The Effectiveness of Honeycomb on Boundary Layer Tunnel to Reduce Boundary Layer Thickness

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Boundary layers contribute in increasing the pressure drag or shear forces to a body moving through a fluid. Many wish to reduce the presence of the boundary layer. More specifically, in the wind near the surface of the ground, there is buildup of boundary and that occurs because the effects of the viscosity are very significant. It's very important for ground vehicles when testing to experience less effect by the layers of the fluid near the surface since these vehicles don't experience any on the road. In other words, it is very important for the wind tunnel testing to be as realistic as possible for passenger cars. Since on the road, cars, for example, and the ground are moving relative to each other, there is no presence of boundary layers. To address this issue, we claim that inserting a flow straightener (honeycomb) in the wind tunnel before the test section will reduce the buildup of the boundary layer. Other way of many ways is to have a non-fixed floor.

Nomenclature

U_{se}	=	Stream Velocity
U/U_{∞}	=	Ratio of Velocity at peach probe to Free Stream Velocity
q	=	Free Stream Dynamic Pressure

I. Introduction

Making wind tunnel testing as realistic as possible is always crucial and greatly desired. But, for motorsport cars, in the wind tunnel, they do not necessarily achieve the same reality as they do on the road.[1] There is a key point why I mentioned "motorsport cars" and I will explain that in the following lines. The focus here is the boundary layer growth in the wind tunnel near the surface of the floor and how to reduce the growth. That alone distinguishes the wind tunnel testing from reality. So, before jumping to why I mentioned "motorsport cars, I prefer to give a physical definition of boundary layer. Boundary layer is a thin layer of viscous fluid near the solid surface of the wall that in contact with the moving fluid particles. That means that the fluid particle's velocity varies from zero at the wall to a constant velocity profile up to U_{se} (See figure 1).[2] Laminar and turbulent are two different types of boundary layers (figure 2). The reason why I mention racing vehicle is simply because they are one to three inches off the surface of the ground. And because of that, they experience a high effect of the boundary due to the fact that they are within the range of the boundary layer growth. Customers desire that the wind tunnel staff find a way to reduce the effect of the fluid near the surface. And that what we aim to address on this investigation. Our goal is to insert a honeycomb in front of the test section. Why honeycomb? Honeycomb was provided to us to do this investigation. Moreover, honeycomb approach is cheaper than any other method. What honeycomb does is that it basically straightens the flow.[3]

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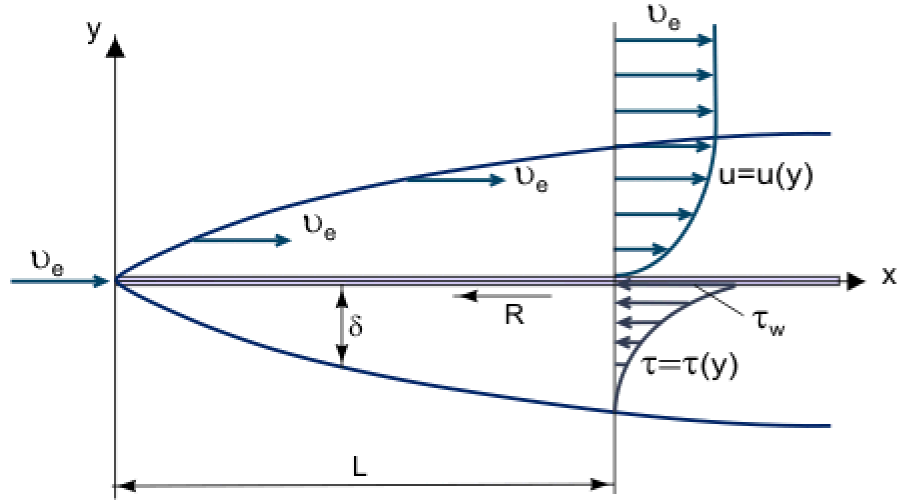

Figure 1. Buildup of boundary layer on a flat plate

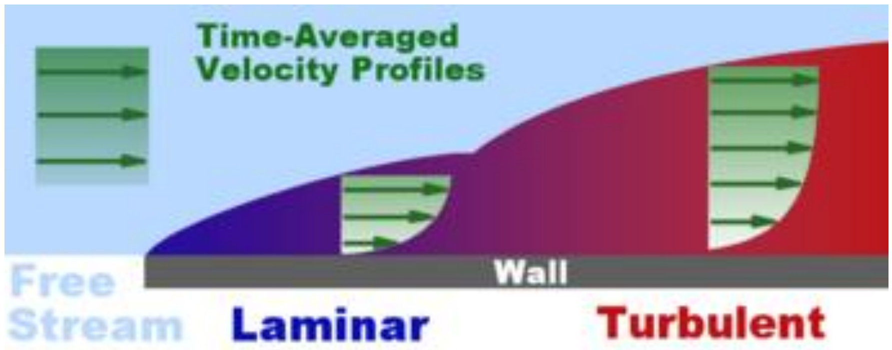

Figure 2. Types of Boundary Layer

II. Background

In 1970, it was discovered that ground vehicles encounter more drag coefficient on a fixed ground in a wind tunnel. That was discovered when Formula 1 cars were doing testing on their products in the wind tunnel. It was then realized that such a case can't obtain the correct result. Formula 1 figured that by ignoring this effect would result a large effect on the overall performance. The solution to that matter wasn't hard to obtain. It was easy to have the car be placed in a moving belt, so the wheels were moved by the belt. The moving belt, which resembles the ground, obtains a speed that's relative to the car to obtain a real-life situation. [4-5] To conclude on that matter, boundary layer growth exists in a wind tunnel and that was a way to reduce or remove it. But, the idea of the honeycomb was not used as a method to reduce the boundary layers. Honeycomb was discovered as a method to reduce turbulence in the fluid particles. Honeycomb is still used in low-speed wind tunnel. It is the first component that the flow encounters.[6-7]We never came across a paper that talks about putting a honeycomb or screening before the test section. However, the mechanism of the honeycomb is good. In fact, that mechanism of honeycomb could achieve what Formula 1's intent.

There are three different types of honeycomb in the industry. They differ in the shape size. (See figure 3). For each one of them, they produce different results as the flow go through the cells. With that being said, it was calculated that they have different pressure losses. Honeycomb a has 30%, type b carries 22%, and type c carries 20% of pressure loss. For our investigation, we used type c. These elements could change with the material type of the honeycomb as well as the depth of the cell.

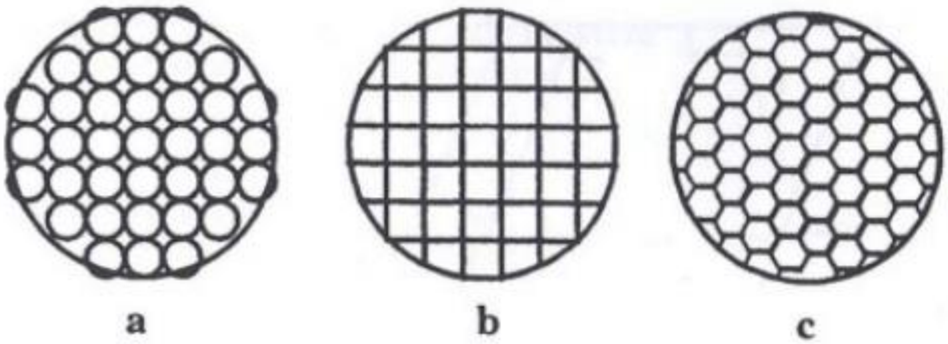

Figure 3. Types of Honeycomb

III. Experimental Approach

For this project, the Boundary Layer Tunnel was used instead of the 3x4 wind tunnel. The reason why the Boundary Layer Tunnel was chosen because the team would like to see if the use of honeycomb will be effective for smaller scale experiment. In the beginning of the project, the team was given bunch of honeycomb with different materials, thickness and diameter cell size. The team decided to use two different kind of materials, with two different kind of thickness and diameter cell size.

The honeycombs that were used for the experiment were aluminum honeycomb and nomex honeycomb. Each of the honeycomb had different cell size. The aluminum honeycomb had one-fourth inch diameter cell size, whereas nomex honeycomb had one-eighth inch diameter cell size. The figure 4 indicates the size of the cell for each of the honeycomb and it was clearly seen the difference of each of the honeycomb. There were some differences of the thickness of the honeycomb. For aluminum honeycomb, there were 0.75 inches, 1.5 inches and 2.25 inches which was the combination of 0.75 inches and 1.5 inches. Similarly, for nomex honeycomb, there were 0.75 inches, 1.625 inches and 2.375 inches which was also the combination of 0.75 inches and 1.625 inches. Therefore, there were 6 configurations of the honeycomb that would be tested for the experiment.

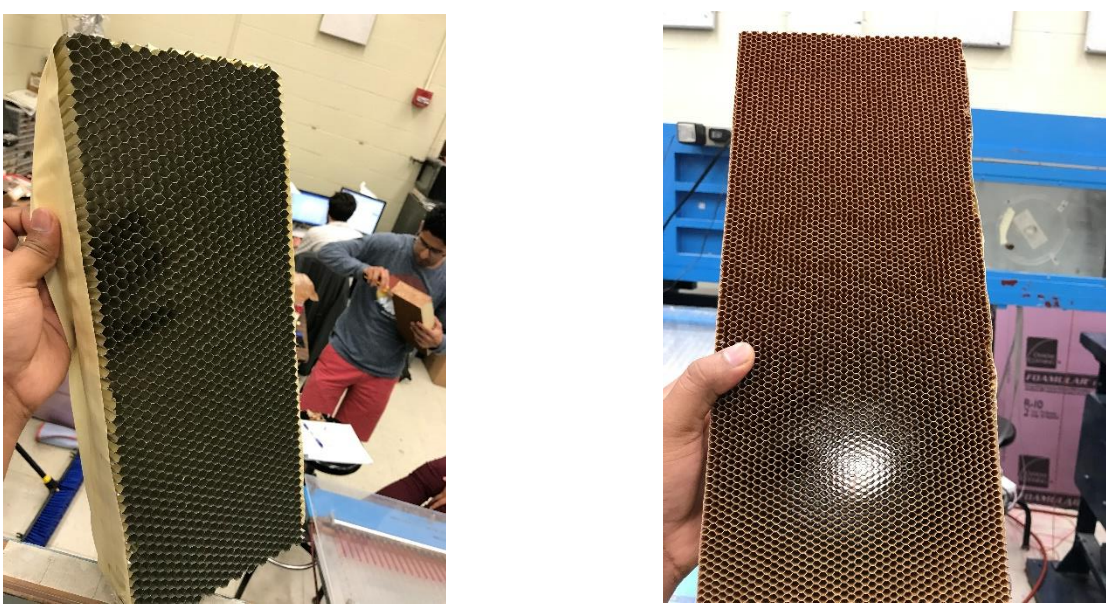

Figure 4. The Preview of Aluminum Honeycomb and Nomex Honeycomb

For this project, the honeycomb would be mounted in the test section of the Boundary Layer Tunnel, which was before the probes that had been placed inside the tunnel from beginning. The distance of the honeycomb was fixed for the entire run, which the team decided to be placed 5 inches in front of the probes. The probes were normally connected to the manometer which was already provided in the lab. However, instead of using the manometer, Scanivalve DSA 3217 was used to measure the pressure differences in the tunnel.

Scanivalve is an equipment to measure pressure differences and pressure coefficient of the tunnel (shown in figure 5). In this experiment, the one that needed was pressure differences and pressure coefficient was negligible. Scanivalve only provides 16 channels for the pressure measurement, whereas the probe in the Boundary Layer Tunnel itself provides 21 channels of pressure measurement. From the previous Boundary Layer Lab that had been done for academic purpose, the boundary layer edge was found on the channel 16 and 17. Therefore, for the Scanivalve, the team used odd number between channel 1 to 10 and used the remaining channels to be connected. This was because channel 1 to 10 on the probe were close to each other. Hence, the channel 11 to 21 were more important to give significant results. The Scanivalve has an ethernet connection that had to be connected to the computer that was provided for the team and also made sure that the connection was attached properly before doing the experiment. Also, for pressure reference, static pressure was used.

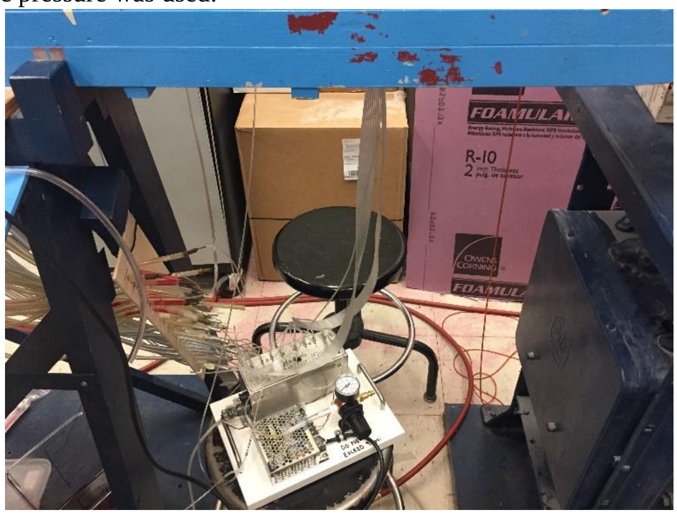

Figure 5. The Scanivalve was Attached with the Tube Channels from the Probe

Before proceeding the experiment, the honeycomb had to be cut into certain dimension to make sure that it would be able to fit into the test section of the tunnel. To cut the honeycomb, bench saw was used to cut the honeycomb from huge piece into smaller piece. In the beginning, the dimension of the honeycomb was purposely to be cut bigger than the size of the test section. Afterwards, the honeycomb was trimmed and adjusted by the scissors. It was not hard to cut the entire honeycomb pieces; however, it was hard to make sure that the sides of the honeycomb were really straight and perfect. It would be better if the side of the honeycomb would be straight. Since, the side of the honeycomb was also rough, paper tape was used to cover the sharp parts to make less friction between the side of the honeycomb and the tunnel wall.

The distance of the end of the honeycomb and the probe was fixed, which was 5 inches in front of the probe. This made that the variable was fixed. Also, the freestream velocity that was used around 58 ft/s for the entire configuration. For each configuration had to go through more than one run to get more accurate results.

Mounting the honeycomb was a little bit a problem. It was not hard to slide in the honeycomb to the test tunnel (as shown in figure 6) however, it was hard to make sure that the honeycomb was straight enough to be inside the test tunnel. The team found out that when the tunnel was on, the honeycomb position would move due to the flow and the orientation would not be straight anymore. Therefore, to minimize any extra movement during the experiment, two sticks were attached behind the honeycomb to make sure that it did not move and it was straight. In this case, it would help to limit any kind of movement that happened inside the tunnel. Figure 7 showed how the honeycomb was mounted inside the test section.

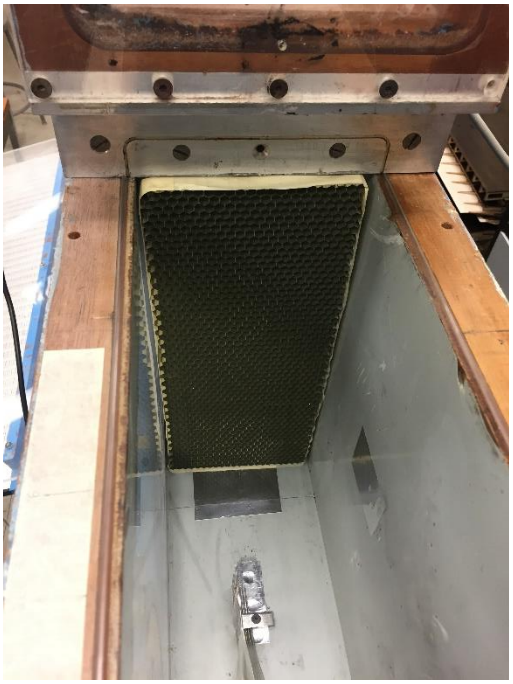

Figure 6. How to Slide in the Honeycomb Inside the Test Section of the Tunnel

Before mount the honeycomb inside the tunnel, control experiment had to be done first. This became the reference for the entire experiments with the honeycomb. For all configuration, which was also include the control experiment, the q-value was constant therefore it would be the constant variable for all experiments. The q-value that used was 4.0 ft/s. For each configuration was done for about 2 runs each time and for control, it was about 3 runs.

Two of the configurations were the combined thickness of honeycomb, which was for aluminum honeycomb had 2.25 inches thickness, whereas for the nomex honeycomb had 2.375 inch thickness. One thing what the team had to make sure before the experiment was, the cell of honeycomb had to be in line between one honeycomb to another. It meant that the flow would go through the cell for both honeycomb. Therefore, before cutting both of the honeycomb in the beginning stage, the team made sure that the orientation of the honeycomb cell had to be the same for the combined thickness honeycomb.

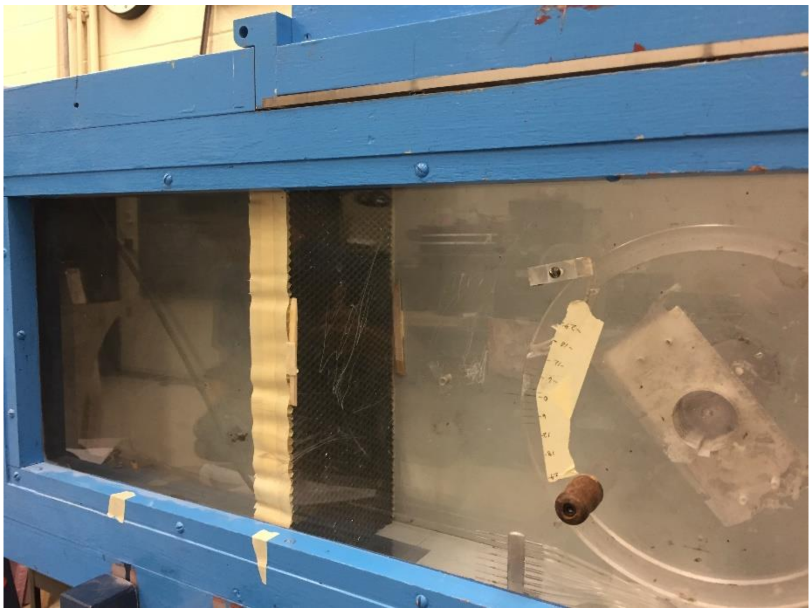

Figure 7. How the Honeycomb was Mounted in the Test Section of the Tunnel

IV. Results and Discussion

The results obtained from the experiment supports the original goal of this project. Using honeycomb inside the test section resulted in boundary layer thickness reduction. However, few configurations of honeycomb that were used had significant free stream dynamic pressure losses. All the data obtained for each set of honeycombs were compared with the control. Boundary layer thickness inside the empty test section of the boundary layer wind tunnel was found to be 1.6 inches which was used as the control of this experiment. The following table illustrated the result obtained for each honeycomb.

Table #: boundary layer thickness reduction and dynamic pressure loss

Honeycombs	Percentage reduction of thickness	Dynamic pressure loss
Nomex Combined (2.375 in)	63%	35%
Nomex Thick (1.5 in)	38%	13%
Nomex Thin (0.75 in)	20%	7%
Aluminum Combined (2.25 in)	25%	0
Aluminum Thick (1.5 in)	20%	0
Aluminum Thin (0.75)	10%	0

The dynamic pressure loss of the nomex honeycombs were due to the smaller cell sizes of the honeycomb. Since the aluminum honeycombs had bigger cell sizes, the flow could pass through them more easily and hence there were no pressure loss. However, the percentage boundary layer thickness reduction by the aluminum honeycombs were comparatively lower than the nomex honeycombs.

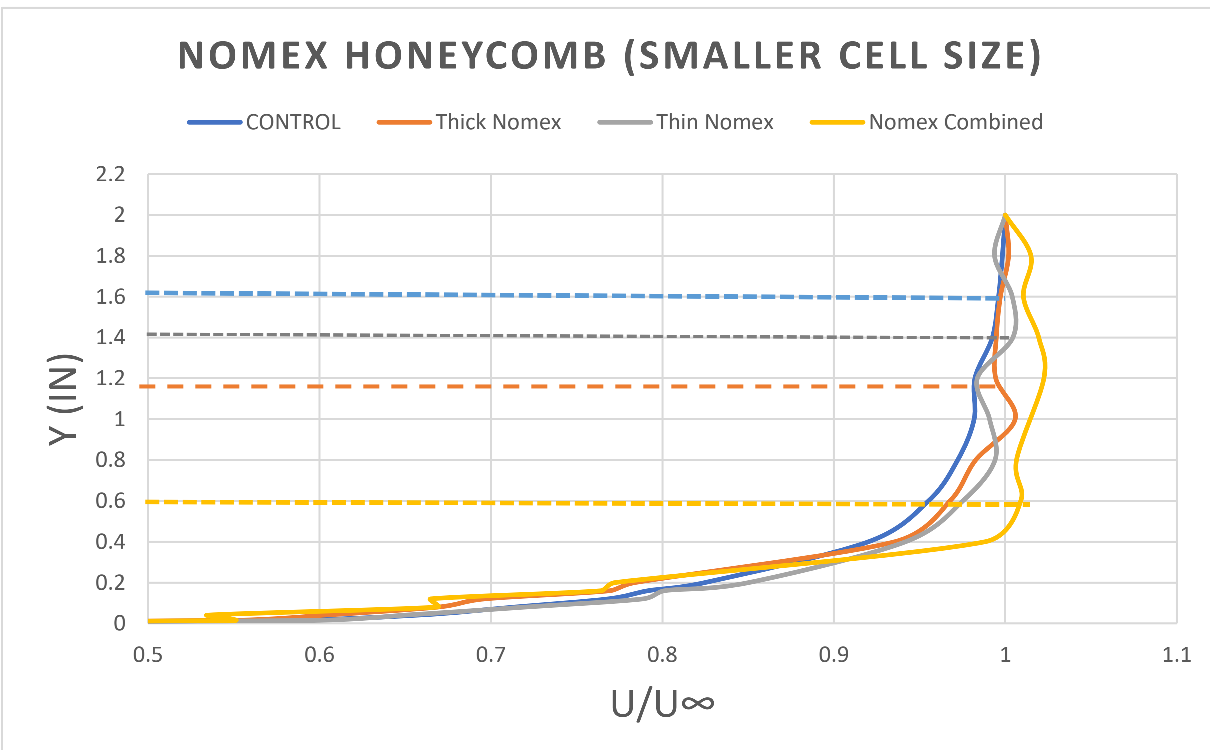

Figure 8. Graph of Nomex Honeycombs' boundary layer thickness against the ratio of velocity at each probe to the free stream velocity.

The graph for nomex combined honeycomb which had a thickness of 2.375 inches stretched beyond U/U_∞ of 1 which is unexpected. The installation of the nomex combined honeycomb was not perfect. Due to the force exerted on the honeycomb by the flow, the original positioning of the honeycomb was compromised and it positioned itself at an angle to the pressure measuring probes. Due to this phenomenon, the flow was coming out from the honeycomb at an angle instead of being parallel to the probes. Some of the probes read higher velocities than the expected free stream velocity. The team was unable to fix this problem and decided to work with the data obtained.

Boundary layer thickness of the control was determined by looking at the data table and identifying the point from which the dynamic pressure at each probe were nearly constant. Theoretically the gradient of the graph should be vertical at U/U_∞ of 1 at which point the velocity at the probe matches the free stream velocity. The graphs plotted with the experimental data illustrate a similar phenomenon. The same process was also followed to find the boundary layer thickness for all the honeycombs.

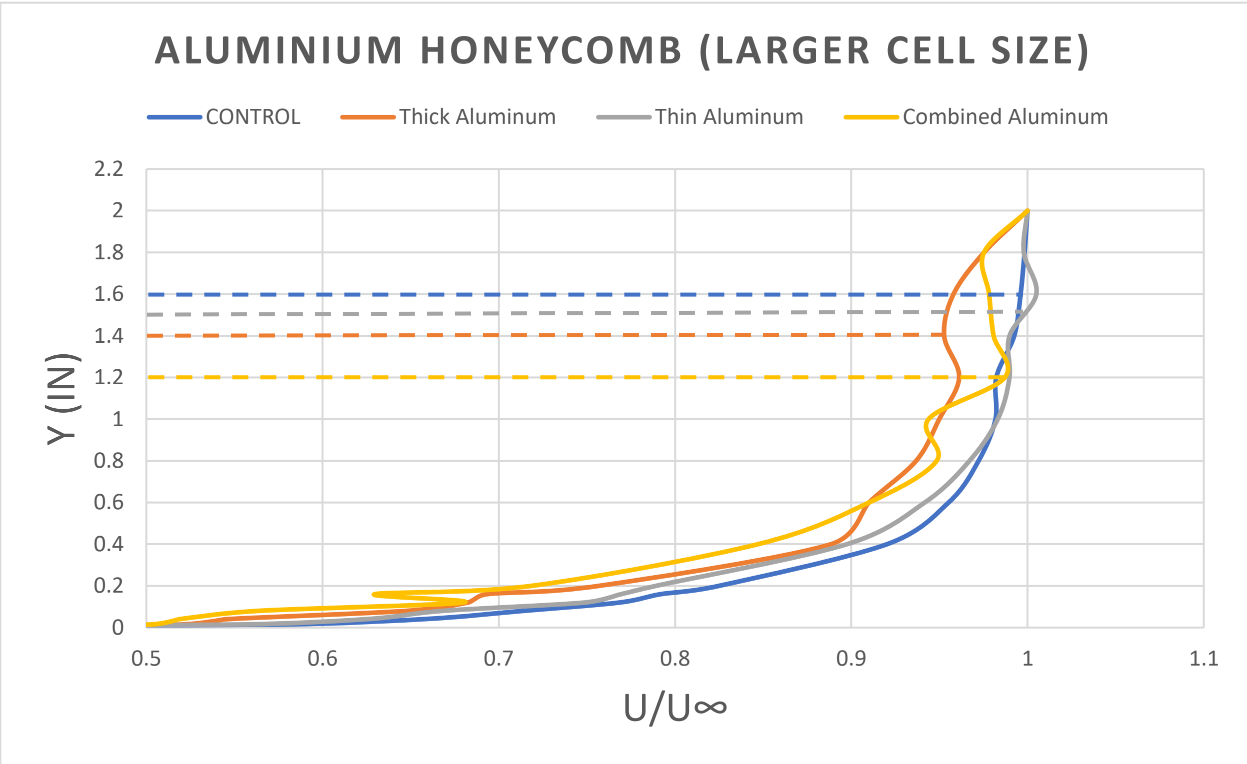

Figure 9. Graph of Aluminum Honeycombs' boundary layer thickness against the ratio of velocity at each probe to the free stream velocity

The data obtained for all the honeycombs had significant inaccuracy to it. The graphs do not look similar to the control. The errors in the data were due to the shape of the honeycombs. The team tried their best to cut the honeycombs using the resources available to them. However, the edges of the honeycombs had roughness to it and the bottom cells where not as smooth as it were supposed to be. Rough edges and unsmooth cells disturbed the flow as it went through the honeycombs. This resulted in ununiform flow in from of the probes and hence the inaccurate data. However, there were still a continuous increase in dynamic pressure till a certain point.

V. Conclusions

The objective of this experiment was to reduce the boundary layer thickness of a wind tunnel by using honeycomb inside the test section. The reason behind this experiment was to aid in improving ground vehicle testing in the wind tunnel. According to the results, using honeycomb inside the test section does reduce the boundary layer thickness. The best result was obtained from the nomex honeycomb of thickness 2.375 in. It reduced the boundary layer thickness approximately 63%. The data reveals that as the thickness of the honeycomb is increased the boundary layer thickness in the test section decreased. The cell size of the honeycomb also had a major contribution. A smaller cell sized nomex honeycomb introduced free stream dynamic pressure loss, however, the larger cell sized aluminum honeycomb had no pressure loss. To conclude, it can be said that the thickness of the honeycomb is directly proportional to the amount of boundary layer thickness reduction.

Further studies should be carried out to identify the effect of cell sizes of the honeycomb on boundary layer thickness reduction. The distance between the honeycomb and test object is also something that needs to be experimented with to identify its relationship to boundary layer thickness reduction. In future experiments, it is paramount that the shape of the honeycomb used is almost perfect since it has a very big effect on result obtained. A better mechanism to install the honeycomb inside the test section must be developed in order to illuminate any flow angularity.

VI. References

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