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EML4551-2

Team 506: Mobile Anechoic Test Chamber

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Abstract

Disclaimer

Acknowledgement

Table of Contents

Abstract ii

Disclaimer iii

Acknowledgement iv

List of Tables vii

List of Figures viii

Chapter One: EML 4551C 1

1.1 Project Scope 1

1.2 Customer Needs 3

1.3 Functional Decomposition 4

1.4 Target Summary 5

1.5 Concept Generation 8

Reduce Ambient Sound 8

Measure Sound Pressure 11

Convert to Sound Power 15

1.6 Concept Selection .... **Error! Bookmark not defined.**

1.8 Spring Project Plan 24

Chapter Two: EML 4552C 27

2.1 Spring Plan 27

Project Plan. 27

Build Plan... 27

Appendices.. 28

Appendix A: Code of Conduct 29

Appendix B: Functional Decomposition 32

Appendix C: Target Catalog 33

Appendix D: Concept Generation.. 34

References... 36

List of Tables

No tables as of yet.

List of Figures

No figures as of yet.

Chapter One: EML 4551C

1.1 Project Scope

Danfoss Turbocor seeks an efficient and consistent way to record sound for their "TT" series compressors while reducing surrounding noise. Customers of Danfoss have requested testing the sound power as a specification for their compressors. A mobile anechoic chamber was requested as an idea from the initial problem statement, but we are also able to come up with various options to perform this task. The chosen mechanism would provide a more efficient way of gathering the consistency of sound data. The mobility of the chamber allows for testing to be easily transferable between testing stations. The compressors are tested for 40 minutes and each test consists of ramping the power to the compressor, holding speed, then powering down. The design will need to be easily and quickly disassembled, as well as easily storable.

Goals:

- Find a solution to measure whether the sound power of Danfoss compressors are consistent before shipping out to customers.
- Determine a more specific type of solution, as there are multiple options available to us to solve the current problem.
- Prove the viability of ideas and show a firm plan of action before selecting materials and assembling the design.
- Choose a design that will complete our task with high efficiency on the floor of an active plant.

Primary Market:

Graduation year: 2019

- Danfoss-Turbocor personnel use
- Air-conditioning companies

Secondary Market:

- Tool companies to measure different sound characteristics of products
- Companies which employ compressors who want to find out the sound characteristics of their compressors inside buildings or outdoors
- Wildlife organizations to test sound characteristics of their vehicles and tools to see impact on environments that may be sensitive

Assumptions:

- Dimensions of compressors used are the same.
- Our design will need to be implemented in the compressor testing station supplied by Danfoss.
- Power is supplied to the testing rig by Danfoss.
- Refrigerant closed loop system is supplied to the testing stations.
- Danfoss Turbocor will provide all machining services.

Stakeholders:

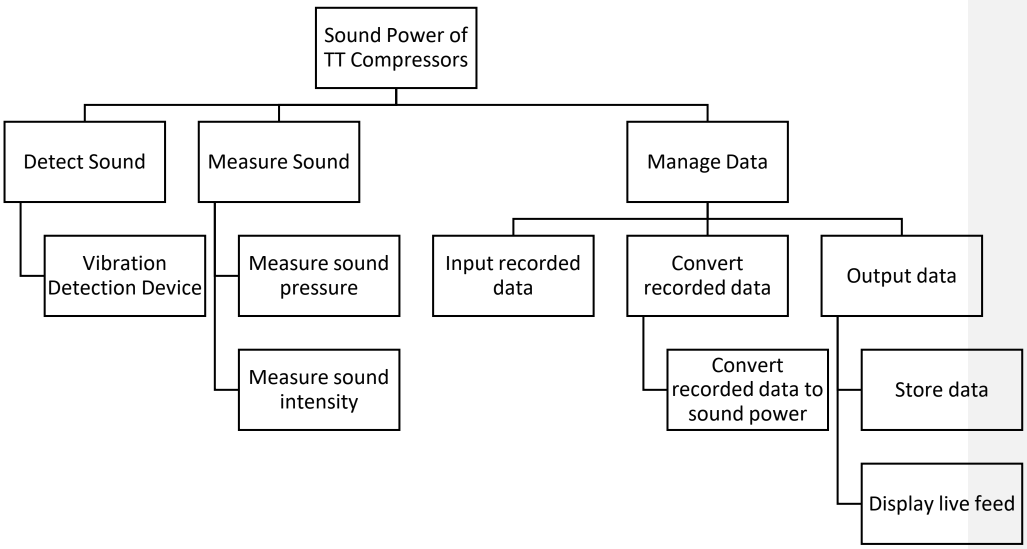
- Danfoss Turbocor- Sponsor and customer
- Dr. Shayne McConomy- Facilitator

1.2 Customer Needs

The initial meeting with Danfoss Turbocor concluded that our project will consist of designing an anechoic chamber, or similar system, that will measure the sound power across the "TT" series compressors. The recorded sound power will be used to determine the consistency across the compressors, which has been requested by their customers. Below are statements from our customer concerning different components of the project and what we interpreted those statements as. These statements allow us to narrow down the scope of our project.

#	CUSTOMER STATEMENTS	INTERPRETED NEED
1	Danfoss wants to measure the sound power and consistency across the compressors.	Need to measure the amount of sound being emitted by each compressor.
2	Danfoss wants a mobile anechoic chamber.	System needs to be easily constructed to transfer between test stations.
3	Customers have requested the consistency of sound across the chambers.	Produce a system that will reduce the surrounding noise and measure the consistency of sound power from the compressors.
4	Customer needs of a way to display or store this sound power data.	Either procure a way to store/display the data or integrate into their current system.
5	Danfoss will provide all necessary power sources and test stations.	System needs to be compatible with the supplied testing station.
6	System does not have to be a chamber.	System needs to be able to record the sound power while reducing the amount of surrounding sound.
7	The compressors will be the same and measured at the same point.	Do not have to account for a variance in kind of compressor.

1.3 Functional Decomposition



The main function for our project is measuring the sound power of the TT compressors. To accomplish this, there are three objectives that must be completed: detect sound, measure sound emitted, and manage data. To detect the sound, a type of vibration detection device must be implemented. Measuring the sound can be done two different ways: measure the sound pressure (recorded in decibels) or the sound power (recorded in Watts per square meter). Once the sound is measured, the data acquired must be managed appropriately. To manage the data, the data found from measuring the sound must be inputted. The data will then be converted from the units recorded into Watts. Once the data is converted it will display a live feed of the data OR store the data based on customer requirements.

1.4 Target Summary

Function	Metric	Target
Vibration detection device	Wave length frequency detected (Hz)	20-20,000 Hz
Measure sound pressure	Measured sound pressure (Pa or dB)	92 dB
Measure sound intensity	Measured sound intensity (W/m^2)	+-5
Input recorded data	Amount of data that can be input Binary or Hex bits	24 Bits
Convert recorded data to sound power	Sound power converted from dB or (W/m^2) to Watts (W)	+-5
Output data	Digital Format	64 Bit
Store data	Memory of storage (bytes)	250 GB
Display live feed	Delay (Seconds)	1 millisecond

Compatible with Testing Stand	Time (min)	30 min
Weight	lbs	50 lbs
Reduce ambient sound	dBA	+-5dBA

The main targets of our project are listed above. The last three concepts listed (compatibility, weight, and reducing ambient noise) are not included in the functional decomposition.

Our system needs to be able to detect vibrations from the compressor. The vibrations can be detected from a sound transducer, which would be measured in Hertz, and fall under a range of frequencies between 20 – 20,000 Hertz. This is the standard range that a microphone, and the human ear, can detect. To test this, we will need to use experimental sounds with known decibel ratings and frequency to compare the frequency from the transducer. This will need to be tested at the minimum and maximum to test the range of sound with known frequency. To measure sound pressure (Pa or dB) and sound intensity (W/m^2), the vibration detection device would be a transducer that quantifies the pressure or intensity. The target for sound pressure is 92 dB from preliminary data that Danfoss has provided us. Our goal is to ultimately be below that quantity for a more accurate test result. There is not a quantified number for the sound intensity of the compressors, so the goal is to that all the data points fall in the range of +5 of the mean.

There will be a connection from the system to a computer that will input the recorded data. The size of the recorded data should be 24 bits to be compatible with an audio transducer. A conversion will be implemented towards the recorded data to transform the data from sound intensity (W/m^2), or pressure (dB), to sound power (Watts, W). Our target is a standard deviation of the calculated value of the quotient of sound intensity and area of our proposed system. To test this target, it will be done by mathematical calculations to ensure that the recorded and analyzed data are equivalent. To output and store the data, the size should be 64 bits and have a digital display of numbers. The numbers will then be stored and have 250 GB of storage available, which is a relatively high number. This is the standard size of storage for computers. Storage of this size will ensure that all necessary data will be recorded and stored for future reference. A live feed of the data will be displayed on the system with a delay of 1 millisecond. This accounts for the time lost from inputting, converting, and outputting the data. To test our delay, a sound will be transmitted and the delay from the sound that is measured will be evaluated. The live feed of data is not necessary to complete from the customer, however the customer said this could be a positive if implemented.

The system should be compatible with the testing stations provided at Danfoss. The compatibility will be measured by the set-up time. The system needs to be relatively easy to assemble and disassemble. The target of 30 minutes is the time it will take to assemble and put the system into the operational position within the test stand. This target will be tested by measuring the time it takes for an operator to put the system into the correct position. If the hoist is needed for our system, the weight cannot exceed 500 lbs. Although the capacity of the hoist is large, the aim for the weight of the system is 50 lbs, which is 10% of the capacity. A scale will be used to measure the total weight of our system. The system needs to reduce the ambient noise by a standard deviation of the previously recorded ambient noise. This will be measured in decibels and should be a smaller quantity than the previously recorded deviation. The reduction of sound will ensure our sound power is accurate and consistent in the compressors.

1.5 Concept Generation

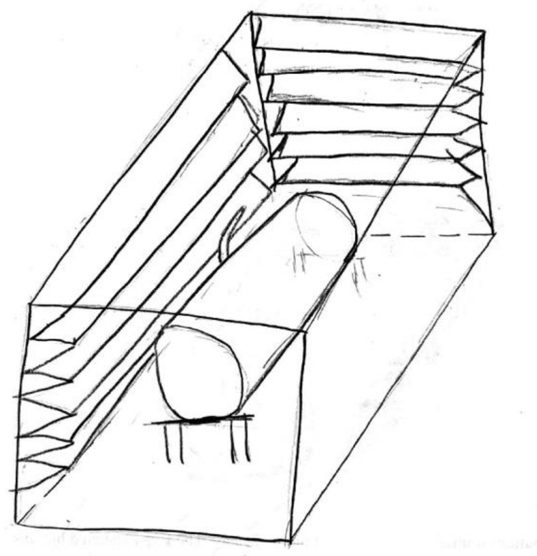
For the concept generation, we conducted background research to determine different solutions to fulfill our project scope. These solutions should fall into subcategories that will explain our project more thoroughly. We broke down the main components of our proposed system and created various results for each subsystem. These results are listed below and are explained in depth farther into the discussion.

SUBSYSTEM	#	CONCEPT DESCRIPTION
Reduce Ambient Sound	1	Anechoic Chamber
	2	Record average ambient sound and compare
	3	Sound-reducing material around compressor
	4	Directional microphone
Measure Sound Pressure	1	Array of microphones a specific distance apart
	2	Probe-style microphones that measure sound intensity
	3	Single microphone a specific distance away from compressor
Convert to Sound Power	1	External storage on recording device to convert on computer
	2	Direct connection from recording device to computer

Reduce Ambient Sound

Reduction of surrounding sound is one of the main functions of our system. This will give a more accurate and consistent reading of the sound pressure when the system is implemented in various facilities. We have determined several ways of tackling this task.

Concept 1.

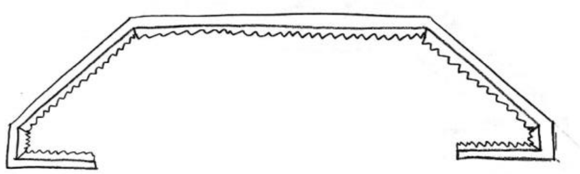


The first concept to reduce the ambient sound is the anechoic chamber method. This will be done by using some sort of special pattern anechoic foam, as well as a material to dampen the sound in the chamber and the ambient sound. To reduce the ambient sound, the anechoic foam will be applied to a certain undecided material. The surrounding sound does not have to be completely reduced but needs to be reduced enough so the main sound source is from the compressor. The anechoic foam will reduce the sound emitted from the compressor from echoing in the chamber. This will be a relatively high-priced concept based solely on the fact that the anechoic foam is expensive, however, this will dampen the sound by a high amount.

Concept 2.

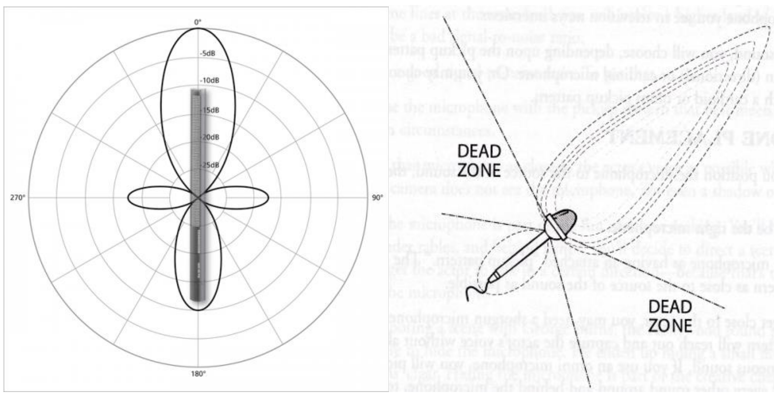
The second concept to reduce the ambient sound from the targeted measurement is a differential between the ambient sound and the sound from the compressor. The average sound of the ambient room will be recorded while the compressor is not running, and the average sound of the compressor will be recorded while running. From these two measurements the sound recorded of the ambient room will be subtracted from the sound recorded of the compressor. This method will be relatively a cheap concept however the precision of the measurements will be low.

Concept 3.



The third concept to reduce the ambient sound would be to apply some material onto a dome-like structure to dampen the sound. The material will be some sort of sound-dampening material, like carpet, that will be cheaper than the anechoic foam. The structure that the dampening material is applied to will not fully encompass the compressor but will cover the top of the compressor and all sides that are not attached to piping systems. This will be like a tent design to dampen the sound from most of the surfaces but not all of them. This design will be relatively cheaper than the first concept but won't be as accurate. It will be more expensive than the second concept but reduce the ambient sound more consistently.

Concept 4.



The fourth concept to dampen the surrounding sound would be to use a directional microphone like what is used in production sets. These microphones only measure in a certain direction, which will focus on the desired sound needed to be measured while ignoring the sound from sources outside of the focused direction. The microphone will be fixed on the compressor to record the sound of the compressor and not the surrounding noise. This method will be reasonably priced since the directional microphones are more expensive than regular microphones but will be reasonably accurate as well.

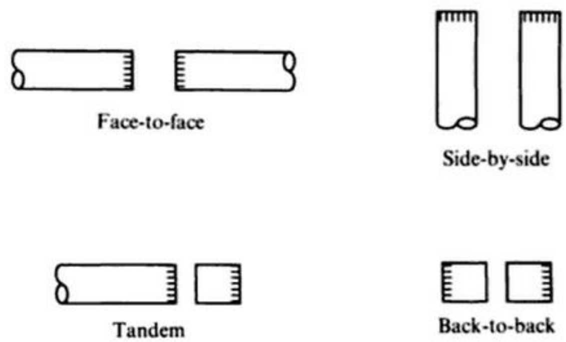
Measure Sound Pressure

The next of the main goals of our project is to measure the sound pressure or intensity of the compressor. Measuring sound pressure would be the easier task but measuring sound intensity would give a more accurate reading, especially when being converted to sound power. Sound transducers, such as microphones, can be applied to the system in a particular setup that would aid in reducing the ambient noise. The transducers should be utilized in conjunction with the device to reduce the ambient sound.

Concept 1.

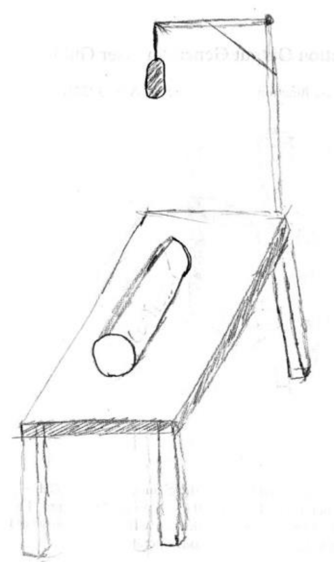
Concept 1 will record the sound intensity over a specific area. The sound intensity would then be integrated over the area to determine the sound power. The array setup would also be able to locate an area on the compressor where the sound intensity is more defined. This function, however, is not a requirement of our scope. The frequency range for the microphones incorporated into the array fall under our target of 20 to 20,000 Hz. This specification allows for a better variance in sound. The arrangement of the microphones in the array will be dependent on how accurate the measurement needs to be and how much of the compressor needs to be encompassed to reach that accuracy.

Concept 2.



Concept 2 would resemble a sound intensity probe. The sound intensity probe consists of two microphones that are attached in a specific configuration. For the scope of this project, the configuration chosen will be the back-to-back arrangement. This arrangement makes the conversion from sound pressure to sound power more manageable. The back-to-back layout will be able to measure the sound pressure of the compressor and integrate the velocity of the particles and the distance between the microphones to finally get a measurement of sound intensity. To convert to sound power, the sound intensity would be integrated over the area that the probe travelled to record the pressure.

Concept 3.



Concept 3 will consist of single microphone at a fixed location and distance from the compressor. Using the directional microphone mentioned in Concept 4 of Subsystem 1 in this configuration aids in reducing the ambient noise and measuring an accurate sound pressure value. This value would use the distance from the compressor to convert into the desired sound power. Theoretically, this concept will work if the compressor is a monopole, meaning the sound being emitted is constant around the whole compressor. Unfortunately, this is not the case and the sound emitted from the compressor changes at different points along the system. To combat this issue, the use of multiple microphones at different points along the compressor would account for the inconsistency in sound and read a more average value

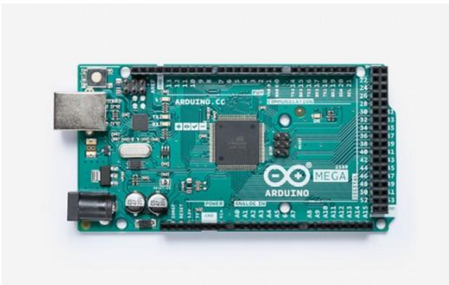
Convert to Sound Power

The conversion to sound power should be executed almost instantaneously. This, however, can be done remotely or in the server. The conversion should be able to take the measured value for either sound pressure or intensity and the area in which the sound is being measured and determine the actual sound power for the compressors.

Concept 1.

Microphone receiver to convert signals captured and turned into voltage back into a usable digital signal by the computer. This receiver would hopefully be built for the specific plug that microphones use if it did not use a standard USB type plug. It has a preprogrammed software to convert to certain values and knobs to attenuate their values if needed.

Concept 2.



Custom setup using a microcontroller to perform the conversions needed from Sound Pressure or Intensity into Sound Power. This could lead to quicker conversions for a lower price. This will provide a highly customizable solution for converting and capturing sound data. It will also make manipulating the process easier but would take an increased time to program and debug. Can be acquired rather cheaply for how powerfully it can perform.

1.6 Concept Selection

Once concept generation was completed the concept selection process was initiated. For the concept selection process, multiple tools assisted in narrowing down the concepts as well as ensuring that there is no bias towards a certain criterion during the selection process. The first tool utilized in concept selection was the Pairwise Selection Table. From this table, the customer requirements were compared to one another to determine which concepts are more important based on a "weighted" factor. This weighted factor of the customer requirements would then be used in another tool -- the House of Quality. For the pairwise selection, the customer requirements were labeled 1-9 on the vertical axis and correlate to the first row. They are then compared to each other on the horizontal axis with a "1" to signify that it is more important than the other and a "0" to signify that it is of less importance. To ensure the same requirements are not compared to each other a "-" is inputted in the cell as a placeholder.

Pairwise Selection										
	1	2	3	4	5	6	7	8	9	Sum
1. Measure Sound	-	1	1	1	0	0	1	1	1	6
2. Compatible with Testing Station	0	-	1	1	0	0	1	1	1	5
3. Store Data	0	0	-	1	0	0	1	0	1	3
4. Display Data	0	0	0	-	0	1	1	0	0	2
5. Consistent Recording	1	1	1	1	-	0	1	1	1	7
6. Convert to Sound Power	1	1	1	1	1	-	1	1	1	8
7. Ease of Conversion	0	0	0	0	0	0	-	1	0	1
8. Reduce ambient sound	0	0	1	1	0	0	0	-	0	2
9. Mobility of system	0	0	0	1	0	0	1	1	-	3
Sum	2	3	5	7	1	1	7	6	5	n-1=7

From the pairwise selection table, the highest weighted customer requirement was converting to sound power, and the least weighted requirement was ease of conversion. The weights are then used in the house of quality tool presented below. The customer requirements are depicted in the second column, while the functional requirements, or the targets of our project, are shown in the fourth row. The functional requirements are compared against the customer requirements in the house of quality to determine the most important requirements of our system.

		Functional Requirements										
	Direction of Improvement	□	▲	▲	□	▲	□	▲	▲	▼	▼	▼
	Units	Hz	Pa or dB	W/m^2	Bits	W	-	Bytes	Sec	Min	lbs	dBA
Importance Weight Factor	Customer Requirements	Wave length frequency detected	Measured sound pressure	Measured sound intensity	Amount of data that can be input	Sound power conversion	Output Data Digital Format	Memory of storage	Delay of live feed	Time to set up ad break down	Weight of System	Recorded ambient Sound
6	Measure Sound	9	9	9		3						9
5	Compatible with Testing Station		3	3						9	9	
3	Store Data	3			9	3	3	9				
2	Display Data	3			9	3	9	1	9			
7	Consistent Recording	9	9	9	3	3	1					9
8	Convert to Sound Power	9	9	9								9
1	Ease of Conversion	1	1	9	3				1			3
2	Reduce ambient sound	3	9	1		3						9
3	Mobility of system		1	1				1		9	9	
	Importance Rating Sum (Importance x Relationship)	211	226	218	69	60	34	32	19	72	72	210
	Relative Weight	21%	22%	22%	7%	6%	3%	3%	2%	7%	7%	21%
	Rank Order	3	1	2	6	7	8	9	10	5	5	4

Relationships	Weight
Strong	9
Medium	3
Weak	1
Direction of Improvement	
Maximize	▲
Target	□
Minimize	▼

The house of quality was used in conjunction with the customer requirements and target that we developed. The purpose of this tool is to determine which targets are the most important to satisfy the customer requirements. We then compared these to the targets that we developed and how we wanted to improve them: be maximize, meet, or minimize that requirement. The targets and customer requirements are then compared to one another based on their relationships to each other. The relationships were based on a scale of 3:1 being the lowest, 3 being moderate, and 9 being the highest. Once the relationships are compared, the weight of the importance factor is multiplied by the ranked number of the relationship. The sum of these numbers is taken for each row and then ranked from highest to lowest to determine which targets are the most important. From the house of quality, the four most important targets to meet are: measure sound pressure, detection of wavelength frequency, recording of ambient sound, and time to set up and break down. These will then be the most important for the selection criteria in comparing the concepts that were developed.

The selection criteria for the Pugh matrix is developed based on the five highest-ranking targets from the house of quality, as well as extra targets of cost and ease of conversion to sound power. Once the selection criteria are established, the four concepts for our first subsystem of reducing ambient sound are put into the Pugh matrix to be compared to a datum concept. The concepts of the first subsystem are being compared in a Pugh matrix because there are multiple concepts to decide between. The other two subsystems only have three or two concepts to decide between. The concepts of the other two subsystems will be narrowed down by the selection criteria created. The datum is using the testing lab at Danfoss and is compared to the concepts. The first subsystem of reducing ambient sound is compared against the datum. The concepts are ranked to the selection criteria by either a "+", "-", or "S". A "+" means that the concept is better than the datum, a "-" means the concept is worse than the datum, and a "S" means the concept is the same as the datum. Concept 1 is a typical anechoic chamber, concept 2 is subtracting the ambient noise from the recorded sound, concept 3 is a sound dampening container, and concept 4 is a directional microphone. These concepts are taken from the concepts generated in the previous section.

Selection Criteria		Concepts			
		1	2	3	4
Measure Sound Pressure	Datum	+	S	+	+
Wavelength frequency detected		S	S	S	S
Recorded ambient sound		+	-	+	+
Time to set up and break down system		-	S	-	-
Weight of system		-	S	-	-
Cost		-	S	-	-
Ease of Conversion		+	-	+	+
Sum of Positive		3	0	3	3
Sum of Negative		3	2	3	3

Datum: Current testing lab they have with standard microphone

From the Pugh matrix, concept 1, concept 3, and concept 4 were determined to work best because they each had 3 positive and 3 negative comparisons. These were then plugged into another Pugh matrix to narrow down the concepts even more. The datum compared to the concepts was concept 4 in the second Pugh matrix. The selection criteria remained the same as the first Pugh matrix as well as the level of ranking.

Commented [GU1]: Should I add the concept names or expect that they know from concept generation?

Selection Criteria		Concepts	
	Concept 4	1	3
Measure Sound Pressure		+	+
Wavelength frequency detected		S	S
Recorded ambient sound		+	+
Time to set up and break down system		-	-
Weight of system		-	-
Cost		-	+
Ease of Conversion		+	+
Sum of Positive		3	4
Sum of Negative		3	2

From the second Pugh matrix, the concepts of the first subsystem (reducing the ambient sound) were narrowed down. Concept 1 and concept 3 were selected as the two remaining concepts and a final selection would be determined later.

Remaining Concepts		
Reduce Ambient Sound	Measure Sound Pressure	Convert to Sound Power
Anechoic Chamber	Array of Microphones	External storage
Sound dampening container	Sound intensity probe	Direct connection

After analyzing the criteria for the project and concepts of each subsystem, the different components of the design were narrowed down from the concepts generated in Section 1.5 to the concepts listed above. For the second subsystem, measuring the sound pressure, the two remaining concepts that were determined was concept 1 and concept 2. This decision was based on presenting the concepts to our sponsor, as well as doing the criteria comparison matrix for both subsystems. The third concept from subsystem 2 was determined to be not feasible in a meeting with our sponsor. The third subsystem, convert sound data to sound power, did not have any type of process to narrow the concepts down because only two concepts were generated.

The criteria comparison matrix below establishes the importance of a criteria against another. The criteria comparison above the datum line is the inverse of the inputted rating. The ratings are as follows:

1 – A and B are of equal importance.

3 – A is moderately more important than B.

5 – A is strongly more important than B.

7 – A is significantly more important than B.

The selection criteria from the House of Quality and Pugh matrix are compared against each other to determine the criteria of highest importance.

Criteria Comparison Matrix for Subsystem 1						
	Measure Sound Pressure	Wavelength Frequency Detected	Recorded Ambient Sound	Time to set up and break down	Weight of system	Sound power conversion
Measure Sound Pressure	1.00	1.00	0.14	0.20	0.20	3.00
Wavelength frequency detected	1.00	1.00	0.14	0.20	0.14	1.00
Recorded ambient sound	7.00	7.00	1.00	1.00	1.00	7.00
Time to set up and break down system	5.00	5.00	1.00	1.00	0.33	5.00
Weight of system	5.00	5.00	1.00	3.00	1.00	1.00
Sound power conversion	0.33	1.00	0.14	0.20	1.00	1.00
Sum	19.33	20.00	3.43	5.60	3.68	18.00

Criteria Comparison Matrix for Subsystem 2						
	Measure Sound Pressure	Wavelength Frequency Detected	Recorded Ambient Sound	Time to set up and break down	Weight of system	Sound power conversion
Measure Sound Pressure	1.00	1.00	1.00	1.00	1.00	7.00
Wavelength frequency detected	1.00	1.00	0.33	1.00	0.33	3.00
Recorded ambient sound	1.00	3.00	1.00	1.00	1.00	3.00
Time to set up and break down system	1.00	1.00	1.00	1.00	1.00	1.00
Weight of system	1.00	1.00	1.00	1.00	1.00	0.14
Sound power conversion	0.14	0.33	0.33	1.00	7.00	1.00
Sum	5.14	7.33	4.67	6.00	11.33	15.14

Criteria Comparison Matrix for Subsystem 3						
	Measure Sound Pressure	Wavelength frequency detected	Amount of input data	Sound power conversion	Output of data	Memory Storage
Measure Sound Pressure	1.00	1.00	0.20	0.14	0.20	1.00
Wavelength frequency detected	1.00	1.00	0.14	0.14	0.14	1.00
Amount of input data	5.00	7.00	1.00	0.14	1.00	3.00
Sound power conversion	7.00	7.00	7.00	1.00	1.00	5.00
Output of data	5.00	5.00	1.00	1.00	1.00	1.00
Memory Storage	1.00	1.00	0.33	0.20	1.00	1.00
Sum	20.00	22.00	9.68	2.63	4.34	12.00

Once the criteria are rated and compared the sum of each criteria is calculated. The sum indicated the importance of each criteria. From the matrix, it is determined that, for subsystem 1, wavelength frequency detection and sound pressure measurement are the most important. This value is not normalized against the other criteria, though. The CCM was also performed for subsystems 1 and 3. Since there are only three concepts for subsystem 2 and two for subsystem 3, the final concepts were able to be determined without the CCM. To verify our assumptions, however, the matrix was utilized for these subsystems. To normalize this data, the ratings were evaluated against the sums of each criteria. This is shown in the chart below.

Normalized Criteria Comparison Matrix							
	Measure Sound Pressure	Wavelength Frequency detected	Record ambient sound	Time to set up and break down system	Weight of system	Sound power conversion	Weight
Measure Sound Pressure	0.05	0.05	0.04	0.04	0.05	0.17	6.67%
Wavelength frequency detected	0.05	0.05	0.04	0.04	0.04	0.06	4.56%
Recorded ambient sound	0.36	0.35	0.29	0.18	0.27	0.39	30.72%
Time to set up and break down system	0.26	0.25	0.29	0.18	0.09	0.28	22.46%
Weight of system	0.26	0.25	0.29	0.54	0.27	0.06	27.73%
Sound power conversion	0.02	0.05	0.04	0.04	0.27	0.06	7.87%
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Normalized Criteria Comparison Matrix for Subsystem 1							
	Measure Sound Pressure	Wavelength Frequency detected	Record ambient sound	Time to set up and break down system	Weight of system	Sound power conversion	Weight
Measure Sound Pressure	0.05	0.14	0.08	0.02	0.02	0.15	7.76%
Wavelength frequency detected	0.02	0.05	0.08	0.02	0.01	0.15	5.50%
Recorded ambient sound	0.38	0.33	0.58	0.60	0.72	0.35	49.39%
Time to set up and break down system	0.27	0.23	0.08	0.09	0.03	0.25	15.94%
Weight of system	0.27	0.23	0.08	0.26	0.10	0.05	16.63%
Sound power conversion	0.02	0.02	0.08	0.02	0.10	0.05	4.79%
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Normalized Criteria Comparison Matrix for Subsystem 3							
	Measure Sound Pressure	Wavelength frequency detected	Amount of input data	Sound power conversion	Output of data	Memory Storage	Weight
Measure Sound Pressure	0.05	0.05	0.02	0.05	0.05	0.08	0.05
Wavelength frequency detected	0.05	0.05	0.01	0.05	0.03	0.08	0.05
Amount of input data	0.25	0.32	0.10	0.05	0.23	0.25	0.20
Sound power conversion	0.35	0.32	0.72	0.38	0.23	0.42	0.40
Output of data	0.25	0.23	0.10	0.38	0.23	0.08	0.21
Memory Storage	0.05	0.05	0.03	0.08	0.23	0.08	0.09
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The normalized criteria comparison matrix above establishes the actual weights of each criteria that needs to be met. The weights are found by normalizing the data from the CCM and comparing it against itself. This matrix determined that the most important criteria for subsystem 1 is to record ambient sound, followed by the weight of system, and then the time to set up and break down. For subsystem 2, the significant criteria are to measure sound pressure and record ambient sound. Subsystem 3's highest ranked criteria are to convert to sound power and the output of that data.

Consistency Check for Subsystem 1		
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.584	0.067	8.753
0.432	0.046	9.484
5.157	0.307	16.786
1.316	0.225	5.860
1.635	0.277	5.897
0.482	0.079	6.127
Average Consistency	Consistency Index	Consistency Ratio
8.818	0.564	0.154

Consistency Check for Subsystem 2		
Weighted Sum Vector	Criteria Weights	Consistency Vector
1.995	0.210	9.483
1.101	0.133	8.291
1.597	0.212	7.541
1.000	0.144	6.928
0.858	0.135	6.359
1.399	0.166	8.439
Average Consistency	Consistency Index	Consistency Ratio
7.840	0.368	0.294

Consistency Check for Subsytem 3		
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.324	0.050	6.476
0.300	0.047	6.411
1.308	0.201	6.508
3.133	0.403	7.772
1.387	0.212	6.529
0.543	0.087	6.276
Average Consistency	Consistency Index	Consistency Ratio
6.662	0.132	0.106

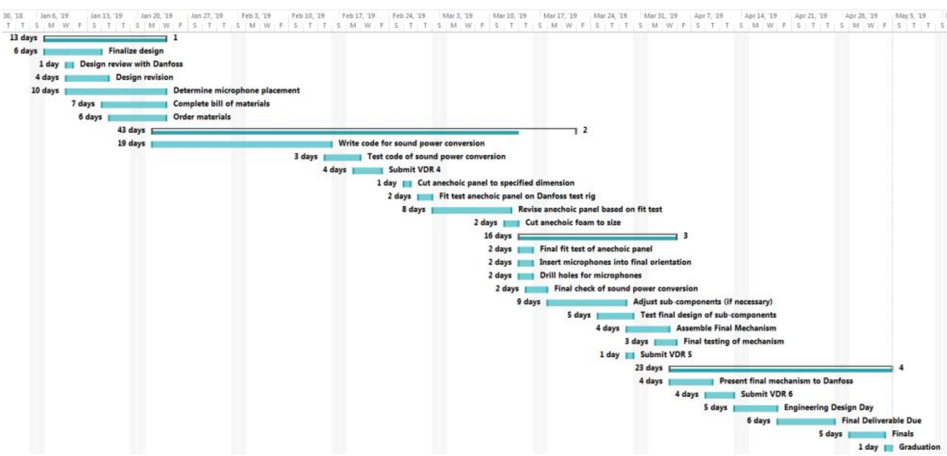
The consistency of the data is shown below. Our consistency ratio was found to be 0.154. Since the value is larger than 0.10, this means are data is in consistent. The consistency check for subsystem 3 was determined to be 0.106, which is closer to the goal of 0.10. These discrepancies are due to the ratings of the criteria against each other not being accurate and consistent throughout the matrix.

Final Concepts		
Reduce Ambient Sound	Measure Sound Pressure	Convert to Sound Power
Anechoic Chamber	Array of Microphones	External storage

Using the above methods to analytically narrow down our conceptual possibilities, one design for each subsystem of our project has been selected. In combining these three methods we should be able to achieve our goals in a way which focuses on the most relevant parameters in each specific subcategory, while also avoiding confirmation bias in our design selection. The final design for reducing ambient sound was the anechoic chamber. For measuring sound pressure, it was the array of microphones. And for the conversion to sound power, the design was an external storage device.

1.7 Spring Project Plan

A plan for the spring semester has been generated after the design was selected. The timeline can be seen below in the Gantt chart.



The timeline covers design revisions, design testing and any deliverables that we will need to develop. The tasks were broken into four major components to complete our project. The first component is the detailed design. This will consist of finalizing the initial design and reviewing this design with our sponsor, Danfoss. In this timeline, the placement of the microphones will be determined to ensure optimal data measurements. After the design is reviewed and approved by Danfoss, the bill of materials will be revised to incorporate any new materials that need to be added, as well as specific sizes and quantities of those materials. Once the final bill of materials is developed, materials will begin to be ordered based on lead times and current needs.

After the detailed design stage is completed, prototyping and testing will commence. During this stage the materials will be gathered and used to assemble the first design. We will also need to begin the code for converting the measured sound pressure into sound power. This will need to be completed before the final testing stage. The fourth deliverable will need to be developed and submitted during this time. The anechoic panel will be measured and cut to size to fit on top of the test chamber. After the initial test is completed, the panel will likely need to be revised and retested. After the panel is matched with the test chamber, the anechoic foam will be attached. The placement of the microphones will also be etched on the panel.

During the final testing stage, the final fit test of the panel will be conducted. After it passes the test, the holes for the microphones will be drilled and the microphones secured into place. This will not be performed during the prototype testing, because damage to the microphones may occur. The final check for the conversion to sound power will be conducted since the microphones are in their established position. Any last adjustments to the design should be performed during this stage. The final mechanism will be assembled and testing on the system as a whole will commence. During this period the fifth deliverable will be submitted. Spring break will occur during this stage as well.

The final stage of the project occurs in April, starting with presenting the final mechanism to Danfoss. The sixth deliverable will be submitted and the final report summarizing the project and its accomplishments will be developed during this time. Engineering Design Day is projected to occur in the middle of April where our final mechanism will be displayed and judged. After the design day, finals will be taken and graduation will occur.

The tasks can also be seen below in the table for easier reading.

Task Name	Duration
1 Detailed Design	**13 days**
1.1 Finalize design	6 days
1.2 Design review with Danfoss	1 day
1.3 Design revision	4 days
1.4 Determine microphone placement	10 days
1.5 Complete bill of materials	7 days
1.6 Order materials	6 days
2 Prototype and Test	**43 days**
2.1 Write code for sound power conversion	19 days
2.2 Test code of sound power conversion	3 days
2.3 Submit VDR 4	4 days
2.4 Cut anechoic panel to specified dimension	1 day
2.5 Fit test anechoic panel on Danfoss test rig	2 days
2.6 Revise anechoic panel based on fit test	8 days
2.7 Cut anechoic foam to size	2 days
3 Final Testing	**16 days**
3.1 Final fit test of anechoic panel	2 days
3.2 Insert microphones into final orientation	2 days
3.3 Drill holes for microphones	2 days
3.4 Final check of sound power conversion	2 days
3.5 Adjust sub-components (if necessary)	9 days
3.6 Test final design of sub-components	5 days
3.7 Assemble Final Mechanism	4 days
3.8 Final testing of mechanism	3 days
3.9 Submit VDR 5	1 days
4 Project Closure	**23 days**
4.1 Present final mechanism to Danfoss	4 days
4.2 Submit VDR 6	4 days
4.3 Engineering Design Day	5 days
4.4 Final Deliverable Due	6 days
4.5 Finals	5 days
4.6 Graduation	1 day

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Mission Statement

Team 506 is committed to contribute their full effort to create and maintain a positive environment where we will perform our tasks to the best of our ability. We will ensure that our team will be professional and act with integrity.

Roles

Each team member is assigned the following roles based on their past experiences. Each member will be held to a certain standard and contribute their respective parts.

Marissa Jackson- Project Manager

Responsible for managing the team, creating a timeline and plan for the project, and delegating the work amongst the other members. Responsible for final editing and submission of documents. The project manager will maintain contact with the sponsors and arrange and organize meetings. The project manager will act in the best interest of the project and will keep track of the progress. The project manager will manage the budget and be responsible for meeting all deadlines.

Bryce Lankford- Mechanical Engineer

Responsible for research and designing of concepts, as well as assist in editing documents and maintaining the budget. The mechanical engineer will prepare meetings for the group with updates and questions on the project. Bryce will be responsible for providing the manufacturing engineer with proper documents to assemble the final concept.

Nick Ajhar- Mechanical Engineer

Responsible for implementing final design concept as well as review of designs. The mechanical engineer will assist in editing documents, as well as conduct research for design. Bryce and Nick will work closely together to ensure the designs are clearly documented and up to date. Nick will be responsible for ordering the material and assisting in maintaining the budget.

Communication

The team will communicate via either email or cell phone. Use of cell phone will be for casual conversations, while email will be used for planning, setting up meetings, and contact with advisers. The team will meet every Tuesday and Thursday from 4-5:30 p.m. to discuss progress and review the project actions. Outside of this set meeting time, casual group meetings can be set up through agreement of group members. Such meetings will be set up with enough notification so that all members can be present if possible. The team will meet with the sponsor every other Thursday from 3-4 p.m. at the Danfoss facility. If any questions were to arise for the sponsor, they will be contacted through email.

Attendance Policy

All members must be present at all meetings or must notify the group 24 hours in advance of absence. For casual group meetings attendance is not mandatory but recommended.

Dress Code

For team meetings, casual dress is acceptable. Meetings with sponsors, however, require business casual attire. Business formal attire will be held for all presentations.

Individual work schedule

Other than the required meetings, each individual group member will be required to give at least 10 hours per week for the project. This can be done by either individual work or group work outside of required meeting time.

Statement of Understanding

By signing this document, the following agrees to all statements above as well as any amendments come from a group vote.

Marissa S. Jackson

Sign:______________________________________ Date:____________________

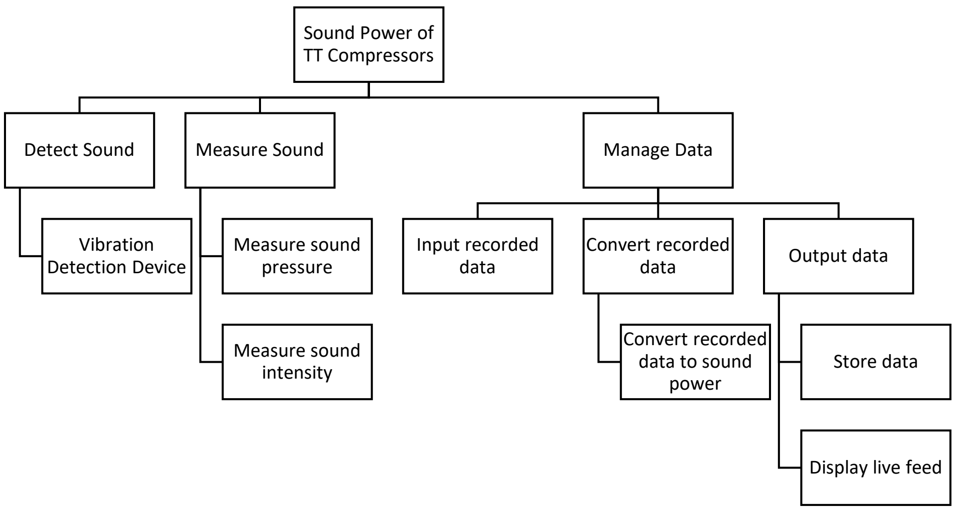
Bryce L. Lankford

Sign:______________________________________ Date:____________________

Nicholas C. Ajhar

Sign:______________________________________ Date:____________________

Appendix B: Functional Decomposition



Appendix C: Target Catalog

Function	Metric	Target
Vibration detection device	Wave length frequency detected (Hz)	20-20,000 Hz
Measure sound pressure	Measured sound pressure (Pa or dB)	92 dB
Measure sound intensity	Measured sound intensity (W/m^2)	+-5
Input recorded data	Amount of data that can be input Binary or Hex bits	24 Bits
Convert recorded data to sound power	Sound power converted from dB or (W/m^2) to Watts (W)	+-5
Output data	Digital Format	64 Bit
Store data	Memory of storage (bytes)	250 GB
Display live feed	Delay (Seconds)	1 millisecond
Compatible with Testing Stand	Time (min)	30 min
Weight	lbs	50 lbs
Reduce ambient sound	dBA	+-5dBA

Appendix D: Concept Generation

Problem	Concept Solution
Reduce Ambient Sound	• Noise cancellation technology to reduce surrounding sound around compressor • Create foam enclosure for speaker and compressor to sit in jointly • Line walls of assembly floor with anechoic foam to reduce echoes on shop floor • Create tank of water for compressor to sit in. This is because sound doesn't travel well through water • Create cubicles for each station on assembly floor. This will reduce the noise emitted from each assembly station. • Line walls of test stand with cotton to reduce noise • Study frequency emitted from microphone. Then use dynamic microphones to have selective recording based on frequency • Once sound has been recorded use audio software to cancel ambient noise. • Line the test stand walls with dense material to absorb noise • Use a high pass filter on the microphone to reduce low frequency sounds • Place microphones on the compressor to record at a closer distance • Create cone around microphone and point at compressor to focus on the compressor • Have speaker with known sound pressure play through the shop floor. Then record while compressor is on and subtract the two from each other • Find frequency of sound compressor emits and use microphone that records accurately over a small frequency width that encompasses it • Create shield that goes on back of microphone to reject background noise • Use vacuum container that compressor sits in to separate ambient noise • Have speakers pointed on shop floor with constant white noise to separate assembly floor noise
Measure Sound Pressure	• Use vibration detection device to get frequency and convert to sound

	• Use multiple directional microphones in a setup that accounts for the variance in sound pressure • Sound level meter to record the acoustic measurements • Record the sound intensity using a probe • Replicate an array of microphones using the directional microphones • Use mix of directional and normal microphones • Three microphones at the front, center, and rear of compressor • Make a dome around compressor and have microphones at specific points along each arc
Convert to Sound Power	• Use a receiver to convert information to a usable format if microphones have specific ports • Use a microcontroller to run measurements through so that custom calculations can be written • Obtain data and do conversions within a program like Excel • Use a program like MATLAB along with Excel to obtain graphs and calculate values • Have a device preprogrammed to output sound power values • Take the recordings of a single microphone to do our conversions • Do conversions by hand • Make a custom calculation to account for a microphone measuring ambient noise away from the compressor • Utilize pre-built software to collect data and then run through another prebuilt software to do calculations.

References

There are no sources in the current document.