Building a Wind Tunnel

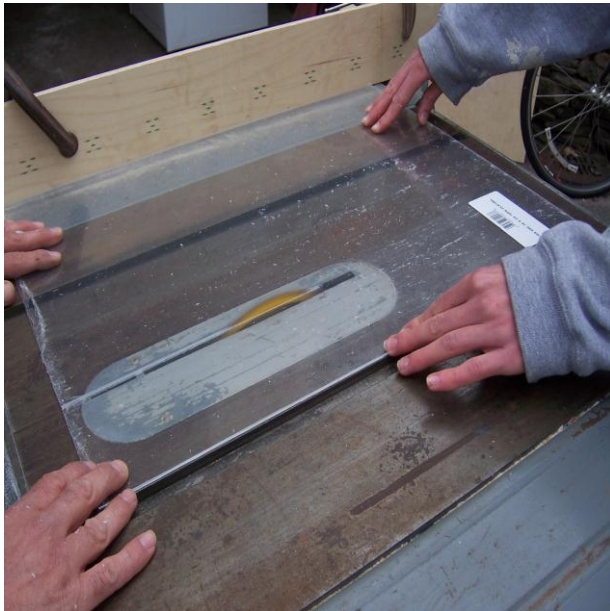
#1: Contraction Cone



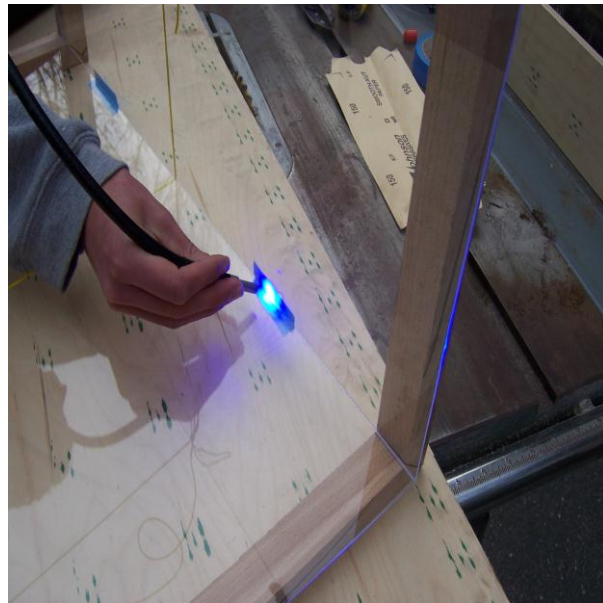
#2 Test Section Frames



#3: Cutting Plexiglass



#4: Gluing

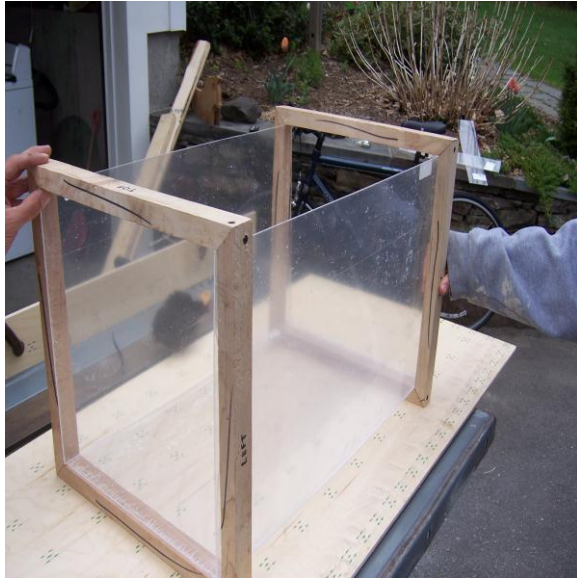


Building a Wind Tunnel

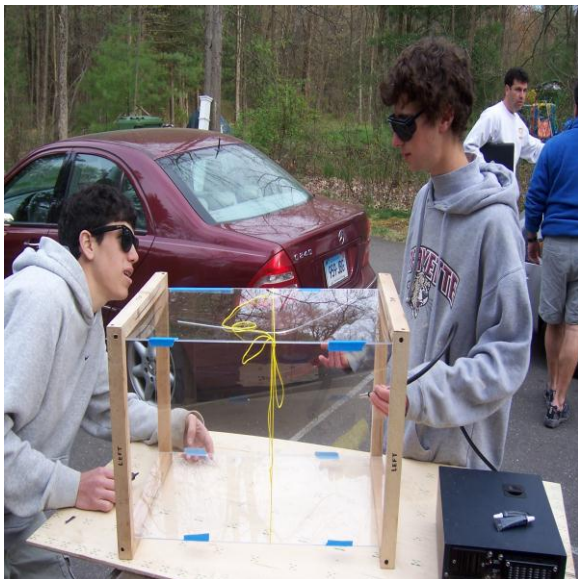
#5: Test Section



#6: Test Section



#7: Test Section



#8: Diffuser



April 30, 2008 – The Fan:

Over the course of constructing our wind tunnel concerns about the fan's electrical system have led to specific research in the field, small scale testing, and a few key design modifications. Although this is specific to our fan and wind tunnel design it is very relevant to anyone trying to have a variable speed controller on an AC motor, and worth discussing individually due to the complexity involved.

The purpose of the main fan in all small open circuit wind tunnels is to provide the force that pulls the air through the wind tunnel. Although this seems like a relatively easy task there are a few critical components involved. The first is due to the nature of wind tunnel design and the several inefficiencies in air flow from flow straitening and screens. To overcome the severe pressure differences that can occur it is necessary to have a fairly powerful fan. Another important aspect of the fan and power system is to have fine control over the flow rate through the tunnel. Although this can be accomplished a few ways the most obvious and reasonable way to do so is to have the fan operate at variable speeds. Because it is important to test models at variable air speeds, and because we are unsure of what air speed would make the best for flow visualization it was deemed necessary to have a variable speed fan.

The fan purchased for this project is an industrial strength fan used to air out or dry very large buildings. It came stock with a 3 position switch for high, low, and off and could push a maximum of 8100 cubic feet per minute through its 25in diameter fan shroud. Although this fan had the right dimensions and power requirements there were several problems that required modifications, specifically to the electrical system. One was that the control panel was mounted on the fan shroud making it impossible to access once it was installed, and the other was that the fan had only had two speeds and not the variable speed

required. Originally both were seen to have easy solutions; however, further research caused some concerns about variable speed AC motors.

The original thought of wiring a common dimmer switch into the circuit was something our research warned against. However, not fully convinced it would not work we purchased a single pole dimmer switch and did our own testing. Not wanting to risk damage to the fan we tested the dimmer switch on an old window fan that was far less expensive. By interrupting the hot leg with the dimmer switch through a 4 position switch from the fan we were able to successfully use the dimmer switch as a variable speed control. However, with long term damage to the motor still a possibility we decided to seek expert advice about the issue. By consulting an electrical engineer we learned a great deal about how AC and DC motors work and how using alternating current was the source of our problem (Ligotti).

More typical DC motors work with the electricity flowing in one direction. Because the motor would only do a half turn with this scenario a split ring commutator is used to reverse the direction of current every half turn. This results in keeping the motor spinning continuously in one direction. To alter the speed of a DC motor the only required change is the voltage which can be controlled easily through things like transformers. Unlike the simple process of DC current AC motors operate very differently. In alternating current the electricity is pushed forward and then pulled back continuously, in essence modeled by a sinusoidal function. For something like a light bulb (a resistor) the electricity is continually pushed and pulled back and forth through the filament. A light bulb, not sensitive to the amplitude or wavelength takes an average of the current and lights up. In fact the current is alternating so fast that the light bulb can stay lit between direction shifts. The complexity comes in when motors are designed to run off of AC current. Unlike DC motors who switch the direction of the current themselves AC motors have the “advantage” of having the current switched for them, and thus do not have or need a split ring commutator. However, this

does mean that every AC motor must be designed specifically to operate at a single given frequency of AC current. The reason a light bulb can be dimmed so easily is because it can just take an average of the current to operate. The way a dimmer switch works is complicated but can be simplified by using the sinusoidal model. When inverted (again to simplify things) a sinusoidal function is basically a series of repeating bumps. What a dimmer switch does is adjust the line at the base of the function. By moving it up or down you are adjusting how much of the function is shown; to the point where you can barely see the tops of the function is where the light bulb is most dimmed. It is for this same reason that, in theory, you can not use the same dimmer switch on AC motors. Because they are designed to operate at given frequencies controlling them with variable speed requires a complicated and expensive electrical device. One simple solution noted and seen in the electrical system is the wiring of a capacitor in the circuit. The objective is to shift the frequency over by a known amount, again to another specific frequency designed for the specific fan. This also entails that each AC motor is wired to work at these one or two known frequencies and allows them to operate at two speeds normally high and low (Ligotti).

Although all this information was very interesting and helpful it should also be noted it is a lot of theory. Although you are not supposed to “dim” an AC motor with a single pole dimmer switch, we did, and it worked fine. As it should, because a similar electrical configuration is at work in all houses that use ceiling fans with adjustable speeds. The rather simple solution to this complex dilemma was to purchase a dimmer switch designed for ceiling fans and also checked to meet the specific voltage and amp limits of our motor. After testing the new and slightly better dimmer switch on the old fan we implicated it on the real thing and found that it worked fine as expected. This is most likely due to the idea that even though we are doing the wrong thing to the motor the “damage” is probably very slight or very long term(not noticeably in the foreseeable future). With the major problem rectified we extended the wires from the motor to a control box where we mounted the 3 position switch and the dimmer switch. (See schematic attached for specific

wiring configuration) In conclusion the result was a fine working fan with variable speed and a gained knowledge of alternating current and AC motors(Ligotti).

May 9, 2008 – The Flow Straightener:

The flow straightener has been fairly difficult to construct being on such a low budget. If we had thousands of dollars to work with, there is extruded aluminum honeycomb that we could have purchased to serve as our flow straightener. Being low-budget, we decided to go on a more unconventional route using straws to produce a normal airflow. However, this is not that farfetched because this method has been used before. The Myth Busters used it in their wind tunnel and straws were also used in an experimental wind tunnel at MIT (Maniet 1). The main purpose of the honeycomb flow straightener is to reduce the swirling effect the fan has on the air. In order to simulate conditions close to those an airplane flying in the air would experience, the flow needs laminar to produce the effect of a wind traveling through the air as opposed to the air traveling over the wind as it is in all wind tunnels. The construction of this piece has been difficult to say the least.

After deciding to go with the straw method, we needed to calculate how many straws we would need and where we would get them. Each of these variables, though, depends on each other. The bigger the straw, the less you need. After doing hours of research on just where we could get straws, BJ's was the cheapest to buy straws in bulk. After actually obtaining the 1800 straws, we needed to figure out a way to cut the straws into 1.75" sections and place them into a frame that would fit into the Plexiglass test section. After cutting 1.75" strips of wood, we assembled the frame that the straws would go in by placing the wood pieces together in the test section to get the exact dimensions and then gluing the corners with wood glue. To contain the straws in the frame, we used a window screen stapled to each side of the frame. However, before we could attach the window screen to the top of the frame, we still needed to figure out how to cut

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the straws in bulk so we would not have to place each straw in the frame individually. There was a lot of trial and error in this process. Ultimately, we bundled the straws into circles and we cut the 1.75" sections with a band saw. In the end, there were 4 groups of approximately 400 straws and 14 groups of approximately 100 straws. To fill in the gaps, individual straws were placed in between these larger groups of straws. That's over 3,000 straws! Even though this may seem somewhat like a fairly menial task, it required hours of thought and hours of construction; at least 20 hours of work combined. Just on this one section!

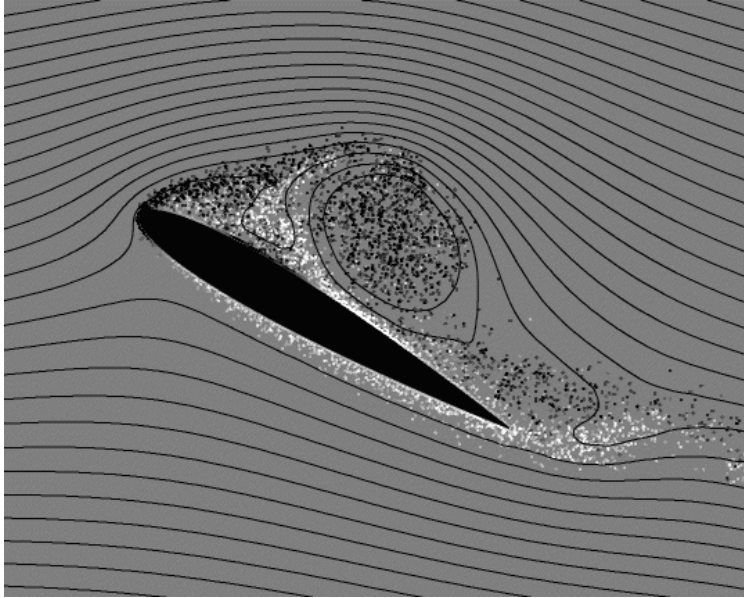
**May 26, 2008:**

After having had the wind tunnel completed for a few weeks, we have been putting all nearby objects into the tunnel, partly just for fun and partly to understand and visualize basic fluid dynamics. For our presentation, people will probably say, either to themselves or out loud, "So you have a wind tunnel

but what does it show?" Clearly, our wind tunnel does not have the technology that would be required to calculate the precise drag and lift forces; however, we can demonstrate these concepts to teach people the basics of things they use in their everyday lives. For example, with golf balls, there are hundreds of models on the market that say they are more 'aerodynamic' and people will take the companies word for it. What a wind tunnel does is qualitatively verify that these advertisements are accurate. By hanging two types of golf balls on a string and placing them in a wind tunnel, you can measure the angle that the ball is blown back. With this simple data, you can calculate the drag the different balls have while in the air. Or qualitatively, you can see a difference between the angles that the 'better' or 'worse' balls are pushed back.

Similar to the golf ball experiment, we also want to demonstrate the importance of the honeycomb straightener. To do this, we can have a similar ball attached to a string and observe what happens with and without the honeycomb straightener. With the straightener, there should be no 'wobble' in the ball and without the straightener, the flow will be swirling, thus giving the ball a wobble. However, when trying to conduct this experiment, it turns out that it's not quite that easy. There is another variable and that is that there is a different amount of air moving through the test section with and without the honeycomb. The honeycomb straws provide more resistance to the air, slowing the flow. If we can achieve a similar flow rate in each experiment, it might be a valid demonstration and would be a good answer as to why we need the honeycomb that took us such a long time to build.

For a better view of what the air is actually doing, we have implemented a smoke system to see how the air moves around objects. As of now, we have 5 plausible methods of obtaining smoke. Strings, incense sticks, mineral oil, smoke-in-a-can, and dry ice. After doing numerous tests with each method, so far the dry ice seems to be the most successful. With the smoke, you can see the air flow over and around airfoils very well. We built a small airfoil section complete with remote controlled surfaces that

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demonstrate what is happening on an aircraft when air moves over a wing and the control surfaces. We can simulate flaps, spoilers and ailerons with the one wing section. One thing the smoke shows

really well is a stalled wing section. As the air comes over the wing, it gets stuck on top the wing and creates turbulent air. This drastically reduces lift and can be very dangerous when flying a plane. The phenomena seen is similar to the picture above, where the air begins to swirl over the airfoil (Szu-Chaun).

Also with the smoke, we can put various model cars in the tunnel and see how aerodynamic they are and how they react to doors being open or how drafting can improve efficiency, etc,

It has been a lot of fun so far testing in the wind tunnel and we will continue to find new things to put in there to observe some common and uncommon phenomena.

After completing the project, here is how much the project totaled, both in what it would have cost us had we paid full price for all of our generous donations and what we actually paid(attached).

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Fan	FlowPro Premium Cooling Fan — 25in., 8400 CFM, Model# 11409	199.99		eBay	125
Plexiglass	18" x 24" - Clear Acrylic Plexiglass Sheet - 1/8" Thick	31.96		Lowes	24.99
Ductwork	Custom Plans	250		Duct People	0
Dimmer Switch	A/C Fan Dimmer Switch	12.99		Fan Person	14.99
Wire	50 feet - 12 Guage	4.99		Lowes	4.99
UV Glue for Plexiglass	Loctite UV Adhesive	24.99		Loctite	0
UV Light Source	Dymax Modular UV Light 2000-EC	2395		Loctite	0
Straws	1800 Flexible Straws	14.97		BJ's	14.99
2x4's	2x4's for Test Section Stand	9.98		Mr. Percival	0
Window Screen	Fiberglass Window Screen	35		Mr. Carlone	0
Silicone	GE Silicone	5.96		Lowes	5.96
Incense	Green Tea Incense Sticks	2.5		Pier 1	2.5
Mineral Oil	Mineral Oil	4.99		Walgreens	4.99
		2993.32			198.41