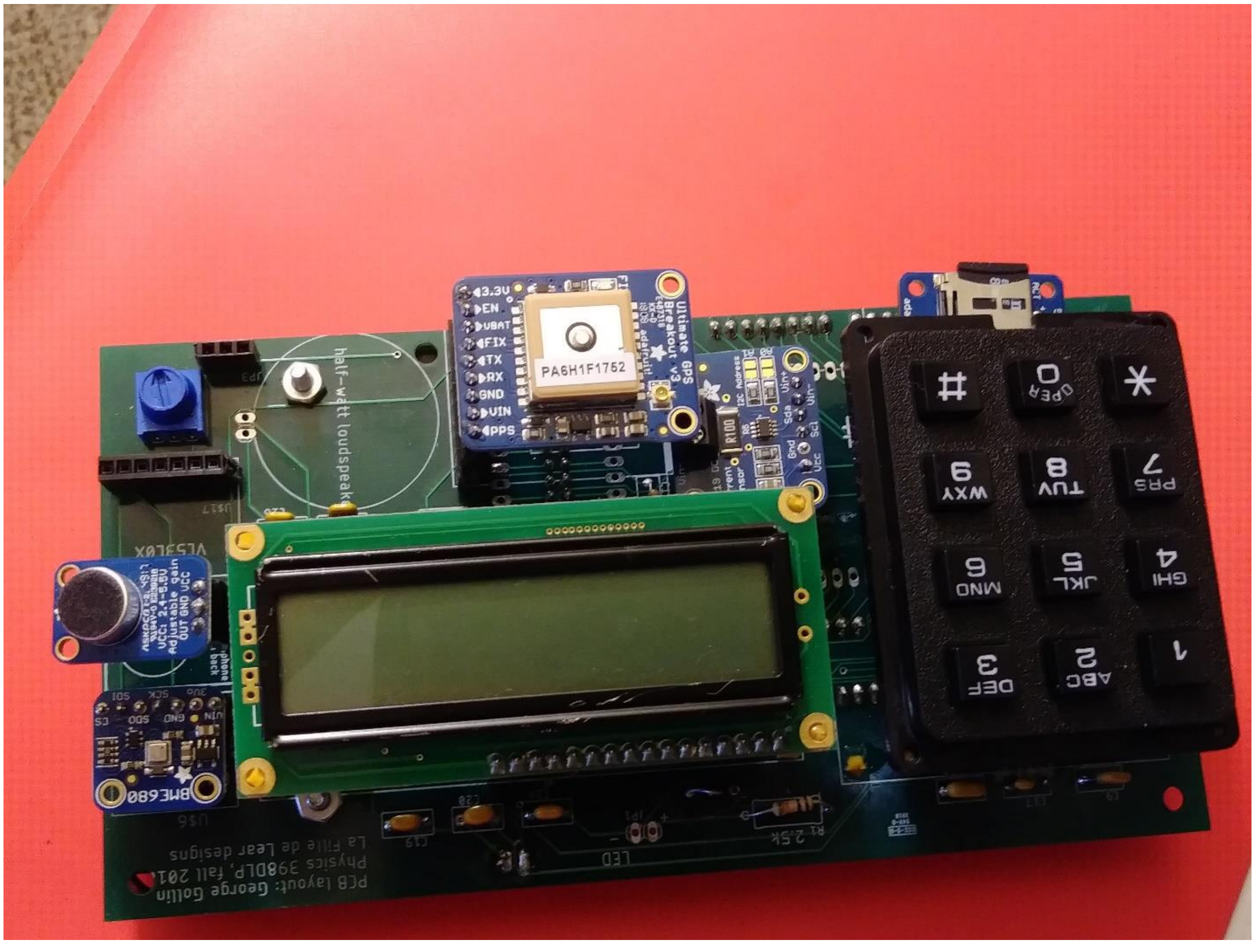
“Exploratory Experiment on Noise Reduction in a Sedan”



Andrew Engel and Marco Palella

University of Illinois Urbana Champaign

Physics 398 DLP

December 3rd, 2018

I. Introduction:

Automobile companies have always been committed to giving their customers a comfortable and affordable driving experience. That is why auto companies dedicate resources to produce an acoustically sound cabin and to reduce noise. For example, many auto companies have tried to reduce engine noise by syncing the motion of pistons in the engine such that the sound waves produced by the pistons cancelled one another out. This helped to limit the amount of noise coming from the engine. In recent years, however, many companies have decided that fuel efficiency is a greater priority than noise reduction and have removed this syncing to improve the fuel efficiency of the engine. As a result, other methods that reduce the noise coming from the engines have been made. One example comes from the 2013 Ford Fusion, which contains a microphone/speaker system that records ambient noise in the cabin, inverts it, and plays it through speakers near the headrests of the passenger's and driver's seat.

The following document details the research that was conducted on the noise levels at different points in the 2014 Ford Fusion. The goal of this research was to better understand how Automobile companies can decrease the amount of noise being perceived by the driver and passenger from sources like the engine, wheels, and AC/Heating system. Our experiments test a sound absorbing material at different positions in the cabin to compare resulting changes in measured noise levels heard by the passenger. The experiments performed provide statistically significant variations in noise levels near the passenger's headrest and a baseline mapping of the noise levels inside the cabin with fans set to maximum flow.

II. Development of Software and Hardware:

The apparatus we used was composed of two main sections: the hardware and embedded software. The hardware section (testing apparatus) consisted of the following components:

- The Arduino Mega Microcontroller
- Printed Circuit Board (PCB)
- Adafruit electret microphone (MAX4466) with adjustable gain
- MicroSD card breakout board
- 4 x 3 Keypad
- Crystal Fonts Liquid Crystal Display (LCD)

Using the printed circuit board design software, EAGLE, we used a customized PCB layout that would connect the pins on these individual components to the necessary Arduino communication pins and power systems. Housings were then 3-D printed for the PCBs to provide protection. The PCB and cases were used in order to improve the ergonomics of the device and to mitigate damage if the devices were accidentally dropped.

The electret microphone was an essential part of testing and has several important qualities. The microphone contains an operational amplifier that can produce a gain from 25 times to 125 times the initial input from the microphone. Our microphone op amps were set to max gain (125x) since we were looking for signals with minimal variation. To give a baseline for the loudness that is associated with a specific microphone measurement, the signal from the microphone/amplifier exhibits a variance value of around 2 when no noise is being made, and when a conversation is occurring two feet away from the microphone, it produces a value of around 25. The frequency response of the microphone can be observed in figure 2.

The Arduino development environment was used to program the microcontroller. The code on the Arduino worked in the following manner:

1. Components are initialized
2. User is Prompted to press * to run program, and program waits for * to be pressed on keypad
3. Once * is pressed, the Arduino obtains 100 readings from the electret microphone at a sample rate of approximately 1,000 Hz, each having a value from 0-1023. These values correspond to the voltage that is being measured at the analog pin that the electret microphone is plugged into on the Arduino. Note, values below 512 correspond to a negative voltage value, so the value 0 is communicating that a negative voltage value is being detected.
4. The variance of the 100 samples is then calculated; variance is defined as $\mu(x^2) - \mu(x)^2$ (with μ being the mean of the random data set, and x being that dataset)
5. The program repeats this process 100 times, thus taking 100 variance values, which are then stored into an SD card via the breakout board so that further analysis can be done.
6. SD prompts user to take more measurements by pressing #

This device would allow the user to record 100 variance audio values at any moment that they desire, which was a necessary design criterion due to the need for constant repositioning during testing.

Figure 1: Final Apparatus

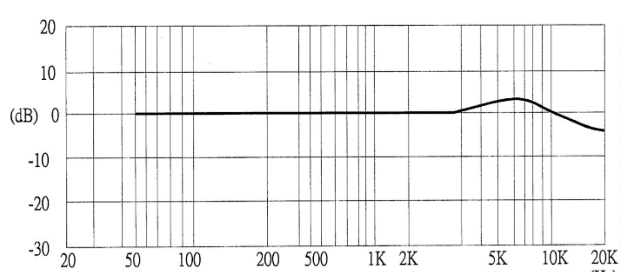


Figure 2: Frequency Response of Electret Microphone

III. Procedures:

For the first round of measurements, we wanted to create a rough map of the noise level as a function of position inside the vehicle. Towards this end, a grid system was created in the car using masking tape. Eight front-to-back columns and thirty side-to-side rows were created (see figures 5, 6, 7, and 8). The details of the gaps between each point are unnecessary to our use of the grid system, as we are only interested in having a qualitative picture of where to place insulating material. We also took care to put increased emphasis in points of interest to passengers of the vehicle, which would be the passengers, driver's, and the rear passenger's headrest. The noise level in these areas matter the most because this is the region where noise will be perceived by passengers.

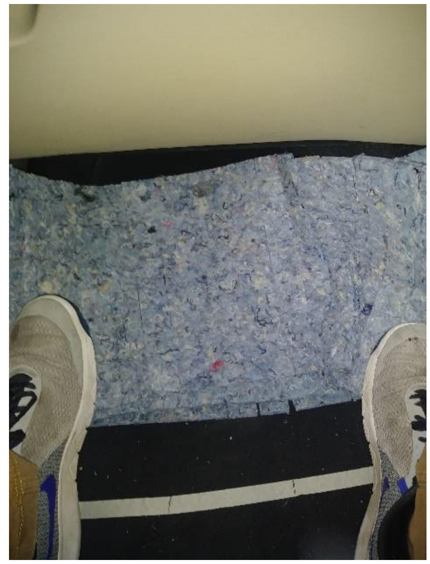


Figure 3: Insulation placement for Experiment 2 in passenger's footwell. This is a quadruple layer of 0.25" thick recycled denim sound absorber, making our layer about 1" thick, our layer is 29" wide and is 12" long.

With the grid system in place, a measurement was taken at each point on the grid while the car was on and the AC/heating fans were set to their maximum. Two experimenters, each with an apparatus, took variance measurements at each point on the grid. The experimenters took care to start recording audio at the same instance in order to reduce errors in the collection of data. One experimenter started in the front driver-side footwell and the other started in the very rear of the vehicle behind the passenger-side headrest.

In addition to making a map of the noise in the car, we also measured the ambient noise around the passenger's headrest while repositioning a strip of denim UltraTouch audio insulation strips for each experiment. In experiment 1, a 0.5" layer of the material was placed in the footwell on the passenger's side. In experiment 2, a 1.0" layer of the insulation was applied to the same footwell. In experiment 3, a 0.5" thick layer of the insulation was placed on the top of the dashboard. One experimenter drove the vehicle, while the other experimenter sat in the passenger seat and recorded eight values starting from the lower right side working across the rows and then up the columns until all points were recorded on the passenger's headrest.

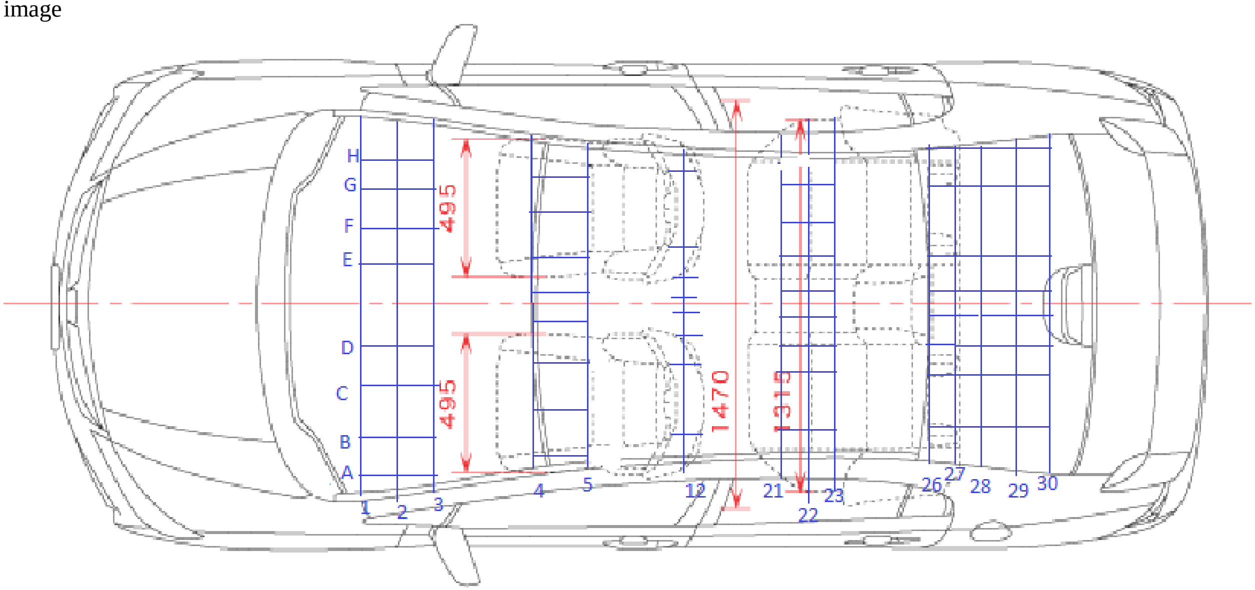
A data sheet for the audio insulation material can be seen below in figure 4. We chose this recycle denim material because of its safe handling, cheapness, and availability. It also has maximum effectiveness in the lower frequency range, where we naively expect the highest amplitude sounds to appear.

Figure 4: selection from data sheet of UltraTouch Denim Insulation

			ABSORPTION COEFFICIENTS @ OCTAVE BAND FREQUENCIES (HZ)						
R-VALUE	THICKNESS	(MM)	125	250	500	1,000	2,000	4,000	NRC/STC
R-13	3.5"	89	0.95	1.3	1.19	1.08	1.02	1.0	1.15 NRC
R-13	3.5"	89	21	40	48	52	46	48	45 STC
R-19	5.5"	140	0.97	1.37	1.23	1.05	1.0	1.01	1.15 NRC
R-19	5.5"	140	40	53	57	63	53	63	57 STC

Sound Absorption was tested in accordance with ASTM E90-02, ASTM C423 (Type A mounting per ASTM E 795)

Figure 5: Top down plan view of a sedan demonstrating grid system implemented. The bottom axis names the rows numerically, and the right axis names the columns alphabetically. Some points are obstructed from view and are omitted on this top down image



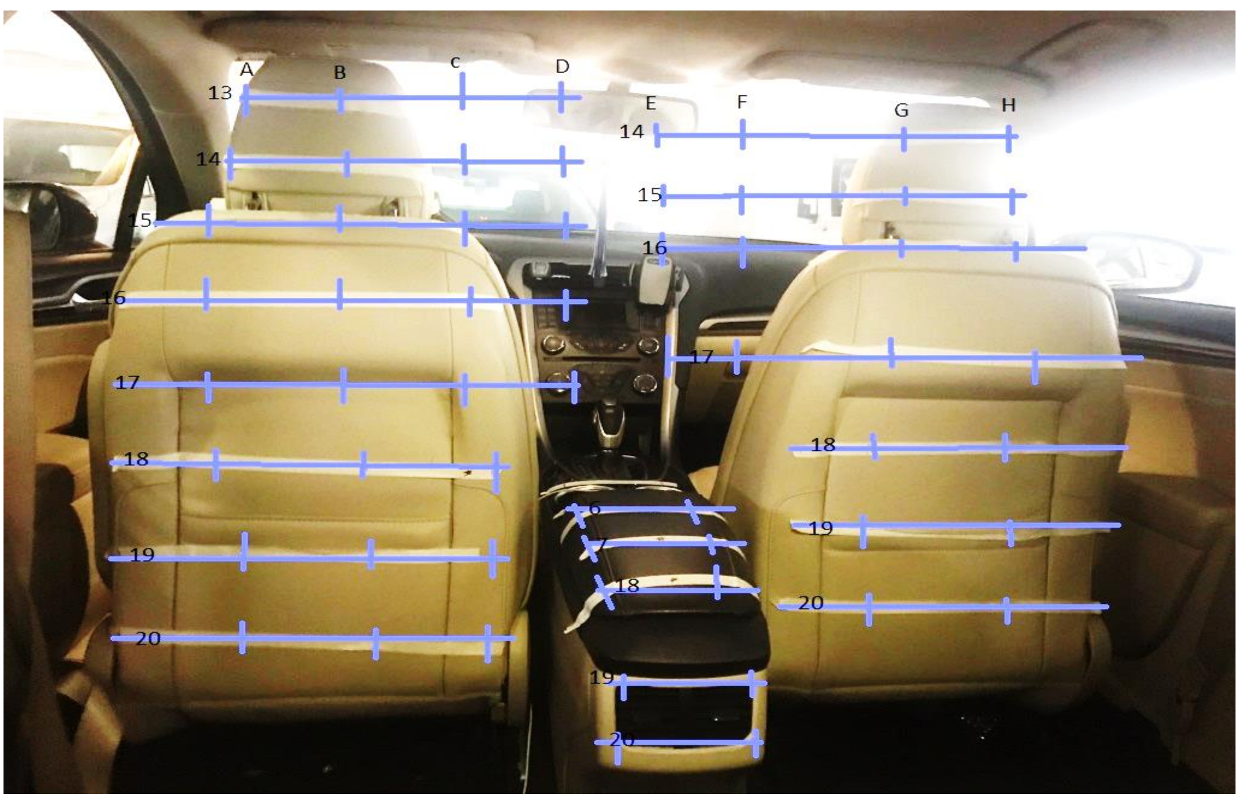


Figure 6: View from the back seats. Notice: the grid points hanging in the air were taken as shown, by extrapolating the grid into the air. We also jump to the center console at row 18. We had set the vehicle's front seats so that row 18 sat in line with row 18 on the center console.

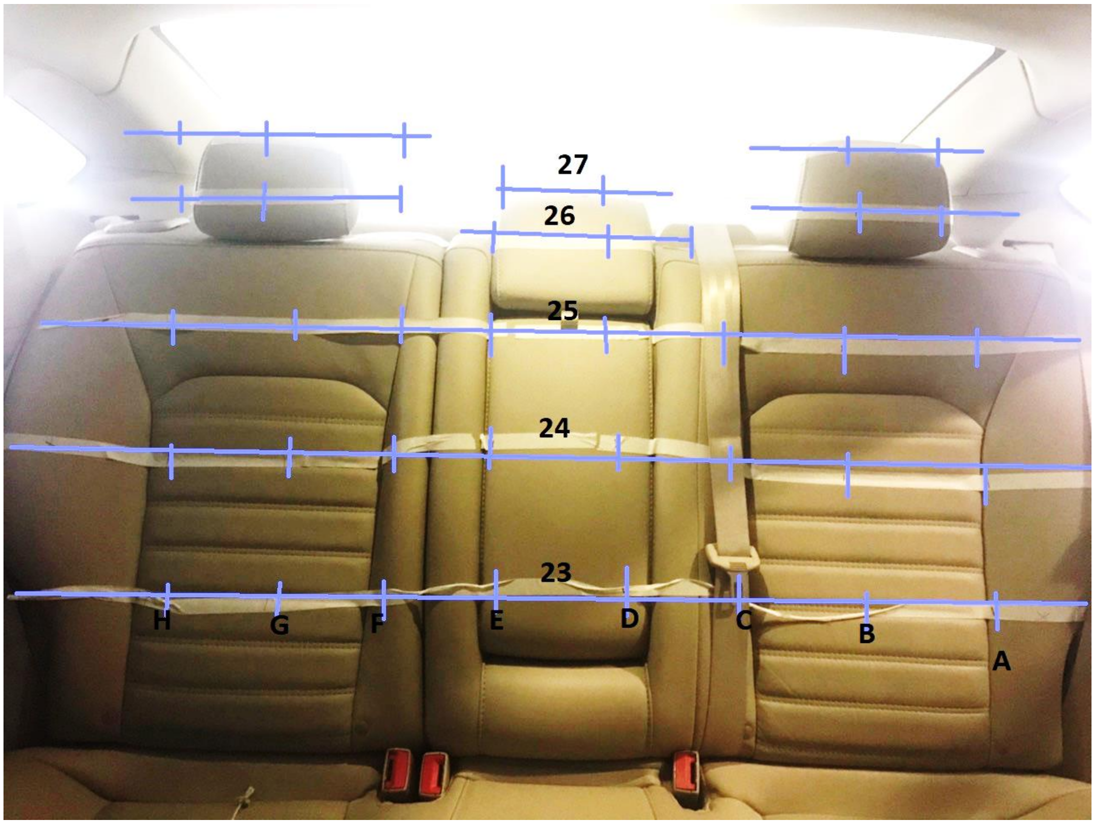


Figure 7, above: Image depicting the grid on the rear seats. Note: the grid points hanging in the air were taken as shown, by extrapolating the grid into the air.

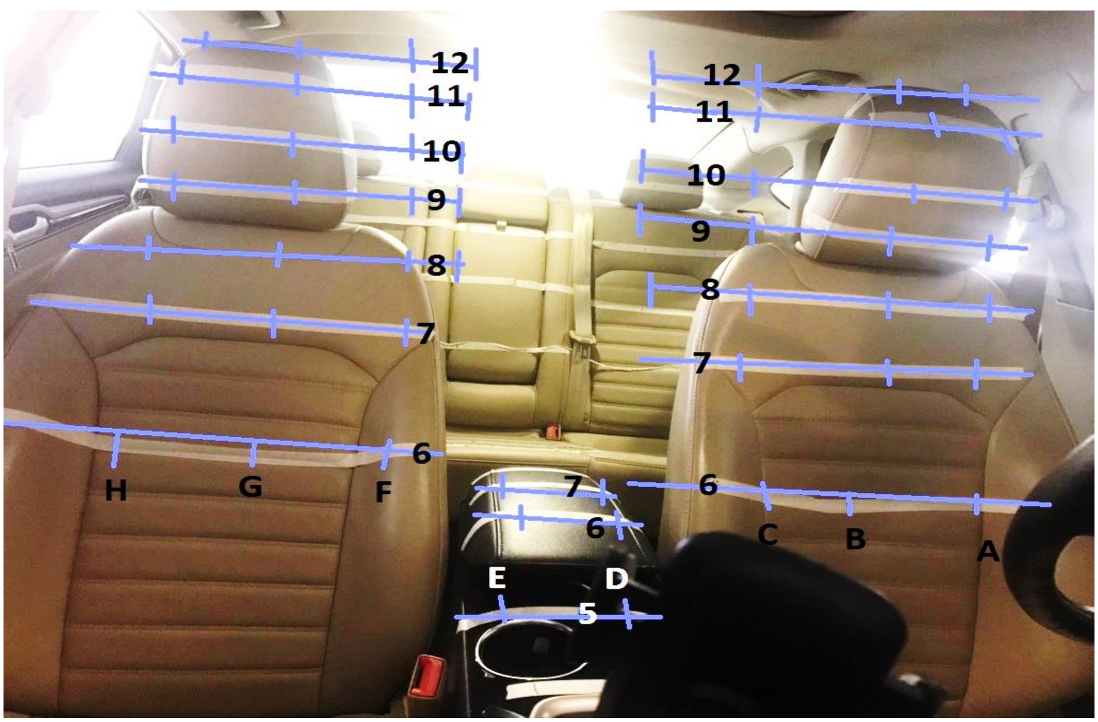


Figure 8: Image depicting the grid on the front of the driver and passenger seats. Note: the grid points hanging in the air were taken as shown, by extrapolating the grid into the air. We also jump to the center console on lines 6 and 7. Lines 5 and 4 go over the center console and the bottoms of the seats.

IV. Results and Analysis:

All analysis was conducted in Python. Using the obtained data, we identified areas in the cabin where additional sound absorption may yield a reduction in the noise level. Figure 9 shows the result of this survey as a heat map of the mean variance values obtained at each point. We hypothesize that this heat map is showing a large amount of noise emitted from the vents located on the dashboard, and then steadily falls off towards the rear of the vehicle as the driver and passenger seats block some of the sound. We were surprised that the very rear of the vehicle experienced a large increase in noise level. Using this result, we decided to experiment with the noise level by placing the insulation in the footwell of the passenger, and on top of the dashboard.

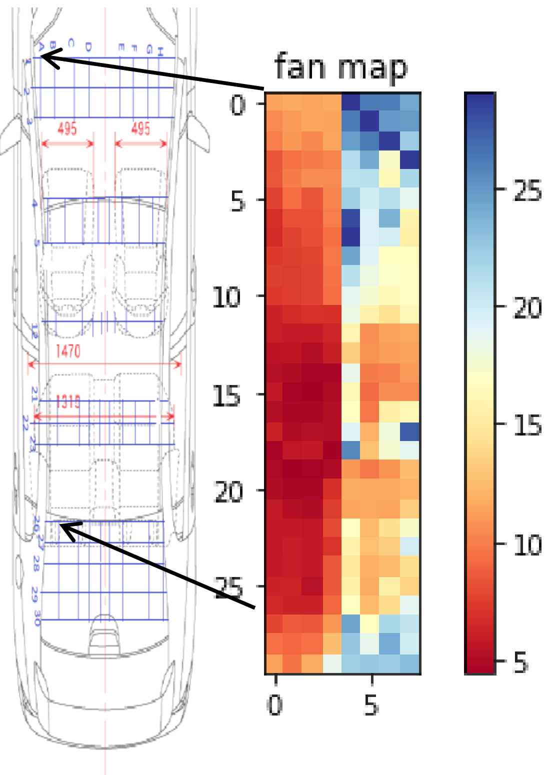


Figure 9. The map is created top down, so the top left corner corresponds to the front of the vehicle, driver's side. The horizontal and vertical axis gives the coordinates of the grid (A=0). The color bar represents the mean variance collected at that point. The space between rows changes throughout our grid, so this image is not to scale. Reference figures 5,6,7, and 8 for row numbers.

The data were normalized using a calibration method. We placed both devices on a table with microphones facing towards one another and took a 100-variance sample on each device at the same time. We then took the ratio of the means of these sets and used it to normalize our data set. One can see that this was not effective in eliminating the inter-device variance in our data, as seen in figure 4. The first four columns in figure 4 were taken by one device, and the second half of the columns were taken by another. With this in mind, a pattern still emerges that the variances are relatively higher in the front and rear of the cabin.

Analysis of our results shows that there is a significant difference $(\alpha < 0.01)$[1] in the noise level at the passenger's headrest as additional insulation is placed in the car. These results are represented in figure 10. Each of our experiments could not reduce all the noise levels of the passenger's headrest beyond our baseline, though there was variation with which positions contained large levels of noise.

To analyze our data, we first checked how well our data could be represented by a gaussian distribution. This was done by implementing the Shapiro-Wilkes test of normality on each of the one hundred sets of variance values collected for each position. The data collected did not model a gaussian distribution well, so we decided to bootstrap our data. Bootstrapping our data allows us to find the standard error on a feature of our data without knowing the parent distribution. This is useful in our situation because the distribution of variances are not normal, and are therefore difficult to analyze. In Figure 10, we show these results.

1: For those unfamiliar, the alpha is a statistical notation representing the level of false positives one is comfortable with in their test.

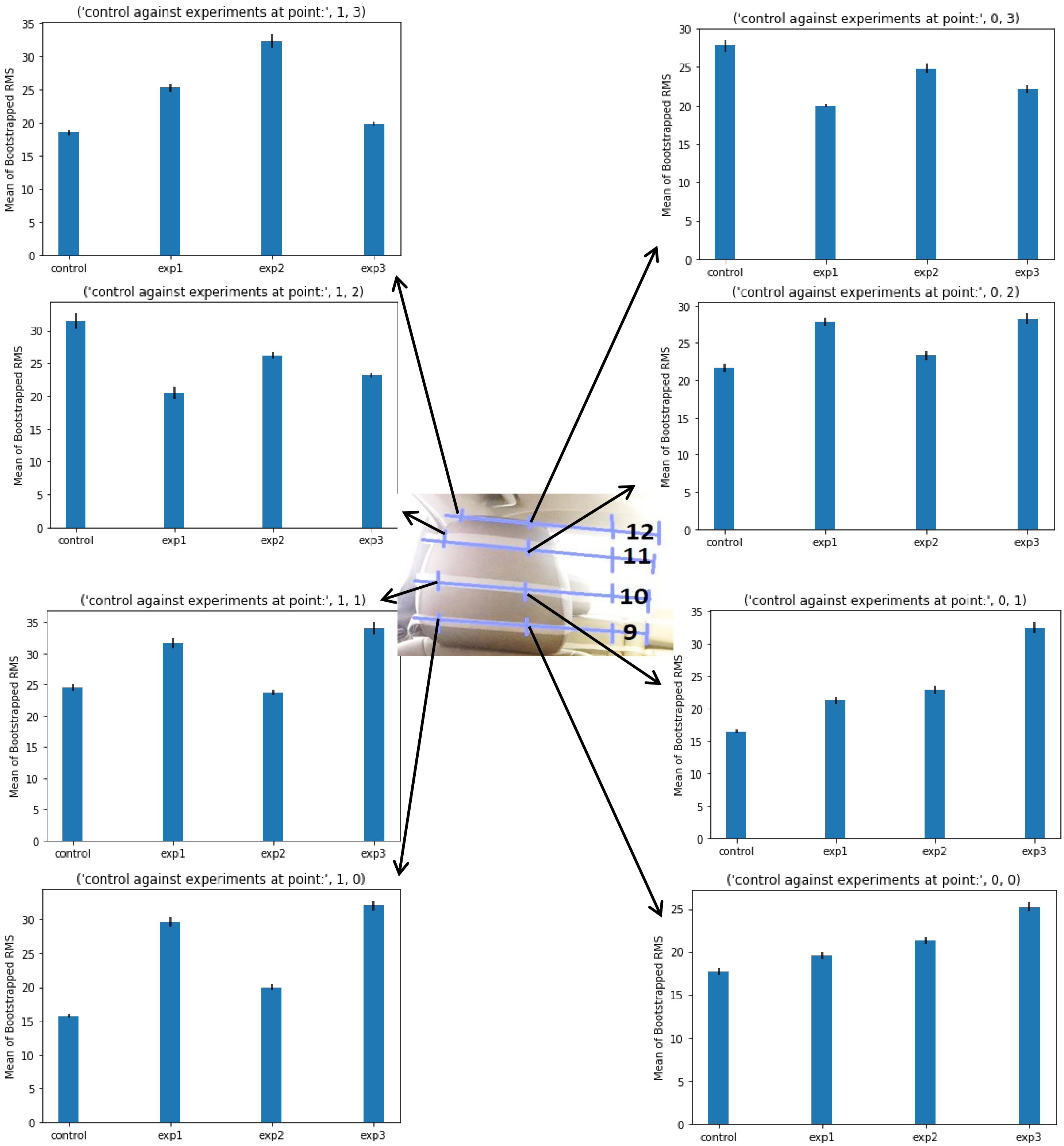


Figure 10: Each grid point is graphed with reference to the experimental variance values at that same point. The layout on the paper forms a grid that recreates a picture of the passenger headrest as though one were looking at it. the control is the baseline case: we drove the ford fusion with fans set to max, but no insulation placed in the vehicle. Exp1 is the experiment with 0.5” insulation in the footwell of the passenger. Exp2 has 1” of insulation in the footwell. Exp3 has 0.5” of insulation laid across the dashboard. Plotted are the mean values of our variances with error bars the standard error obtained from our bootstrapping method.

V. *Conclusion and Next Steps:*

In this experiment, the operant definition for what makes a strong noise reduction for the passenger is that all eight points along the headrest observe a drop in the mean variance value recorded, as compared to the baseline measurements. The drop must also be outside the range of the calculated confidence interval so that one can be more confident that this was not just a fluke. In figure 10, one can see that these experiments failed to produce this result. In fact, no experimental case performed better than the baseline on a simple majority of the points, suggesting that, if anything, the addition of our material yielded a weak increase of noise experienced by the passenger. We conclude that the addition of the material to the cabin did not lower the noise experienced by the passengers.

Our results also show that there is a significant difference (i.e. outside of error bars) between the points on the passenger's headrest. This means that the perception of noise one experiences changes as a function of how the chair and head is positioned inside of the vehicle. This suggests future studies that could be done with using our apparatus to measure slight changes in the position of the seat to find, for instance, the optimal seat position to eliminate noise.

Our analysis has showed us what cannot work in improving the acoustics of the Ford Fusion; however, there are many other experiments that still need to be done to have a complete understanding of how different materials can be used to reduce ambient noise. Due to time constraints, we were unable to perform more specific testing, which would involve putting customized bass traps in the front and back of the car and lining the interior of the car with noise dampeners to limit the amount of ambient noise being produced by the frame of the car. Additionally, since our different test cases gave varied results, it would be ideal to repeat the test in a more controlled way to test that these variations are being caused by the denim dampeners and not by the slight variations in our driving. Though we were unable to reduce the noise levels with soundproofing materials, our research has shown that these materials do influence the noise within the car. Thus, we believe that with more testing, it is possible to place material in such a way that noise will be reduced. Furthermore, analysis with different materials and checking for error in our experiments are important future endeavors.

The design and procedure of our project could still use some fine tuning in the future. For instance, our use of only two microphones made the process of mapping noise levels in the car extremely tedious, and we would suggest that in the future, all grid points should be measured simultaneously. Thus, a measuring device with multiple microphones that are all taking data at once would be a much more ideal approach to mapping the necessary data. This would also help to decrease error that occurs during experiments, because road conditions would be the same. In addition, error was introduced during our different test cases because we were moving in the car. Though, we took the same route for each experiment, slight variations in the positioning of the car on the road may have been enough to skew our data. In the future, we would like to see the experiment done solely when the car is not moving. Finally, we were limited by only having 2 apparatuses; if this was not a constraint, it would have been useful to place two devices in the back of the car while taking measurements at the passenger's seat. This would help add more controls to our experiment, which would mitigate any extraneous errors.

The final thing that we would like to see done in the future is to analyze the frequency spectrum of the car cabin at different points. This would give a better picture of the noise itself, allowing us to analyze if there are specific bandwidths of noise with a large gain. This would allow us to select a material that is good at blocking out these specific frequencies, which would reduce noise at a more substantial level. Finally, finding where exactly large points of noise are coming from at the perspective of the driver would be useful information to have. This would be difficult to perform due to the car cabin being so small. In the end, there is still plenty of work to be done on the acoustics of sedans, with plenty of potential for success.