EML4550

Team 509: Environment-Controlled Test Stand Chamber

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Abstract

Danfoss-Turbocor is a leading manufacturer of industrial compressors, serving markets globally. In order to ensure the quality of the compressor, Danfoss-Turbocor must test each compressor under the environmental conditions it may experience in various locations around the world. Our team currently designing and constructing a temperature and humidity-controlled testing chamber to be used in Danfoss-Turbocor's research and development laboratory. The testing chamber will be used to test the TT and TG model compressors. The temperature range requirement is 10° to 55° Celsius, while the relative non-condensing humidity range requirement is 10% to 95%. The tests ongoing inside the environmental chamber range from a few hours to a few days. Power consumption efficiency of the test chamber’s heating, cooling, humidifying and dehumidifying systems is not a major variable of concern. The chamber is designed to protect workers from heat-related injuries and provide a barrier in the case of a catastrophic compressor failure. The chamber provides a clear view of the interior. The operator also has an easy way to access the compressor within the chamber.

Keywords: Danfoss, Turbocor, Testing, Chamber, Senior Design.

Acknowledgement

Thank the FAMU-FSU College of Engineering for the opportunity to participate in the senior design program. I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals and organizations.

- First, I am highly indebted to the Danfoss Turbocor for their guidance and constant supervision as well as for providing necessary information regarding the project and also for their support in completing the project.
- Next, Thanks Professor McConomy for his mentorship and constant encouragement to push us through this project.
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- Lastly, we are thankful to be able to come to our Professors and Teaching Assistants anytime; who have willingly helped out with their abilities.

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Notation

AHP	Analytic Hierarchy Process
ASME	American Society of Mechanical Engineers
CAD	Computer Generated Design
EDM	Engineering Design Method
HoQ	House of Quality

Chapter One: EML 4551C

1.1 Project Scope

- **Project Description:** The objective of this project is to fabricate a chamber that is better than the existing one. This chamber will provide protection for lab personnel, an easy access to what is being tested inside and a transparent view of the interior. In addition, the inside of the chamber is capable of simulate the testing condition of what is being tested within the chamber.
- **Key Goals:** Achieve a temperature range of 10 to 55 degrees Celsius by an A.C. system, buy a humidifier and a dehumidifier that can achieve a maximum allowable non-condensing humidity range (0 – 95%) and also will work in sync with our system. The frame structure should be easy to assemble and disassemble and provide a transparent view of the inside.
- **Primary Market:** For the purpose of this project, the primary market is the group or individual that directly benefits from the outcome of the project. The primary market for this project is Danfoss-Turbocor.
- **Secondary Market:** For the purpose of this project, a secondary market is any group or individual that might indirectly benefit from the outcome of the project. Tool companies, School lab that requires high humidity environment, ASME material testing center.
- **Assumptions:** Dimensions of compressors being tested inside the chamber are the same. The device will be used in the compressor testing station located inside of

Danfoss. Power is from the testing rig. Danfoss Turbocor will provide all machining services. The chamber will sit above the rig. And finally, the tester would like the ideal condition to be reached within 30 minutes.

- **Stakeholders:** For the purpose of this project, stakeholders are any group or individual that has an investment in the outcome of the project. Danfoss is the customer. Jerry Huang, an employee of Danfoss, is the sponsor. FAMU-FSU College of Engineering and Professor Campbell, each has an investment in the outcome of the project, as it contributes to each team member's graduation status.

1.2 Customer Needs

The customer needs for this project were determined by collecting customer statements from our project sponsor and Danfoss employee, Jerry Huang. During our meeting, Mr. Huang provided us with a list of specifications and expectations for the environment-controlled test chamber. Also, Mr. Huang provided us with answers to our initial questions regarding the project. The customer statements collected during this initial meeting were subsequently interpreted into applicable, engineering needs. These interpreted needs allow us to narrow the scope of our project. The customer statements and the associated interpreted needs are listed in the table below.

Table 1: Customer's needs.

Question Asked	Customer Statement/Customer Response	Interpreted Engineering Need
Are there any pressure specifications or concerns within the test chamber?	We do not have any pressure requirements for the test chamber.	Safety precautions and material selection considerations associated with a high-pressure are not an

		enclosure are not a factor
N/A	The estimated material cost is $10,000.	Some materials will be costly, the timeline for receiving these materials could be long. Order parts early.
N/A	The chamber must provide protection for lab personnel.	Safety precautions will be considered in material selection.
What are the dimensions of the compressor(s) being tested?	The rig that was measured is 50L x 40W x 28H (H is to where the rig stop) in inches.	Design so the two compressor models of the same dimensions fit inside the chamber.
How do they switch the compressor on the testing rig?	We need to deposit the compressor into the chamber from above with our overhead crane.	The chamber has dimensions that provide sufficient clearance for the overhead crane.
N/A	Supplied items: Controllers, Humidifier, Dehumidifier, Air conditioner, heater, etc.	N/A
Are there specific features of the existing chamber that you want to incorporate in the design of the new testing chamber?	Meet the project definition: Do not focus too much on the current design.	Use the current chamber as a guide to design a new and improved one.
Has there been a failure that resulted in damage to the compressor or rig while testing? If yes, what was the damage?	No, there have been no failures.	Design to counter a catastrophic event or an unexpected rise in temperature.
Is remote control of elements necessary? Do the humidity and temperature need to fluctuate throughout the test, or will they remain constant at predetermined levels?	The controlling of the elements relies on the proposal. The temperature and humidity will be pre-set and remain constant until changed.	The heating and humidifying controlling systems will not fluctuate over time.
Are we in charge of the actual humidity and temperature control within the chamber, or are we strictly responsible for the structure?	Meet the project definition: Provide a controlled of certain temperature and humidity to simulate the actual applications.	A control unit for temperature and humidity is not within the scope of the project.
How long does it take to make the		

chamber		

1.3 Functional Decomposition

Function decomposition was used to serve as a guide for the project's goals. The environment-controlled test chamber was further decomposed into smaller function and sub-functions. By making a functional decomposition diagram, the team was able to separate the entire project into smaller tasks that can be completed and verified. Below is the functional

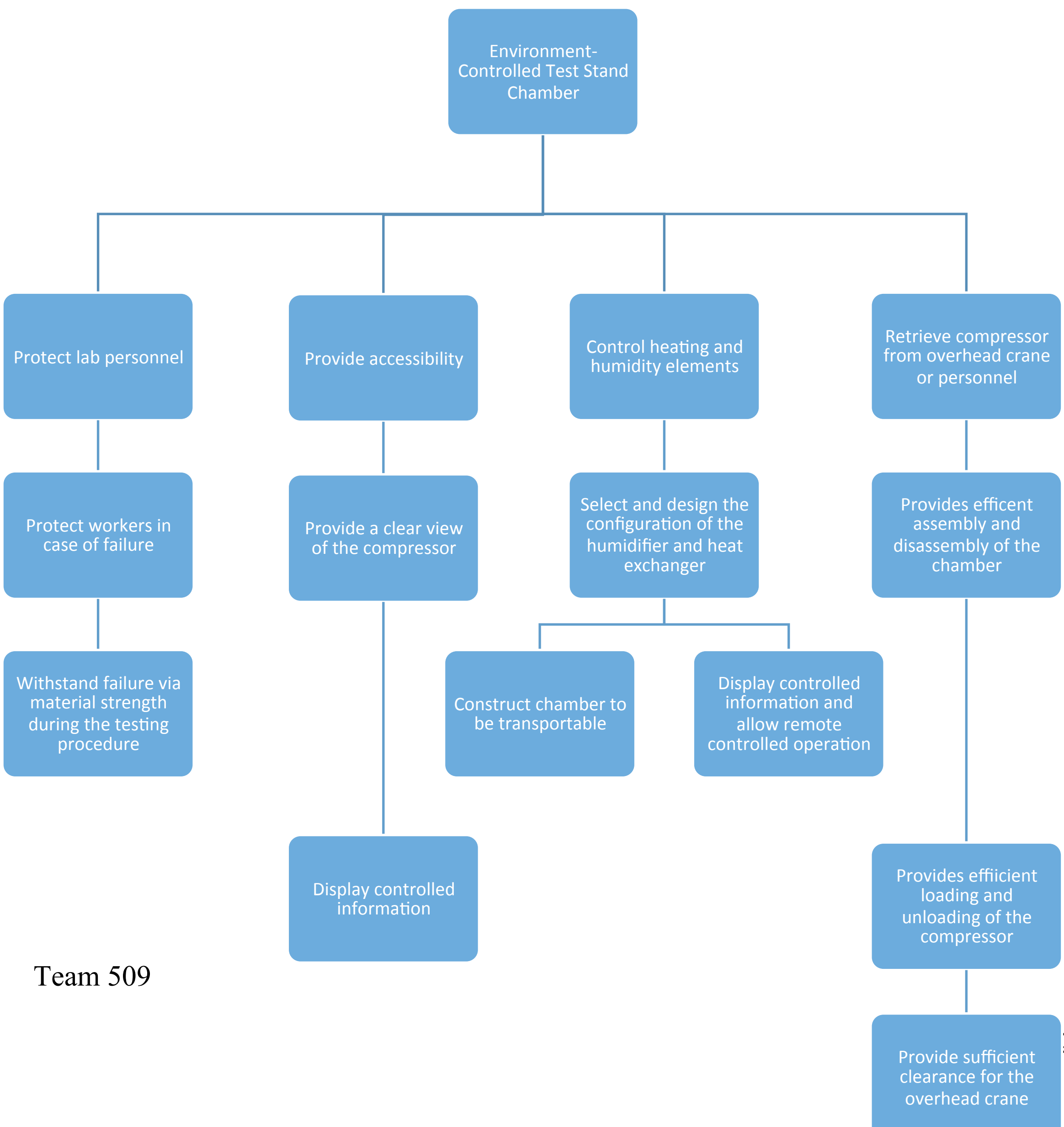

Figure 1: Function Decomposition

decomposition diagram of the climatic chamber.

The functional decomposition flow chart depicts the four main functions that our chamber needs to fulfill. The chamber will provide protection for lab personnel, control of temperature and humidity within the chamber, visibility to the inside of the chamber, and enough clearance for the overhead crane. These specific tasks were generated by taking the information gathered from touring the facility along with research after. Moving forward, the team will use the functional decomposition to convert the functions into achievable and measurable targets.

1.4 Target Summary

By declaring targets for the environment-controlled test stand chamber, the team is able to identify the design features necessary to satisfy the customer requirements. Defining subfunctions allows us to better plan the steps that must be taken to accomplish their respective targets. Below is the table of our targets and metrics.

Table 2: Target and Metric

Main Function	Sub-Function(s)	Metric	Target
Protect lab personnel	Protect workers from compressor failure	Impact strength [MPa]	69 minimum
	Protect workers from temperature and humidity related illnesses	Temperature outside the chamber [°C]	30° C maximum
Provide accessibility	Provide a clear view of the compressor	Visible Light Transmittance [%]	90 minimum
	Allow access to testing mechanisms via doors	Clearance [m]	.762
	Ensure chamber doesn't impede on	Inner volume [m^3]	1 minimum

	workspace		
Control heating and humidity elements	Construct chamber to be transportable	Weight [kg]	70 maximum
	Ensure minimum heat loss	U-factor [W/m^{2}K]	1.06 maximum
	Ensure humidity control inside the chamber	Relative Humidity [%]	0 to 95
Retrieve compressor from overhead crane or personnel	Provides efficient loading and unloading of the compressor	Loading Area [m^2]	0.6 x 0.9 minimum
	Provide enough clearance for connecting the crane to the compressor	Height [m]	0.305 minimum
	Provide enough clearance for the overhead crane	Height [m]	1.65 maximum

The first main function is to protect lab personnel. To do this, two subfunctions were identified; protect workers in the case of a malfunction of the compressors, and to protect workers from heat and humidity related illnesses as a result of the environment-control function of the chamber. To address the case of a compressor malfunction, 69 MPa is the impact strength target. This was decided due to the unnotched Charpy impact strength of acrylic, the material most likely to be used to build the chamber. This can be validated by preforming a Charpy impact test on the material. The other subfunction is to protect workers from heat and humidity related illnesses. This will be achieved by ensuring the temperature around the chamber does not exceed 30° C. This will be tested by constantly checking the humidity.

Our target for the humidifier element is decided based on the customer's need. When the humidifier system is turned on, it could be controlled to set the relative humidity from 0 to 95 percent. We are planning to use a psychrometer to constantly test the humidifier. The placement of the humidifier and the measurement device will be considered to ensure accommodation to other functions. We will make sure that it is easy to change the humidity setting.

Another function of the test chamber is to provide accessibility for Danfoss employees to work with the compressor setup. One way to achieve this is to ensure most of the chosen material is not opaque, so that the compressor can be viewed from all angles during testing. To achieve this goal, a material will be chosen such that at least 90% of visible light is transmitted. The second subfunction is to provide enough space inside the chamber to allow easy access for attaching hoses and pipe fittings to the compressor, while making certain the compressor can be accessed from multiple sides of the chamber. Because the compressor itself has a volume of about 0.2 m^3, a minimum chamber volume of 1 m^3 will provide enough space for pipes, hoses, and handling of compressor attachments. This will be validated by placing the compressor inside our chamber and assembling it for testing.

Because the compressors are moved by use of an overhead crane, it is important that the test chamber does not impede on the loading and unloading process of the compressors. To allow enough space for loading, a minimum area of 0.6 m x 0.9 m is required. Because the overhead crane is used for loading, the test chamber can be no taller than 1.65 m when it is resting on the stand so that the chamber does not interfere with the crane. This can be tested by measuring the height after assembly of our chamber.

Targets will be validated as the group buys equipment and tests the prototype. The material will be tested; as well as the prototype when assembled. Instruments are not limited to ruler, measuring tape but also thermometer and multimeter. Tests will include every condition as expected in the design guideline.

1.5 Concept Generation

The concept generation process follows the selection of targets and metrics. Concept generation is the process of brainstorming solutions to meet the requirements set forth in the project scope and to effectively meet the previously determined targets. To help organize our thoughts and ideas, we utilized a morphological chart which can be views in Appendix B. The morphological chart helps to generate a complete range of design solutions. To make our morphological chart, we incorporated the functions set forth in our functional decomposition and organized them column by column. Under each of these functions we described the variation in options that we might have within these functions. While the morphological chart is a helpful concept generation tool, it is not a limiting factor; ideas were still generated outside of the chart. This is where we strive to be as creative as possible. We met up as a group and starting throwing ideas out at random to come up with the most "out-of-the-box" concepts and to see if any of them were feasible. One of these ideas was using the hinge design of a car hood. We also established forced relationships with different functions of our project in order to develop other ideas. This is how the idea of cutting out the points where the piping or other openings would be exposed along the box. The goal of the concept generation step in the design process is to collectively brainstorm as many ideas and solutions as possible in order to ultimately select the best concept for the design. After constructing this chart and considering other ideas, we were able to generate over 800 ideas.

Upon completion of concept generation, we analyzed our ideas, and selected five medium fidelity and three high fidelity concepts from our idea pool. The next step in the design process will be concept selection, during which we will use tools such as the House of Quality, Pugh matrix, and the Analytical Hierarchy Process (AHP) to rank each of our medium and high fidelity concepts against one another to ultimately select the best and most efficient design idea. Our five medium fidelity and three high fidelity concepts are listed below.

High Fidelity Concepts:

Concept 1.

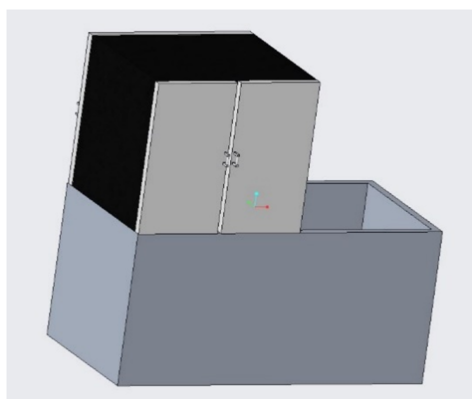

Figure 2: The First Concept

- Shorten the length of the existing prototype
- Use polycarbonate
- 6000 series aluminum
- Magnetic and toggle latches

- Full double doors on one side of enclosure and half double doors on the opposite side
- Cut holes in back pane then seal around pipes

Concept 2.

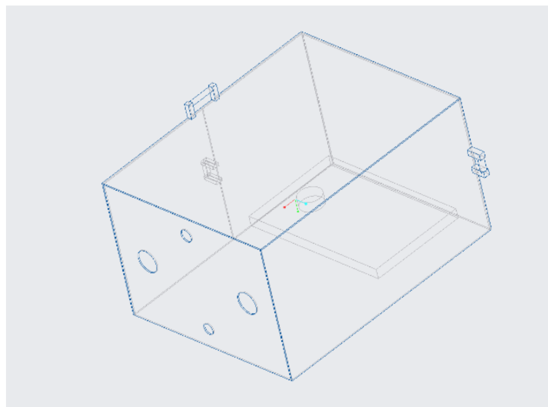

Figure 3: Rough CAD of Concept 2

- Keep the current dimensions of the existing prototype, add flap to cover gap
- Use polycarbonate
- 6000 series aluminum
- Magnetic and toggle latches
- Full double doors on one side of enclosure and half double doors on the opposite side
- Cut holes in the back pane then seal it around the pipes

Concept 3.

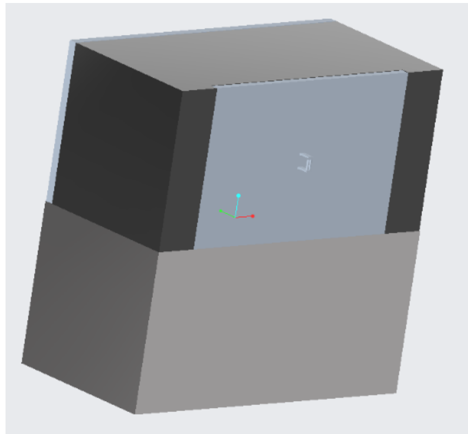

Figure 4: Rough CAD of Concept 3; The Full Enclosure.

- Extends to far end of rig and sits on the ground
- Use acrylic
- 6000 series aluminum
- Magnetic and toggle latches
- Design completely encloses pipes, no sealant needed
- Sliding doors

Medium Fidelity Concepts:

Concept 4.

- Keep the current dimensions of the existing prototype, add flap to cover gap
- Use acrylic
- 6000 series aluminum
- Magnetic and toggle latches

- Full single door on one side of the enclosure and half double doors on the opposite side
- Cut holes in the back panel then seal it around the pipe

Concept 5.

- Keep the current dimensions of the existing prototype, add flap to cover gap
- Use polycarbonate
- 6000 series aluminum
- Magnetic and toggle latches
- Full double doors on one side of enclosure and half double doors on the opposite side
- Separate pane of back wall to piece together vertically around pipes

Concept 6.

- Keep the current dimensions of the existing prototype, add flap to cover gap
- Use polycarbonate
- 6000 series aluminum
- Magnetic and toggle latches
- Full double doors on one side of enclosure and half double doors on the opposite side
- Separate pane of back wall to piece together horizontally around pipes

Concept 7.

- Shorten the length of the existing chamber to exclude the gap in the testing rig
- Use polycarbonate
- 6000 series aluminum
- Magnetic and window latches
- Full double doors on one side of enclosure and half double doors on the opposite side
- Cut holes in back pane then seal around pipes

Concept 8.

- Shorten the length of the existing chamber to exclude the gap in the testing rig
- Use acrylic
- 6000 series aluminum
- Magnetic and window latches
- Bifold doors
- Cut holes in back pane then seal around pipes

1.6 Concept Selection

The next step after concept generation was to start the concept selection process. The design team rigorously followed this process as it was taught in EDM to ensure customer requirement satisfaction as well as guarantee useful engineering characteristics and longevity of the project. During concept selection, many tools were used to eliminate biases in the decision-making process. After going through the process, biases should not affect the solution and the final design is the most trustworthy design.

When the concept generation step was finished, the group had more than a thousand different concepts to work with. Five medium fidelity and three high fidelity concepts were chosen for consideration. From these eight concepts, five concepts were chosen to move on to the concept selection process.

The first tool we used was the House of Quality. The purpose of this chart is to rank the developed targets in order of importance and give direction for improvement. Before this chart was complete, we ranked our customer requirements in order of importance; a weight factor is established for each customer requirement. The targets and customer requirements are then compared to one another based on their relationships to each other. These relationships are magnified by the weight factor of the customer requirement. The result is an accurate order of importance for the targets. According to this table, we will focus our project scope to the most significant targets established including; maintain inner temperature, provide sufficient inner volume, increase the impact strength of material, and maintain the clearance to accommodate loading the compressor. These factors were determined to be the most important selection criteria in choosing the right design concept.

Table 3: The House of Quality.

House of Quality												
	Improvement Direction	↑			↑	↑		↓	↓	↑	↑	↑
	Units	MPa	°C	°C	%	m	m^3	kg	W/(m^2*K)	%	m^2	m
Customer Requirments	**Priority**	Impact Strength	Outer Temp	Inner Temp	Visible Light Transmittance	Clearance	Inner Volume	Weight	U-factor	Relative Humidity	Loading Area	Minimum clearance height
Protect lab personnel	**5**	9	3	1				3	1	1		
Maintain temperature range between 10 and 55°C	**3**		3	9			9		9	9		
Maintain humidity range of 0 to 95%	**3**		1	9			9		3	9		
Chamber provides sufficient clearance for the overhead crane	**5**	1				9	3	1			9	9
Chamber is easily assembled and disassembled by lab personnel	**1**	3					1	9			3	3
Chamber is constructed with lightweight material	**1**	3		3				9			3	
Chamber material is transparent and provides sufficient visibility within	**5**	3		3	9							
Total material cost is under $10,000	**5**	3		9	3	1	9	9			3	3
772	**Raw Score**	86	27	122	60	50	115	83	41	59	66	63
	Relative Weight %	11.1399	3.497409	15.80311	7.772020725	6.476684	14.89637	10.7513	5.31088083	7.642487	8.549223	8.160622
	Rank Order	3	11	1	7	9	2	4	10	8	5	6

Next, a Pugh Matrix was developed in order to determine which concepts provided significant improvements to the already existing test chamber that is currently in use at the Danfoss facility. The Pugh matrix also showed us which design concepts gave the biggest number of improvements over the existing chamber. The original Pugh Matrix showed that concepts 3 and 5 are the best designs. A second Pugh Matrix was then used to determine which design was the second best, by comparing improvements of the other concepts to concept 1. From the second matrix, it was determined that concept 2 is the next best option.

Table 4: The First Decision Matrix

Decision Matrix						
Selection Criteria	Current Chamber	Concept 1	Concept 2	Concept 3	Concept 5	Concept 7
Safety	Datum	S	S	S	S	S
Cost		+	+	S	S	S
Construction feasibility		-	-	+	+	-
Weight of material		+	+	-	+	+
Controlling elements		+	+	+	+	+
Minimize heat loss		+	+	+	+	+
Accessibility		-	S	S	-	-
Clearance		-	S	+	S	-
Clarity		S	S	S	S	S
Portability		S	S	+	+	S
# of pluses		4	4	5	5	2
# of Minuses		3	1	1	1	3

Table 5: The Last Decision Matrix and 3 Selected Concepts.

Decision Matrix				
Selection Criteria	Concept 1	Concept 2	Concept 3	Concept 5
Safety	Datum	S	-	S
Cost		S	-	S
Construction feasibility		+	+	-
Weight of material		+	+	+
Controlling elements		+	+	+
Minimize heat loss		+	+	+
Accessibility		+	+	-
Clearance		+	S	S
Clarity		S	S	S
Portability		S	+	+
# of pluses		5	5	4
# of Minuses		0	2	2

Concept 2
Concept 3
Concept 5

The final step our team took in finalizing our design was to use the best concepts from the Pugh matrix and highest-ranking factors from the house of quality and put them in an Analytical Hierarchy Process, or AHP. The AHP uses pairwise comparisons of each concept to the individual factor to create non-biased, mathematical calculations to which idea is “best”. The results from our AHP are seen below.

Table 6: The Alternative Value Table.

Concept	Alternative Value
Concept 2	0.10697212
Concept 3	0.266543689
Concept 5	0.62648419

Although the results of the AHP indicated that concept 5 is the best option, our group has selected to go with concept 2. Following the presentation of our House of Quality and some of our other concept selection tools, it was determined that keeping the chamber the same size was most ideal. Reducing the size of the chamber would result in limited space for lab personnel to work within the chamber. It was also determined that assembly and disassembly would not be such a high factor to consider. Our sponsor informed us that disassembly of the chamber might only occur once every two to three years, indicating that using holes and sealant around the piping on the back wall might be our best option. A rough sketch of concept 2 is shown in the figure below, generated by Creo Parametric.

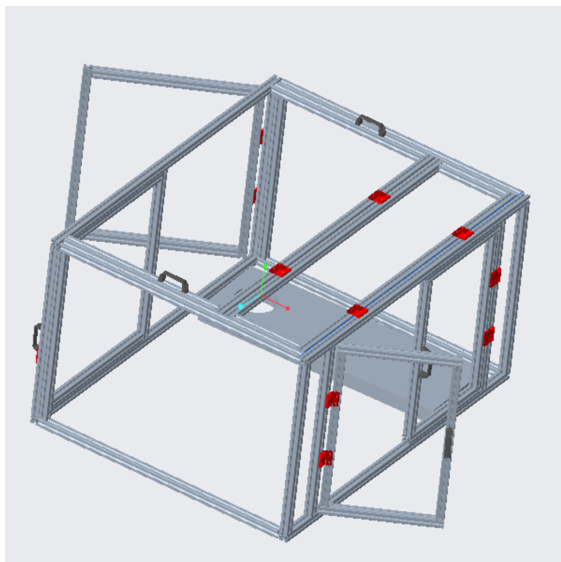

Figure 5: The Complete CAD Design of Concept 2.

This is our final concept of the chamber. The CAD model help us to decide the final value of the volume, which we can use to size our control system. The next step is to perform those calculations. After that, the bill of material can be established to calculate cost and order equipment. The frame will be reinforced with other gaskets and sealant to minimize heat loss.

Our control system is an AC unit and a humidifier. The AC unit can be used as a dehumidifier if the fan is turning on without AC option. The humidifier is a cool and hot mist evaporative humidifier. It would be compactable and easy to use. The controller for the humidifier and the controller of the AC unit are separate things.

1.7 Spring Project Plan

To organize and make sure our team can complete our senior design project before graduation, a spring project plan was created. We have taken major milestones for our project and put them in a Gantt chart, located in the appendix, to keep track of what had been done as well as what is coming up.

A Gantt chart tracks your progress of each milestone and show you where most of time will be used. There are many things that must be done before the incoming spring semester in order to keep the project running smoothly. We will look back at what we have previously accomplished and use them as references for our upcoming work. The tasks and corresponding dates are located below

Environmental Test-Stand Chamber Project Schedule						
Danfoss Turbocor						
	Start Date:	9/1/2019				
	Project Lead:	Michael Stoddard				
W.B.S.	Tasks	Lead	Start	End	Days	% Done
1						
	Odering Parts	Team	12/2/2019	12/27/2019	26	0%
	Receiving Parts	Team	1/6/2020	1/26/2020	21	0%
	Testing Parts	Team	1/13/2020	2/2/2020	21	0%
	Fabricating Chamber	Team	1/27/2020	3/15/2020	49	0%
	Testing & Validating Chamber	Team	3/9/2020	4/19/2020	42	0%
	Prepare for Presentation	Team	4/13/2020	4/22/2020	10	0%
	Engineering Design Day	Team	4/23/2020	4/24/2020	2	0%
	Finals	Team	4/27/2020	5/1/2020	5	0%
	Graduation	Team	5/1/2020	5/2/2020	2	0%

Table 7: Spring Schedule

One of the milestones we set for our team is to order everything on the bill of materials before winter break. This is so if any unexpected delays occur, it won't hinder the project as much. We also gave some milestones extra time for unexpected delays.

The work that will dominate the spring semester is mostly fabricating and testing the chamber. This step will require us to request our materials to be ordered. Team 509 will ensure every function of the chamber is properly tested and validated. The table contains the due dates for every step of the project. Each task on the Gantt chart is also assigned to a team member to take responsibility for that task.

Other than the physical prototype, team 509 will constantly update their evidence manual and website to record the most recent work. We will also work on our presentation skills and plan to meet our sponsor and faculty advisor regularly like before. The website will also be updated with all the PowerPoints, deliverables, poster, etc.

If every step follows the Gantt chart above, we are expecting to deliver our product by April 24th and graduate on May 1st, 2020.

Chapter Two: EML 4552C

2.1 Spring Plan

2.2 Chamber Fabrication

After the Christmas break, our team was able to update the CAD model of our chamber and add the HVAC system seen below in figures 6-11. Given we have systems not designed exactly for this purpose, custom duct transitions are needed.

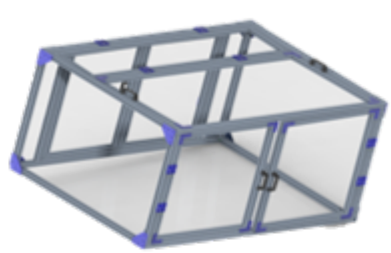

Figure 6: Chamber Assembly

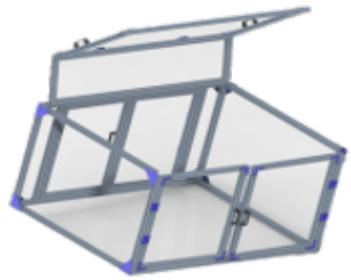

Figure 7: Chamber Assembly with Open Roof

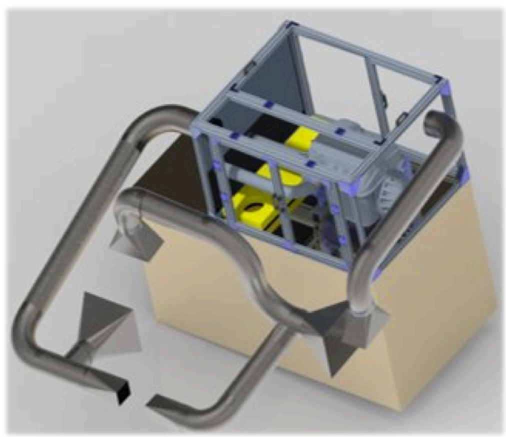

Figure 8: Chamber and Duct Assembly on Testing Rig

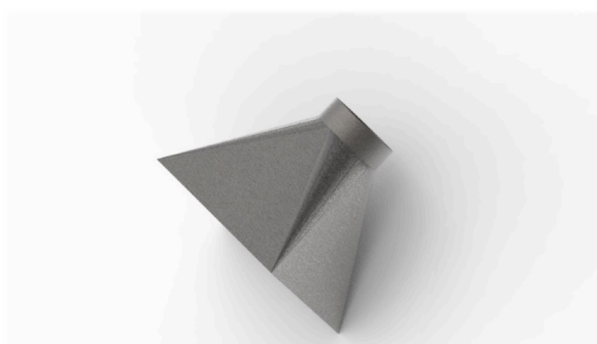

Figure 9: AC Inlet Custom Duct Transition

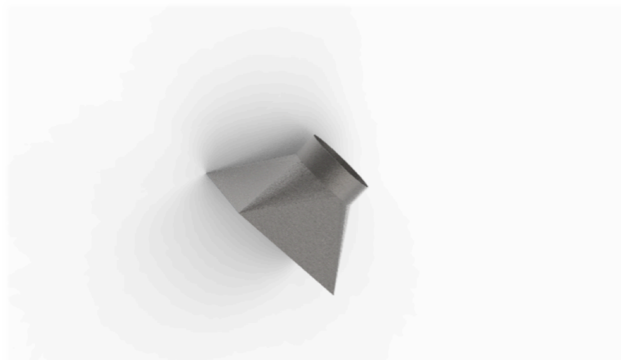

Figure 10: AC Outlet Custom Duct Transition

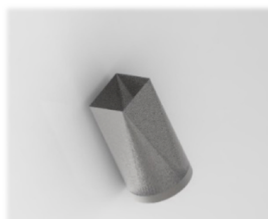

Figure 11: Heater Inlet and Outlet Custom Duct Transition

Appendices

Appendix A: Code of Conduct

- **Mission Statement:** Team 509 is committed to contributing their full effort to the designing process and maintaining a positive environment in order to perform our task to the best of our ability. We agree to act professionally and perform our work with integrity.

- **Team Roles:**

  Michael Stoddard: Engineering Lead. As the lead, Michael will take on the responsibility of perform main calculation with the team. He also checks if works have been done correctly and establish communication with the adviser and sponsor. He can also assign smaller tasks to other members in the team.

  Donald (Lane) Laughlin: Research Engineer. Donald is responsible for find resources and solution to heat and cool the chamber as well as how humidity will affect the heat load.

  Meghan Fonda: Quality Control and Test Engineer. The Quality Control and Test Engineer will work together closely with the Design Engineer to ensure the final product will be delivered. Meghan is responsible for construct and test every component of the chamber and the control system. She is also the web master.

  Dai (Bill) Truong: Design Engineer. The Design Engineer architects and combines every purchased instrument, makes sure that every system sync together when the final product is delivered. He will help with the frame and choose the best material. Dai will design the duct system to delivery humid air and heat/cool currents throughout the box.

- **Communication:** Casual conversation about the project is already established using GroupMe. Every team member has each other's phone numbers. Meetings with our sponsor and visits to Danfoss are scheduled via email. The team will meet every Monday at 1 PM to discuss progress and review the project actions. Team 509 will also have casual group meetings as necessary and will be given prior notice so that all members can be present if possible. Team members have 24 hours to respond to messages. If there has been a meeting scheduled and a team member can't make it because of time conflict, he/she has 24 hours to notify the team; other team members will still conduct the meeting as usual.

- **Dress Code:** For team meetings, casual dress is acceptable. Meetings with sponsors, however, require business casual attire. Business formal attire is expected for all presentations.
- **Attendance Policy:** All members must be present at all sponsor/advisor meetings or must notify the group before the email of invitation is sent out in advance of absence. For casual group meetings, attendance is mandatory unless notify in GroupMe 24 hours in advance of the last scheduled meeting time. An attendance log will be kept by the current project manager; when needed, the project manager can submit the attendance log to the supervisor.
- **Statement of Understanding:** By signing this document, the following group members agree to all statements above, as well as to any futures amendments voted upon by the group.

Appendix B: Figures and Tables

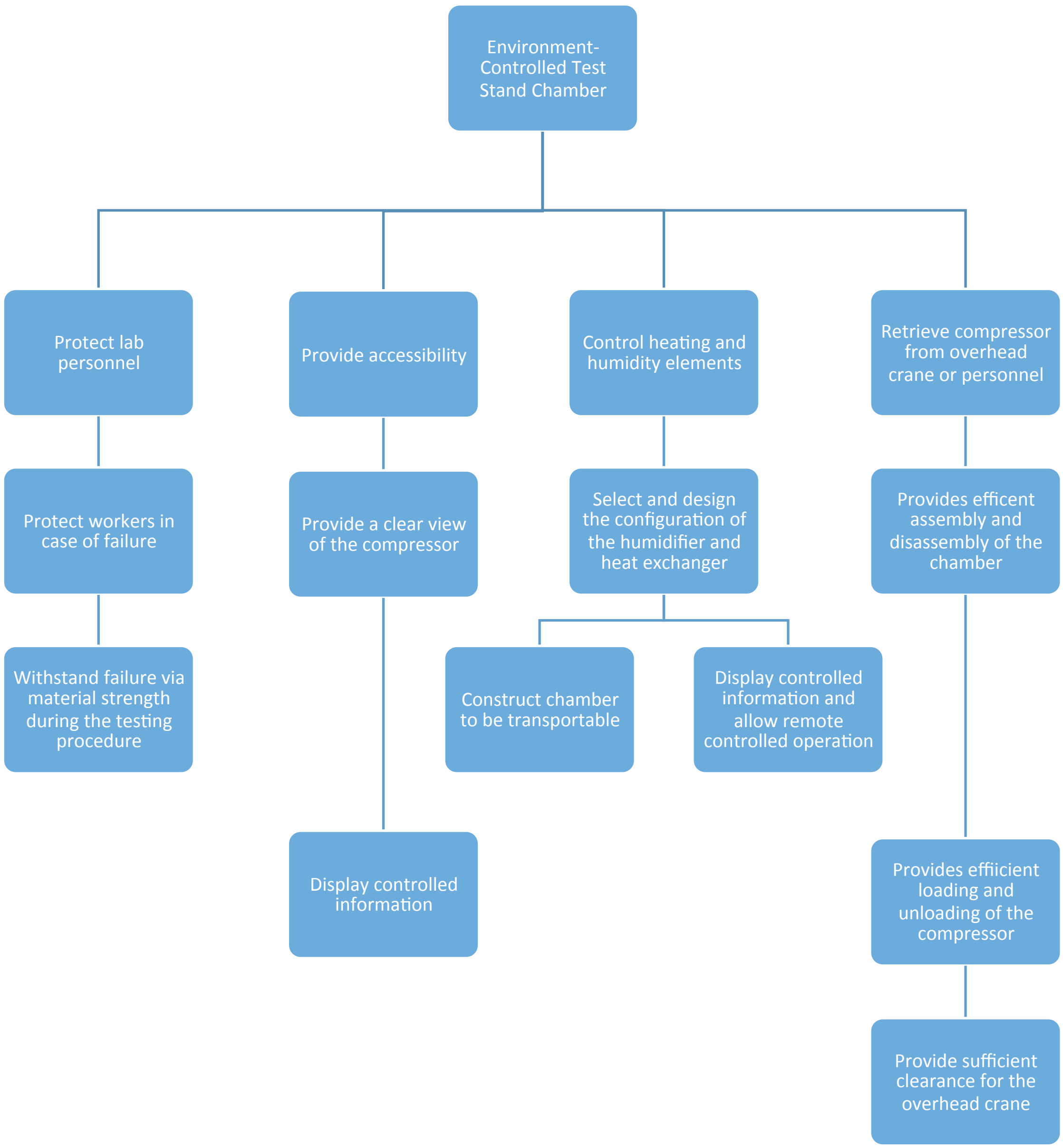

Figure 1. Functional Decomposition flow chart.

Table 1.
Targets and Metrics.

Main Function	Sub-Function(s)	Metric	Target
Protect lab personnel	Protect workers from compressor failure	Impact strength [MPa]	69 minimum
	Protect workers from temperature and humidity related illnesses	Temperature outside the chamber [°C]	30° C maximum
Provide accessibility	Provide a clear view of the compressor	Visible Light Transmittance [%]	90 minimum
	Allow access to testing mechanisms via doors	Clearance [m]	.762
	Ensure chamber doesn't impede on work space	Inner volume [m^3]	1 minimum
Control heating and humidity elements	Construct chamber to be transportable	Weight [kg]	70 maximum
	Ensure minimum heat loss	U-factor [W/m^2K]	1.06 maximum
	Ensure humidity control inside the chamber	Relative Humidity [%]	0 to 95
Retrieve compressor from overhead crane or personnel	Provides efficient loading and unloading of the compressor	Loading Area [m^2]	0.6 x 0.9 minimum
	Provide enough clearance for connecting the crane to the compressor	Height [m]	0.305 minimum
	Provide sufficient clearance for the overhead crane	Height [m]	1.65 maximum

Table 2
Morphological Chart used for concept generation.

Size of the chamber	Wall Material	Frame Material	Sealant Design for enclosure	Door Design	Piping Enclosure Design
Extends to the far end of the rig	Acrylic	6000 Series Aluminum	Magnetic	Full double doors on one side and half double doors on the other	Separate panes on back wall horizontally
Shorten the length of the current prototype	Polycarbonate	3000 Series Aluminum	Toggle Latches	Full double doors on both sides of the enclosure	Separate panes on back wall vertically
Shape is adjusted to exclude most of the piping from the enclosure		5000 Series Aluminum	Both Magnetic and Window Latches	Bifold doors	Cut holes in back pane then seal around pipes
Extends to far end of rig and sits on the ground			Both Magnetic and Toggle Latches		

Table 3
Analytical Hierarchy Process.

Criteria Comparison Matrix [C]					
	Maintain Inner Temperature	Inner Volume	Weight	Loading Area	Minimum Clearance Height
Maintain Inner Temperature	1	0.111111111	0.333333333	0.142857143	5
Inner Volume	9	1	0.333333333	0.142857143	7
Weight	3	3	1	0.333333333	3
Loading Area	7	7	3	1	5
Minimum Clearance Height	0.2	0.142857143	0.333333333	0.2	1
Sum	20.2	11.25396825	5	1.819047619	21

Table 4
Analytical Hierarchy Process.

Normalized Criteria Comparison Matrix [NormC]						
	Maintain Inner Temperature	Inner Volume	Weight	Loading Area	Minimum Clearance Height	Criteria weights {W}
Maintain Inner Temperature	0.04950495	0.009873061	0.066666667	0.078534031	0.238095238	0.088534789
Inner Volume	0.445544554	0.088857546	0.066666667	0.078534031	0.333333333	0.202587226
Weight	0.148514851	0.266572638	0.2	0.183246073	0.142857143	0.188238141
Loading Area	0.346534653	0.622002821	0.6	0.54973822	0.238095238	0.471274186
Minimum Clearance Height	0.00990099	0.012693935	0.066666667	0.109947644	0.047619048	0.049365657
Sum	1	1	1	1	1	1

Table 5
Analytical Hierarchy Process.

Consistency Check		
{Ws}=[C]{W}	{W}	Cons={Ws}./{W}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.487943696	0.088534789	5.511321578
1.475030859	0.202587226	7.280966751
1.366792554	0.188238141	7.260975627
3.320671004	0.471274186	7.046155081
0.253014531	0.049365657	5.125314807

Table 6
Analytical Hierarchy Process.

RI Values for Consistency Check	
# of criteria	RI value
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.4
9	1.45
10	1.49
11	1.51

Table 7
Analytical Hierarchy Process.

Average consistency	6.444946769
Consistency Index	1.722473384
Consistency Ratio	3.312448816

Table 8
Analytical Hierarchy Process.

Maintain Inner Temperature Comparison [C]			
	Concept 2	Concept 3	Concept 5
Concept 2	1	0.111111111	0.333333333
Concept 3	9	1	0.333333333
Concept 5	3	3	1
Sum	13	4.111111111	1.666666667

Table 9
Analytical Hierarchy Process.

Normalized Maintain Inner Temperature Comparison [NormC]				
	Concept 2	Concept 3	Concept 5	Design Alternate Priorities {Pi}
Concept 2	0.076923077	0.027027027	0.2	0.101316701
Concept 3	0.692307692	0.243243243	0.2	0.378516979
Concept 5	0.230769231	0.72972973	0.6	0.52016632
Sum	1	1	1	

Table 10
Analytical Hierarchy Process.

Consistency Check		
{Ws}=[C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.316762917	0.101316701	3.126462988
1.463756064	0.378516979	3.867081655
1.95966736	0.52016632	3.767386091

Table 11
Analytical Hierarchy Process.

Average consistency	3.586976911
Consistency Index	-0.353255772
Consistency Ratio	-0.098482868

Table 12
Analytical Hierarchy Process.

Inner Volume Comparison [C]			
	Concept 2	Concept 3	Concept 5
Concept 2	1	0.333333333	0.2
Concept 3	3	1	0.142857143
Concept 5	5	7	1
Sum	9	8.333333333	1.342857143

Table 13
Analytical Hierarchy Process.

Normalized Inner Volume Comparison [NormC]				
	Concept 2	Concept 3	Concept 5	Design Alternate Priorities {Pi}
Concept 2	0.111111111	0.04	0.14893617	0.10001576
Concept 3	0.333333333	0.12	0.106382979	0.186572104
Concept 5	0.555555556	0.84	0.744680851	0.713412136
Sum	1	1	1	

Table 14
Analytical Hierarchy Process.

Consistency Check		
{Ws}=[C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.304888889	0.10001576	3.048408446
0.304888889	0.186572104	1.634161176
0.304888889	0.713412136	0.427367119

Table 15
Analytical Hierarchy Process.

Average consistency	1.703312247
Consistency Index	-0.824171938
Consistency Ratio	-0.483864271

Table 16
Analytical Hierarchy Process.

Weight Comparison [C]			
	Concept 2	Concept 3	Concept 5
Concept 2	1	0.142857143	0.333333333
Concept 3	7	1	0.2
Concept 5	3	5	1
Sum	11	6.142857143	1.533333333

Table 17
Analytical Hierarchy Process.

Normalized Weight Comparison [NormC]				
	Concept 2	Concept 3	Concept 5	Design Alternate Priorities {Pi}
Concept 2	0.090909091	0.023255814	0.217391304	0.110518736
Concept 3	0.636363636	0.162790698	0.130434783	0.309863039
Concept 5	0.272727273	0.813953488	0.652173913	0.579618225
Sum	1	1	1	

Table 18
Analytical Hierarchy Process.

Consistency Check		
{Ws}=[C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.34799096	0.110518736	3.148705559
1.199417839	0.309863039	3.87079996
2.460489628	0.579618225	4.245017709

Table 19
Analytical Hierarchy Process.

Average consistency	3.754841076
Consistency Index	-0.311289731
Consistency Ratio	-0.08290357

Table 20
Analytical Hierarchy Process.

Loading Area Comparison [C]			
	Concept 2	Concept 3	Concept 5
Concept 2	1	0.333333333	0.2
Concept 3	3	1	0.333333333
Concept 5	5	3	1
Sum	9	4.333333333	1.533333333

Table 21
Analytical Hierarchy Process.

Normalized Loading Area Comparison [NormC]				
	Concept 2	Concept 3	Concept 5	Design Alternate Priorities {Pi}
Concept 2	0.111111111	0.076923077	0.130434783	0.106156324
Concept 3	0.333333333	0.230769231	0.217391304	0.260497956
Concept 5	0.555555556	0.692307692	0.652173913	0.63334572
Sum	1	1	1	

Table 22
Analytical Hierarchy Process.

Consistency Check		
{Ws}=[C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.31965812	0.106156324	3.011201867
0.790082167	0.260497956	3.032968775
1.945621206	0.63334572	3.071973401

Table 23
Analytical Hierarchy Process.

Average consistency	3.038714681
Consistency Index	-0.49032133
Consistency Ratio	-0.161358134

Table 24
Analytical Hierarchy Process.

Minimum Clearance Height Comparison [C]			
	Concept 2	Concept 3	Concept 5
Concept 2	1	0.333333333	0.333333333
Concept 3	3	1	0.333333333
Concept 5	3	3	1
Sum	7	4.333333333	1.666666667

Table 25
Analytical Hierarchy Process.

Normalized Minimum Clearance Height Comparison [NormC]				
	Concept 2	Concept 3	Concept 5	Design Alternate Priorities {Pi}
Concept 2	0.142857143	0.076923077	0.2	0.13992674
Concept 3	0.428571429	0.230769231	0.2	0.286446886
Concept 5	0.428571429	0.692307692	0.6	0.573626374
Sum	1	1	1	

Table 26
Analytical Hierarchy Process.

Consistency Check		
{Ws}=[C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.426617827	0.13992674	3.04886562
0.897435897	0.286446886	3.132992327
1.852747253	0.573626374	3.229885057

Table 27
Analytical Hierarchy Process.

Average consistency	3.137247668
Consistency Index	-0.465688083
Consistency Ratio	-0.148438419

Table 28
Analytical Hierarchy Process.

Final Rating Matrix			
	Design 1	Design 3	Design 4
Maintain Inner Temperature	0.101316701	0.378516979	0.52016632
Inner Volume	0.10001576	0.186572104	0.713412136
Weight	0.110518736	0.309863039	0.579618225
Loading Area	0.106156324	0.260497956	0.63334572
Minimum Clearance Height	0.13992674	0.286446886	0.573626374

Table 29
Analytical Hierarchy Process.

[Final Rating Matrix]^T					
	Maintain Inner Temperature	Inner Volume	Weight	Loading Area	Minimum Clearance Height
Concept 2	0.101316701	0.10001576	0.110518736	0.106156324	0.13992674
Concept 3	0.378516979	0.186572104	0.309863039	0.260497956	0.286446886
Concept 5	0.52016632	0.713412136	0.579618225	0.63334572	0.573626374

Table 30

Analytical Hierarchy Process.

Concept	Alternative Value
Concept 2	0.10697212
Concept 3	0.266543689
Concept 5	0.62648419

Table 30

The Progress Table

Environmental Test-Stand Chamber Project Schedule						
Danfoss Turbocor						
	Start Date:	9/1/2019				
	Project Lead:	Michael Stoddard				
W.B.S.	Tasks	Lead	Start	End	Days	% Done
1						
	Customer Needs	Team	9/2/2019	9/27/2019		100%
	Functional Decomposition	Team	9/13/2019	9/27/2019	15	100%
	Targets & Metrics	Team	9/27/2019	10/4/2019	8	100%
	Concept Generation	Team	10/4/2019	10/18/2019	15	100%
	Concept Selection	Team	10/18/2019	10/28/2019	11	100%
	Heater/Cooling Calculations	Team	10/28/2019	11/27/2019	31	50%
	Bill of Materials	Team	10/18/2019	11/22/2019	36	80%
	Odering Parts	Team	11/25/2019	1/5/2020	42	0%
	Receiving Parts	Team	1/6/2020	1/19/2020	14	0%
	Testing Parts	Team	1/13/2020	2/2/2020	21	0%
	Fabricating Chamber	Team	1/20/2020	3/15/2020	56	0%
	Testing Chamber	Team	3/13/2020	4/5/2020	24	0%
	Prepare for Presentation	Team	3/30/2020	4/22/2020	24	0%
	Final Design Presentation	Team	4/23/2020	4/24/2020	2	0%

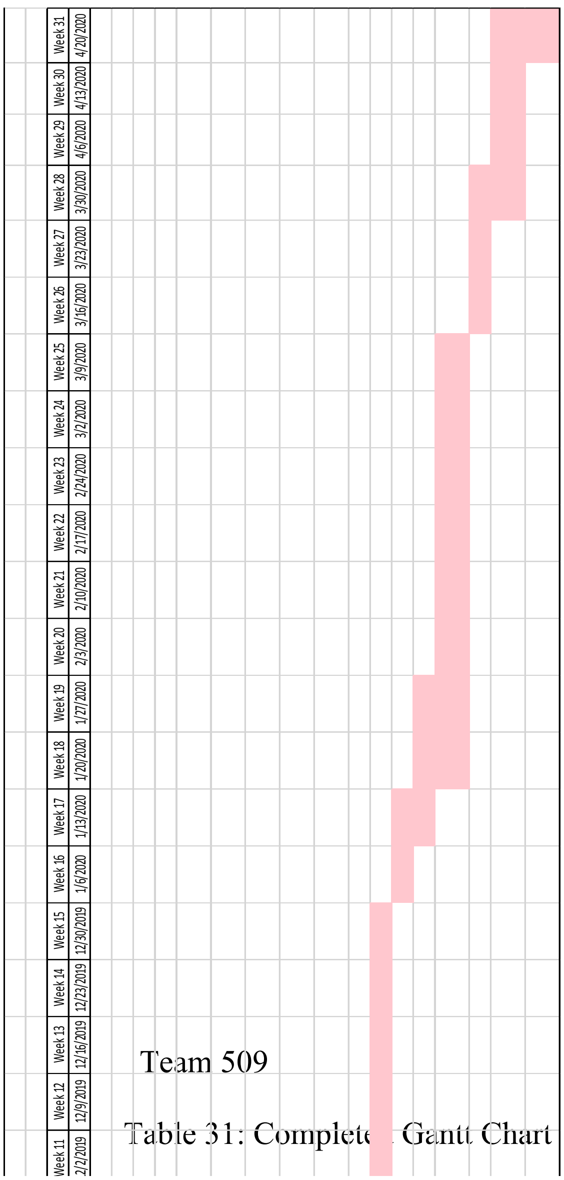

Table 31: Completed Gantt Chart

Appendix C: Target Catalog

References

Danfoss. (n.d.). *Turbocor - TG*. Retrieved from Highly energy efficient and environmentally friendly compressor: https://www.danfoss.com/en/products/compressors/dcs/turbocor/turbocor-tg/#tab-overview

Danfoss. (n.d.). *Turbocor - TT*. Retrieved from Danfoss Turbocor® TT series: Oil free compressors using HFC134a refrigerant: https://www.danfoss.com/en/products/compressors/dcs/turbocor/turbocor-tt/#tab-overview

Danfoss. (n.d.). Turbocor – Danfoss Turbocor Compressor Specification Sheet.