Wind Tunnel Portion Report

Mechanical and Construction Group

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1 Abstract

The Mechanical and Construction (M&C) team was responsible for the construction of a housing chamber for the fan and honeycomb, diffuser, and contraction chamber of a low-speed wind tunnel targeting the 5 to 10 m/s wind speed mark—as determined by choice of fan—at approximately 2.5 meters length total. Several research articles and online textbooks were consulted to discover optimal parameters for preservation of flow uniformity such as settling chamber length, angles of depression for the diffuser and contraction chamber, and flange design. Other quantities, such as contraction ratio, were in part determined in a design document given by Drs. Niculescu. The M&C team prioritized adaptability to changing constraints—such as a change in fan or honeycomb dimensions—and developed construction methods with this in mind. Our findings have resulted in robust, repeatable construction methods that withstand the conditions of a typical, very low speed wind tunnel while achieving target geometries

2 Introduction

The flow source for this wind tunnel is a consumer grade floor fan. It is circular, and has a diameter of 0.545 meters. The fan is placed in the threshold of the intake of the settling chamber so that the lip running the circumference of the fan is directly outside of the back pressure reduction panels. The interior of the settling chamber consists of a honeycomb-style flow straightener whose cells are 0.05 m by 0.05 m to reduce swirl and turbulence in the air flow and to create a more uniform flow. The air then passes through the contraction chamber, which further contributes to a uniform flow and increases the flow in the testing chamber. The contraction reduces the total cross-sectional area to 0.25 m by 0.25 m. The testing chamber is a clear Plexiglass section with electronics implemented to measure wind speed, pressure, and other forces. Finally, the diffuser is mounted at the end of the testing chamber for pressure recovery and returns the cross-sectional area to 0.590 m by .590 m. The diffuser serves the opposite purpose as the contraction chamber, creating a gradual velocity reduction and pressure increase to minimize turbulence. Each piece is connected to the next via flanges, created from four layers of foam used to construct the main pieces of the wind tunnel. All panels are left straight, as to avoid the challenges of bending foam.

3 Mechanical Design and Construction

3.1 Cutting Foam

Cutting single-layer foam is simple, and its general process translates to multi-layer foam. When cutting foam, the team found that clean lines may be achieved through a process dubbed "score-and-snap," in which a razor is gently guided through half of a given layer, then picked up and bent in the direction opposite of the score, then towards the direction of the score. This results in a distinctive "snap" and a clean, repeatable line that is generally difficult to achieve directly by cutting. For multilayer foam, one should seek to cut one layer at a time, using the cut to guide the blade as it goes deeper into the multilayer foam. After reaching the bottom layer, snap as above. With this method for cutting, the team was able to achieve a near-perfect success rate for desired geometries.

3.2 Laminating and Painting Foam

The most basic mechanical design element is the lamination of foam panels for the construction of the body of each chamber. To prepare for lamination, EPS foam boards—commonly used for school projects—are stripped of their paper backing by spraying them down with alcohol and gently peeling off the backing. Prepared panels may be done in two ways, depending on the needs of the project. The first method is for projects whose largest chamber length is longer than the width of the prepared panels, typically 50 cm for boards sourced from Dollar Tree. This method staggers bilayer foam such that the middle of any piece of foam is met by the end of another—that is, staggered like bricks. Staggering like this has the benefit of achieving longer panel lengths; however, the process of measuring to the middle of each foam board can introduce mounting error over time. This is especially true when one factors in that half-panels must also be cut to end this pattern. The M&C team frequently found that it resulted in misaligned panels, despite careful double measurements. Overall, this method should only be pursued if one desires longer chamber lengths. The second method, which we used for the team's project, is direct lamination, in which one prepared panel is placed directly atop another. Both methods require the use of 3M 77 contact cement. The contact cement should be applied conservatively, and from a distance of at least 10 cm from the surface being sprayed, as excess contact cement will melt the EPS foam. The contact cement should be sprayed outside and on grass, so as not to damage facilities. Finally, the contact cement must be tacky prior to lamination, rather than still wet, and may be checked by placing one's knuckles onto the sprayed adhesive. Following this procedure, we were able to rapidly create body panels that may be used in any element of construction.

After lamination, there remains the step to paint the laminated panels with a 1:1 mixture of modge podge and black acrylic paint. The amount necessary is minimal and should only be so much as to eliminate all striations on the prepared panel's surface. The mod podge provides rigidity to the final construction and—though it is not understood why—typically makes the score-and-snap of cutting easier. This step is optional at this point, though highly recommended, as painting finished products is generally more difficult and space intensive.

3.3 Panel-to-Panel Connections

Prepared panels may be joined in a variety of ways, though the team has settled on one that is repeatable, easy, and offers non-permeant fastening for temporary alignment. To join a panel, the team first pins two panels together, normal with respect to one another with the pins contained entirely within the panels. Generally, many pins are needed, approximately one every 5 cm. After a panel is pinned and the team is ready to make a permanent bond, a bead of white glue is run between where the panels meet. This is allowed to sit to correct any topological defects in the panel. After approximately five minutes of dry time, a bead of hot glue is run over the white glue and allowed to dry completely. When fastening together laminated foam panels, one is generally joining them at 90° with respect to one another; however, this procedure works for angles more or less than normal (we used 70° without issue, though more hot glue is necessary to fill the gaps). The extrema of this tolerance have not been explored.

3.4 Honeycomb and Fan Housing Chamber

The honeycomb is an essential part of the wind tunnel—assuring that laminar flow is maintained by straightening the flow—and is placed inside the housing chamber. The honeycomb is friction-fit to the inside of the chamber and may be removed at any time due to the particularly laborious nature of its creation. Should anything happen to the settling chamber, then the honeycomb may be removed and repurposed. The honeycomb is made of 12 layers stacked vertically with an extra 13th layer placed on the side. The housing chamber was assembled by using prepared, painted direct-laminated 0.508 m × 0.762 m panels.

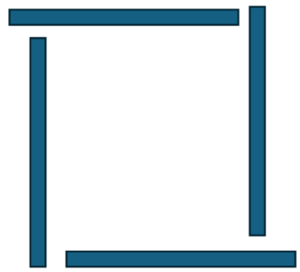

Figure 1: Staggered design of panels for housing chamber.

The panels are assembled in an offset square pattern, as seen in the figure above, and are then fastened in the standard method as described with pins, white glue, and hot glue. The bottom panel is placed onto a level surface, then the leftmost panel is attached with pins. Then, the two panels are flipped so that they are standing. The third panel is then pinned to the correct width to the bottom panel. After, the leftmost panel as shown above is then cut to the desired height after being rotated so that it is on a level surface, and the fourth panel is attached onto the freshly cut surface and pinned to the second and third panels. The interior of each panel is measured to ensure correct geometry and then the panels are permanently bonded as described above. Afterwards, the excess from each panel is removed with the standard score-and-snap. This construction method achieves a team goal of remaining adaptable, as it allows for one standard panel for any size fan, given the fan does not exceed 0.76 m in length. It achieves the desired geometry every time, as the height and width are bespoke to the fan. The results of which are below, in a CAD rendering.

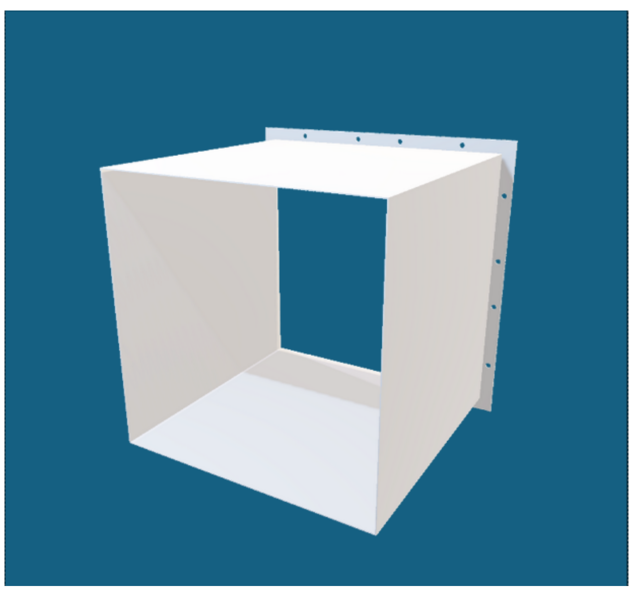

Figure 2: CAD rendering of housing chamber

3.5 Contraction Chamber

The contraction chamber follows the housing chamber with a gentle slope in order to preserve laminar flow while accelerating the air. The contraction chamber is constructed with prepared, bilayer foam panels using a method generalized from the construction of the housing chamber. For our contraction chamber, we were advised to optimize for space and disregard literature values of a 20° angle for the contraction chamber's slope. We proceeded to construct these panels, then, without cutting to a specified width—which determines the angle of the contraction chamber. The key relationship here is that the angle of the contraction chamber's slope, α, is determined by $\alpha = \arcsin \frac{h_{\text{fan}} - h_{\text{TC}}}{2L_{\text{panel}}}$, where the h_i are the heights of the fan and testing chamber respectively (typically determined by experimental constraints), for a square cross section, and L_{panel} is the length of the panel (determined by the construction team). Proceeding with the algebra depending on design specifications on either angle or panel length, one may determine remaining parameters. Note that for square cross-sections, the height and length are interchangable.

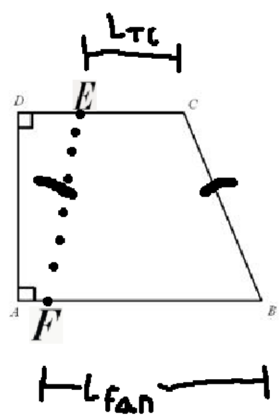

Figure 3: Rough sketch of geometry of contraction chamber panel

To start construction, take a prepared bilayer foam panel, and from one of the corners make a mark that is a distance of $\frac{L_{fan} - L_{TC}}{2}$ on the edge of the side that will meet the testing chamber. Then, score-and-snap from that mark at point C to the corner at point B, resulting in the right trapezoid above. Now, place a mark on the line segment CD that is the length of the testing chamber away from point C—we will call this point E. We will then mark another point, point F, to be the length of the interior of the housing chamber (typically the length of the fan) from point B. A line is then drawn from this mark at point E to point F, resulting in the isosceles trapezoid $EFBC$ of the correct dimension of our panel, without measuring an angle. This process is repeated three more times for each body panel. To assemble, take any CB, and place it outside of the line segment EF so that the edge of the panel is just outside of EF towards AD. Pin together as outlined above and repeat the process until construction is completed. Ensure correct interior dimensions prior to permanently bonding the surfaces with hot glue. This reliably yields a geometrically correct contraction chamber and can be easily completed in under 30 minutes. In the end, our panel length was 0.508 m, our angle of depression was 16.88 degrees, and our chamber length was 0.495 m. The result for the process is below, prior to trimming, on a prototype as well as the CAD rendering of the finished contraction chamber.

(a) From housing chamber's perspective

(b) From TC's perspective.

Figure 4: Prototype of contraction chamber design

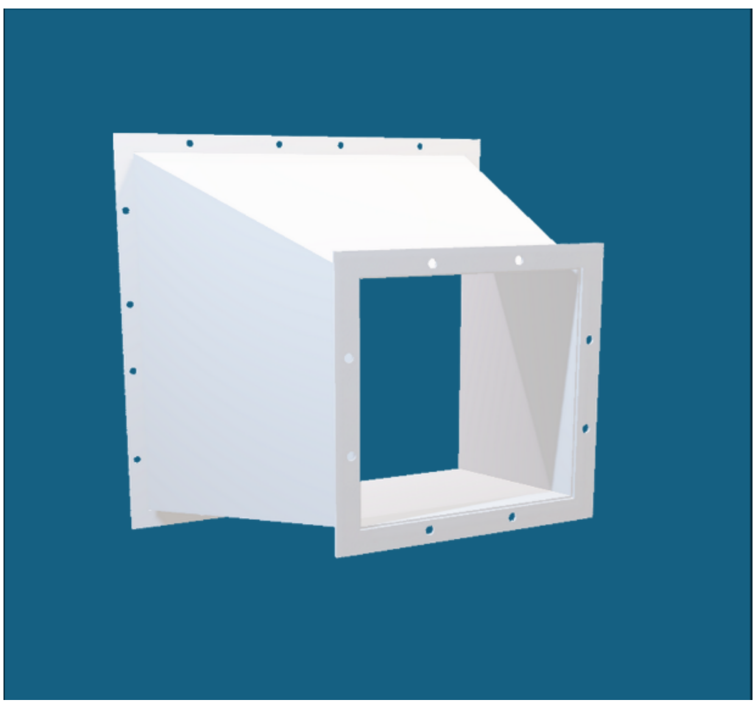

Figure 5: Contraction chamber CAD design.

3.6 Diffuser

The purpose of the diffuser is to gradually expand the flow area of the air from higher speed, lower pressure flow to a lower speed, higher pressure flow to minimize turbulence, and maintain steady airflow. The diffuser is at the end of the wind tunnel and its construction follows the exact same procedure as the contraction chamber, except no large flange is necessary for this piece. In our case, the chambers are slightly different, as we repurposed the intake from a previous iteration, so its angle of elevation is 19.55 degrees, its panel length is .508 m, and its total chamber length is 0.488 m. The literature states that the diffuser's angle should be sharper than the contraction chamber's so that the chamber may evacuate the air more quickly with a steeper angle (Hernandez et al., 2013); however, the team was given specific guidance to make these two parts exactly the same.

3.7 Structural Frame

Each part is attached to the next via a flange, made of four layers of the same foam used to construct the rest of the wind tunnel. Each flange is 0.05 m wide and consists of four pieces of laminated foam with their edges cut to 45 degrees to allow for a higher margin of error as far as measurement goes when constructing the parts. The large flanges, each piece about 0.55 m long, were pinned and hot glued to one end of the housing chamber and to the large end of the contraction chamber. First, four layers of foam were glued together with contact cement and cut at a 0.05 m width lengthwise, which gave the templates for the flanges.

The flanges were attached to each chamber by setting a chamber flat on a table, pinning the flanges in the position they needed to be in, and hot gluing the flanges to the chambers once they were in the proper position. Hot glue was used to fill the gap between the flange and the incline of the contraction and diffusion chambers. After the flanges were firmly attached to their respective chamber, flanges in contact with one another were clamped together and a 3/8" drill bit was used to create holes for the bolts that would attach each flange. A similar process was used for the small flanges, each measuring about 25 cm long, that attached the small end of the diffuser to the testing chamber and the other end of the testing chamber to the diffuser.

Our initial design for the flanges consisted of a hollow square cut from double-layered foam that was just a single piece. We found that this was too much of a constraint, since the measurement of the surrounding chambers was not cut precisely to what we expected. After discovering this, we decided that it would be best to change to a new design and only cut the flanges once all the other parts were complete. This allowed for more leniency as far as dimensions were concerned. In the final design, we also decided to use four layers of foam instead of the two layers in the initial design, which allowed more room to glue each part to the next. Another problem we had was fitting the corners of each flange together. If we could change this design, we would use a staggered square design similar to the design that we used for the housing chamber.

4 Conclusion

The construction of each piece and the integration into a single, functional wind tunnel system was ultimately a success. However, there were various areas that could be improved as far as construction went. One of the major oversights was creating a surface or some sort of support that accounted for the varying lengths of the separate parts of the wind tunnel, most notably was the large difference between the bottom of the large flange and the bottom of the testing chamber. To compensate for this, we stacked multiple layers of foam until the testing chamber was level with small flanges and, although this works as a temporary solution, there are more ideal ways to create a permanent solution such as attaching metal stands to the testing chamber. Finally, it is possible to adapt our construction method to curved forms, allowing for easy, replicable creations of something once thought to be very difficult. Overall, we have proven highly replicable, durable, adaptable, and precise methods for construction of a low-speed wind tunnel; however, several design decisions were made that will be likely hinder preservation of laminar flow, so further testing is needed to verify whether or not our wind tunnel can preserve or even create laminar flow.

Works Cited

Hernández, Miguel A. González, et al. "Design Methodology for a Quick and Low-Cost Wind Tunnel." *Wind Tunnel Designs and Their Diverse Engineering Applications*, IntechOpen, 6 Mar. 2013, https://doi.org/10.5772/54169.