

Miami University  
Department of Engineering Technology  
ENT 498 Senior Design

Prototype Vacuum Former

Campus: Middletown

Professor: Robert Speckert and Zhiyuan (Tiger) Yu

Team Members: Mindy Bach and Danielle Gagliano

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## Statement of Purpose (Executive Summary)

The purpose of this project is to design a small vacuum forming machine capable of running both prototype tooling and service parts for prior models that have ended their production life.

### Project Requirements:

- Accept current production and prototype tooling.
- Modular design that can be easily modified later.
- Machine must be sheet fed.
- Accommodate various material thicknesses.
- A shuttle must be used to move the material from the heater to the tool
- \$15,000 project budget.
- Able to be operated by one person.

This project will create a smaller, more easily manageable, vacuum former to improve the process for producing prototype samples, running early trial orders, and manufacturing prior model service parts. Due to their low volume production of these parts, it becomes too costly and time consuming to produce these on their current machines that are intended for manufacturing high volumes and require multiple people to run.

The machine will operate by transporting a sheet of material by shuttle into the oven where it will be heated, then moved back over the tool where the vacuum can engage removing the air and forming the material to the mold. It will have the capability of running materials of

various thicknesses, including the standard PE and EVA materials currently used in production parts. This vacuum former will have the ability to be fully operated safely by one operator with only minimal training.

Research was conducted on the operation of a vacuum former and all of the individual elements it consists of including the frame, oven, shuttle, vacuum, hydraulics to lift the tool, pneumatics to move the shuttle, control system, and safety guards. Once the elements were selected and the design was complete, finite element analysis tests were run on multiple areas of the design to ensure there were no critical errors in the structure.

Our reported findings and the final design were presented to the company and approved by them. Plans to move forward with the machine's construction were put on hold and the company plans to build it on their own in the future.

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## Scope and Methodology

The purpose of this project is to design a small vacuum forming machine capable of running both prototype tooling and service parts for prior models that have ended their production life.

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This project will create a smaller, more easily manageable, vacuum former to improve the process for producing prototype samples, running early trial orders, and manufacturing prior model service parts. Due to their low volume production of these parts, it becomes too costly and time consuming to produce these on their current machines that are intended for manufacturing high volumes and require multiple people to run.

The scope of this project is to complete a design that meets all of the company's requirements while keeping the cost below \$15,000. The vacuum forming machine must be capable of running thin PE films and other materials for prototyping. It will heat and form parts

from a sheet of plastic, use a shuttle to transport the material to the oven, and will have the ability to be operated by one person. The machine will also need to accept current production tooling so the machine can be used for low volume production runs and producing service parts. Research was conducted for the development of the design when selecting individual elements including the frame, oven, shuttle, vacuum, hydraulics to lift the tool, pneumatics to move the shuttle, control system, and safety guards. Finite element analysis tests were also run to test areas of the design.

## Gantt Chart

The team was tasked with creating a design for a small industrial vacuum former. The following timeline shows the deadlines set in place to keep the project on track for completion by the end of Spring semester.

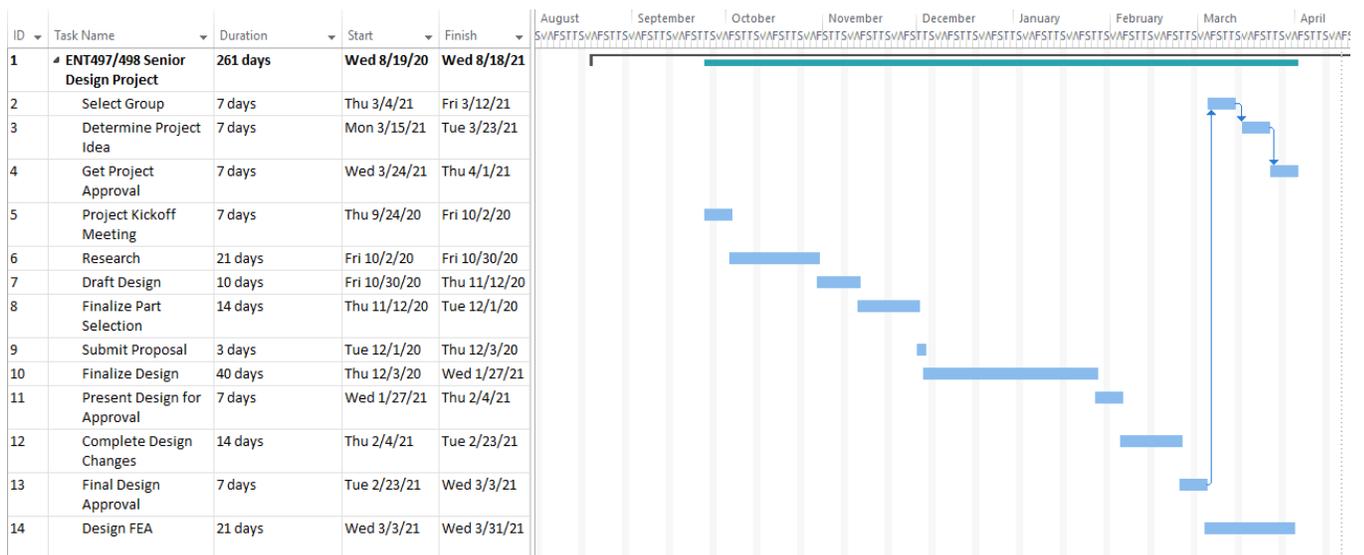


Figure 1 Gantt Chart

This chart covers September to April. The gantt chart is the list of objectives that must get done by the due date given. It helps to organize the project into more manageable tasks.

## Research

### General Research

Initially, we completed research on the vacuum forming process itself, making note of specific elements we would need to include. We looked at some commercially available smaller vacuum forming models, including those available from Sibe Automation. In addition to the commercially available models, we also looked at the current vacuum formers in production at the company. In addition to these machines, we also looked at a few homemade versions available on YouTube, however, it was quickly determined that these models would not be a viable option for a production environment. We also referenced a book on thermoforming that was made available to us by the company. The book was able to give us guidance on many different aspects of forming including temperatures, vacuum capacity, and necessary oven components with specific materials.

Based on our research, we then organized the machine into three main parts including the oven, the vacuum system, and the shuttle for the material. We then continued research on these individual aspects of the machine focusing on what they would need to consist of and determining those specific elements.

### Frame

The first selection we needed to make was to determine the best fit material for the construction of the machine's frame. We ended up selecting 80-20 extruded aluminium since this is what the company used on all its current machines and it was their preference.

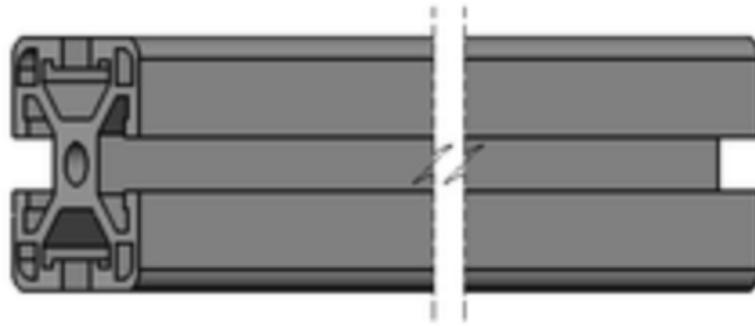


Figure 2 80-20 Extruded Aluminum

Pictured here is the extruded aluminum that the company uses as frame material. It comes in 1.5"x1.5"x10' pieces.

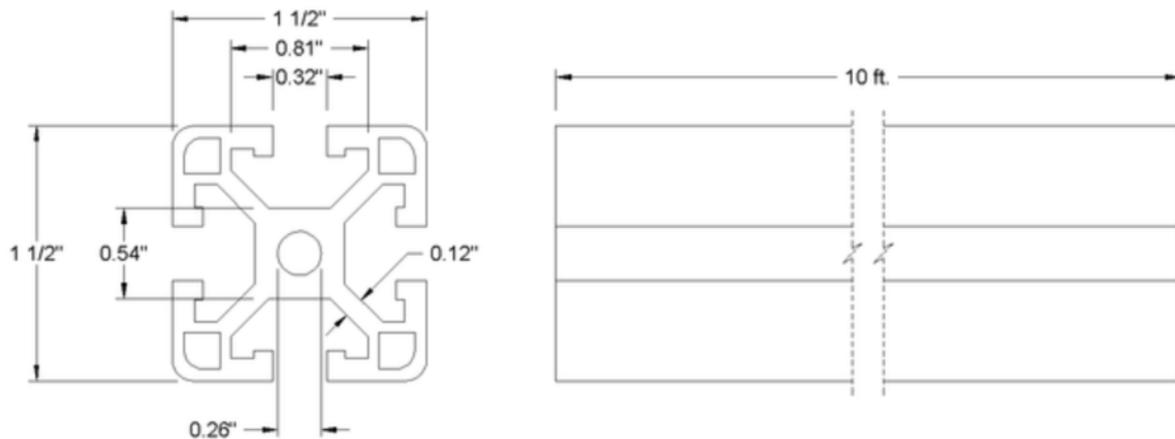


Figure 3 80-20 Extruded Aluminum Specifications

These are the specifications of the extruded aluminum.

## Oven

Before the selection of parts could begin for the oven portion of the machine, research was done to determine what all parts would need to be included. The main components were the frame material, insulation, heating element, control system, and temperature gauge. For the oven's frame we decided to use the same material that we were using for the frame of the whole machine, which was 80-20 extruded aluminum. We also decided to use the same insulation that the other current machines have at

the company. For the heating element, more research was needed to determine the possible options along with the best fit.

The research started with determining the possible methods of heating, which were conduction, convection, or radiation. Because of the application, radiation was the best method for heating the material. Once the infrared method was decided upon, the next step was to research our options for the heating element itself. The most common options were bare nichrome wire heaters, metal tubular heaters (calrod), ceramic heaters, or quartz and halogen. To narrow down these options, we considered the max oven temperature and the materials that would be heated along with their requirements. It was easy to narrow our options down to two, quartz and ceramic, because the material that would be heated is very thin and many of the other options would result in the uneven heating of it. The pros and cons of quartz and ceramic were then compared to determine the best fit in this application. We also compared the efficiencies of the two and found that quartz heating elements are more efficient because they convert more electrical energy into heat resulting in less heat loss. We decided to use a quartz heater because they are more efficient, have a shorter range of heating, provide high heat, heat to required temperature quicker, and cool quicker. Quartz is more expensive than ceramic, but due to the size of this machine, we won't be needing nearly as many units compared to their current machines.

Before deciding on a quartz heater completely, we took one last look at the heaters used on the current machines at the company to see how they compared to our choice. We then ran it by them to make sure the cost wasn't an issue and they preferred quartz because of its efficiency and speed when reaching the required temperature.

When researching the heating element, various information was found on the control system. This information was noted for understanding the setup, but no decision needed to be made on a

specific selection since we needed to use the current type at the company. A temperature gauge was also selected based on what the suppliers we planned to use had available.

## Vacuum System

The vacuum system's frame would also use the same 80-20 extruded aluminum as the frame. With the frame's material already being selected, the next step would be to look at the vacuum. For the next step, research for the vacuum pump itself was required. Since there are many different types of vacuums, the first decision was what type of vacuum to use. There were two different variations of vacuum that were; wet and dry. The choice looked clear from the description of the variations, one is easier to maintain and that would be the dry vacuums. The dry vacuum does not need a lubricant and has less of a chance of contamination.

The step after picking the dry vacuum is now which dry vacuum to pick. There were many options but since the vacuum form itself is meant to do smaller jobs and be quick to change out, the logical choice would be to pick the vacuum form that is meant for small jobs that is low maintenance. However, during the research process there was one vacuum that looked a lot like the one used at Industry Product Company. This one is a wet vacuum and is called a liquid ring pump (the closest looking vacuum).

The size of the vacuum is also something that would be something that would be good to look into, however, the client said he would like a base that could hold varying sizes of vacuums, so a more powerful vacuum could be put into place if needed.

## Shuttle

For the shuttle, we mostly referenced other vacuum formers that were available. We watched several YouTube videos to gather some inspiration for the design of this machine. In addition to the videos, we also gathered some knowledge from the process specialists at the company.

Before selecting components, we needed to figure out how we wanted the shuttle to operate, while keeping in mind how crucial its travel speed and smoothness were. We needed the material to move from the oven to the tool as quickly as possible without having any violent or jerky motions to avoid any creasing or sagging of the heated material. Since the shuttle would be going in the oven, this needed to be considered when selecting what material would be used for its frame. We decided to use the same 80-20 extruded aluminum for the shuttle's frame since it could withstand the oven's heat and would keep things consistent throughout the whole machine's design.

For the shuttle's operation, we decided that it would move into the heater with the use of a pneumatic cylinder and then once it's moved back over the tool, the tool would then be lifted up to the heated material using a hydraulic cylinder. By moving the tool up to the material, we reduce the movement of the material itself to eliminate any deformation that could occur as a result of the material having more movement. It will also give the material less of a chance to cool down during the movement to the tool.

## Expected Findings

### Oven

While looking for a heating element for the oven there were many options such as ceramic or quartz. The deciding factor was the evenness of the heating. This is because the main factors when looking for a heating element for a vacuum form would have to be, how evenly would the material heat up and how quickly can the heating element heat up. Quartz heaters meet the criteria of evenly heating as well as heating up fast. When looking for a quartz heater for the budget, there was a bit of a struggle. The problem was finding a quartz heating element. There were plenty of options when looking for repair kits for quartz heaters, but the team needed the actual element and that did not come with the repair kits. After looking around the team finally found a website that had quartz heating elements. It is from MOR Electric which can be seen on the actual cost table.

Another part of the oven to keep in mind is what will hold the heating elements, the material of the oven itself and its shape. The shape ended up being a rectangular box with an opening on one side. The opening on one side is where the shuttle and material will slide in and out of the oven. Since something will be sliding in and out of the oven there are also two slots on the side of the oven that are for the shuttle to pass through.

### Vacuum Pump

The vacuum pump we selected was oil-free, electric, and has a tank. There are many good reasons as to why this specific vacuum pump was chosen. One being that it is small, it can fit smaller areas such as under the tool for the vacuum former. The dimensions are 30" long, 12 3/8" wide, and 24 1/2" tall. The vacuum pump holds 10 gallons of air. This is about what size the company currently uses

with their thrown together prototype vacuum form. The vacuum pump has a rate of 7.1 cfm, cfm means cubic feet per minute. This is how fast the vacuum pump can move the air.



Figure 4

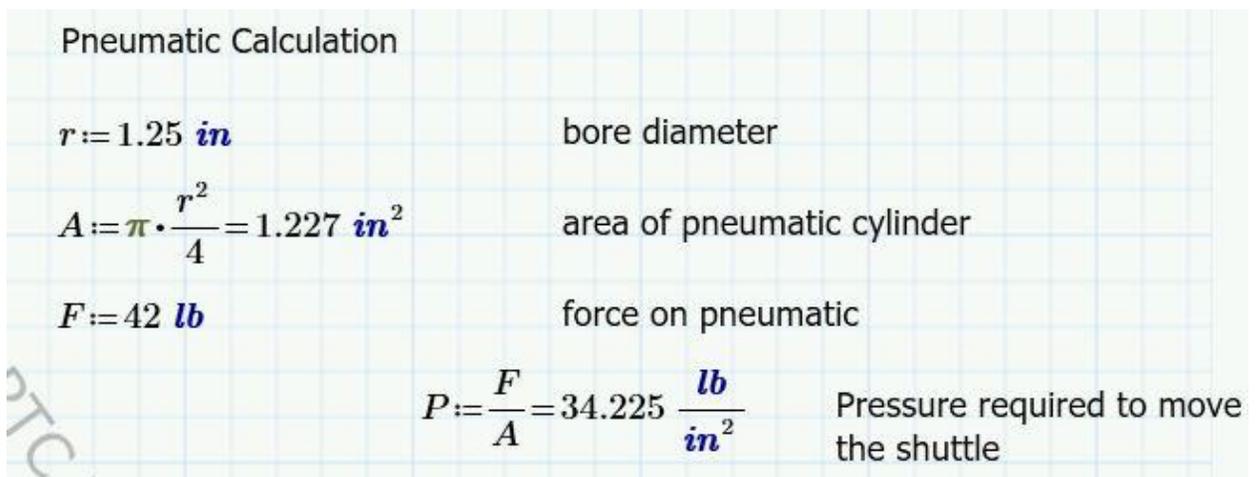
This is a picture of the vacuum pump chosen by the group. The picture comes from McMaster Carr.

## Shuttle

The shuttle is the part of the design that will safely move the material in and out of the oven so a person doesn't have to. The shuttle needs to hold the material still while transporting it smoothly to ensure the material doesn't encounter any violent movements that would cause it to crease or sag. The shuttle will be made out of the same materials as the frame and will be 60" x 60" in size. It will utilize manual clamping mechanisms and mount on rails with linear bearings. In order to move the shuttle in and out of the oven, the team came up with the idea to use pneumatics.

## Pneumatics

Before selecting a pneumatic cylinder to use for moving the shuttle, we needed to calculate how much pressure would be required to move it. We calculated this by dividing the force by area.



Pneumatic Calculation

|   |                                       |
|---|---------------------------------------|
| $r := 1.25 \text{ in}$                                    | bore diameter                         |
| $A := \pi \cdot \frac{r^2}{4} = 1.227 \text{ in}^2$       | area of pneumatic cylinder            |
| $F := 42 \text{ lb}$                                      | force on pneumatic                    |
| $P := \frac{F}{A} = 34.225 \frac{\text{lb}}{\text{in}^2}$ | Pressure required to move the shuttle |

Figure 5 Pneumatic Calculation

We then selected a pneumatic double acting cylinder that could produce this pressure and provide the necessary stroke length to move the shuttle. The cylinder we selected can move 60 lbs. (pounds) with 50 psi (pounds per square inch). The pneumatic only needs to move 42lbs, but if the pneumatic cylinder needs to be able to push more weight it can be easily replaced with and have the same dimensions as this cylinder chosen. The cylinder chosen has the dimensions of an outer diameter of 1 3/4", the stroke is 36". The retracted length of the cylinder is 41.88" and the extended length is 77.88".

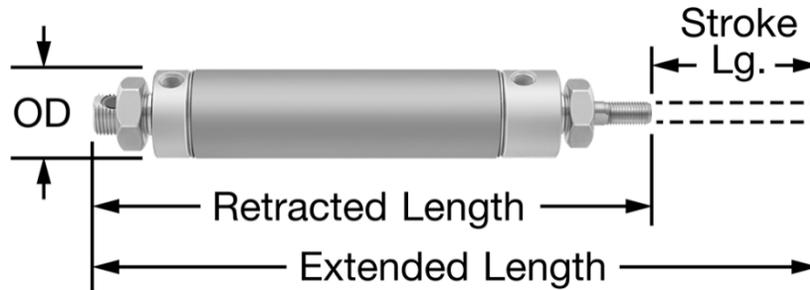


Figure 6

This is the pneumatic double acting cylinder that was selected from McMaster Carr. The picture also includes how the dimensions are measured.

## Hydraulics

In order to reduce the movement of the heated material, we will be using hydraulics to move the tool to the material before formation. This reduces the risk of material deformation during movement since it's so thin. It also cuts down the cooling effect on the material which would happen with movement. The hydraulic will be placed under the table holding the tool and be pushed up. We chose a hydraulic system over a pneumatic one due to the weight of the tool being up to 1,200 lbs. This is very heavy and would be easier to move with a hydraulic instead of a pneumatic because hydraulics can push more weight up than a pneumatic for a cheaper price. Before selecting a hydraulic cylinder, we needed to determine how much pressure we would need to lift the tool. This was calculated by dividing the force by the area.

|  |                                |
|--|--------------------------------|
| Hydraulic pressure   |                                |
| $A := 3.14 \text{ in}^2$                                   | area of cylinder               |
| $F := 1200 \text{ lb}$                                     | weight that needs to be lifted |
| +  |                                |
| $P := \frac{F}{A} = 382.166 \frac{\text{lb}}{\text{in}^2}$ | pressure required to lift tool |

Figure 7 Hydraulic Calculation

The hydraulic that we selected has a maximum push force of 3760 lbs. This will be more than enough to push the tool and the plate holding the tool up to the heated plastic. The height and width of the hydraulic is 2 ½” and its maximum pressure is 1,200 psi. The hydraulic can extend to 29 11/16”, making it easy to push the tool to the height needed to reach the plastic.



Figure 8

This is a picture of the hydraulic cylinder we selected from McMaster Carr.

## Safety

The safety features that needed to be included were safety interlocks, light curtains, a kill switch, and safety grating. Many of these were selected based on what the company's standard and what they currently use. Thus, the light curtain is not listed in our budget because the company already has that to provide. Light curtains are used to block light from the rest of an area so that no one gets surprised or blinded by a light that comes off the vacuum former. The safety grating had to be included since there is so much weight in such a small space. A safety grate is the grate typically seen on floors that have to hold a lot of weight. It is used to distribute the weight so the floor does not get any indents in it caused by the vacuum former. The kill switch is a device that is used to shut off a machine immediately in the case of an emergency. This is useful if something were to go wrong with the machine or if a person were to get hurt. The safety interlock will be used so that one part can not move if it's not time to. This is put in place to keep the operator safe when making adjustments to the machine.

## Control System

The control system that will be used is a PLC from Automation Direct. The Productivity 2000 Series PLC was selected because it is the same type that the company currently uses to control all of their machines. It was important that we use the same PLC in case there would be any problems. The company's maintenance team would already be familiar with its operation, which would make repairs or adjustments easier.

## Final Design

The final design was created in Solid Works. This vacuum former will operate by having a person load the material onto the shuttle so it can be moved into the oven, using the pneumatic system, where it will be heated until it's pliable. The shuttle will then move the heated material back over to the tool (where it has been loaded on its support) so it can be brought up to the material using the hydraulics system. The vacuum pump will then engage, removing the air and forming the material to the tool's mold. Once the vacuum disengages, ejection air will be blown onto the part to cool it down so it will keep its form.

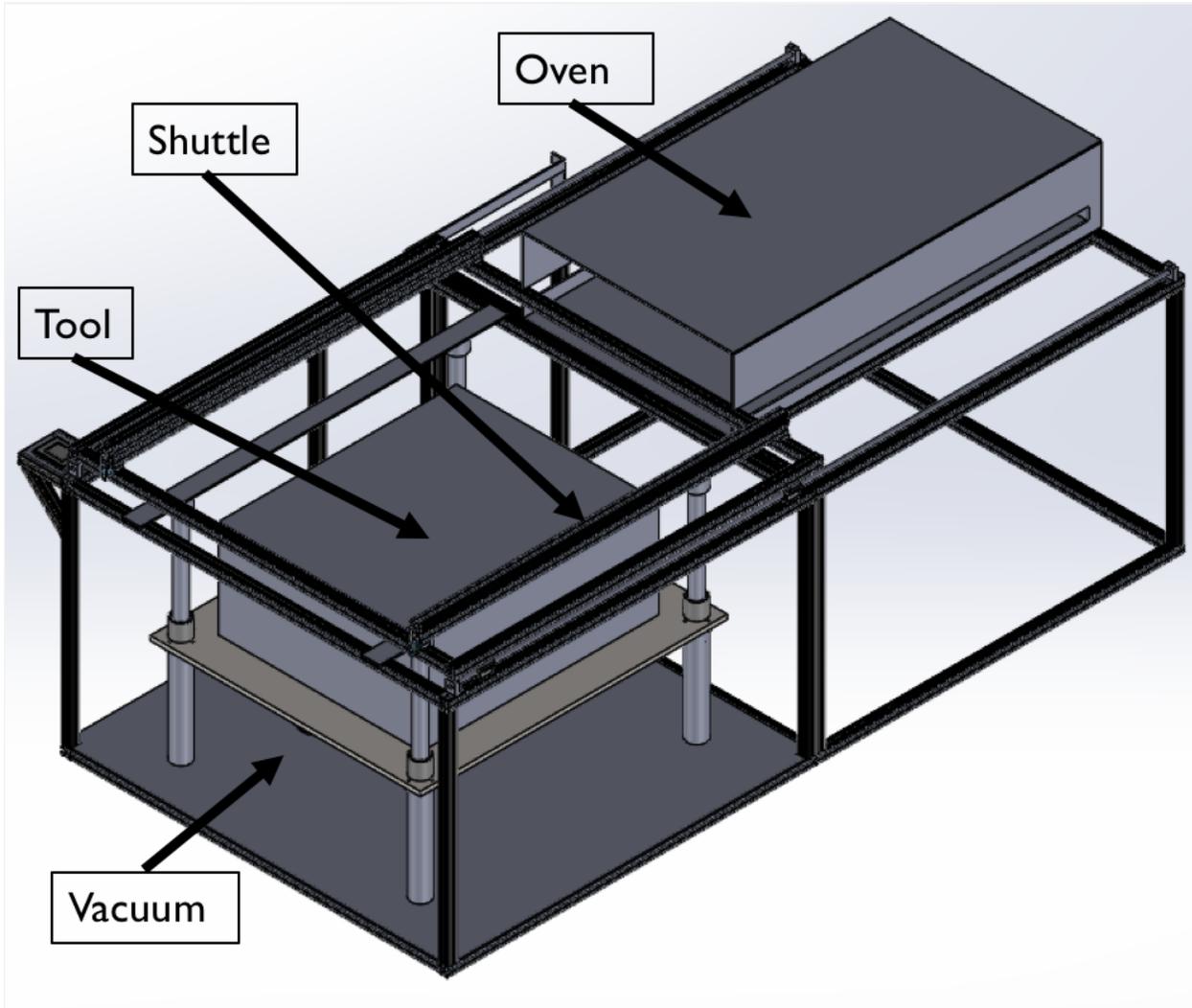


Figure 9

The black beams around the entire structure are the extruded aluminum. This is a picture of the final design showing each major part.

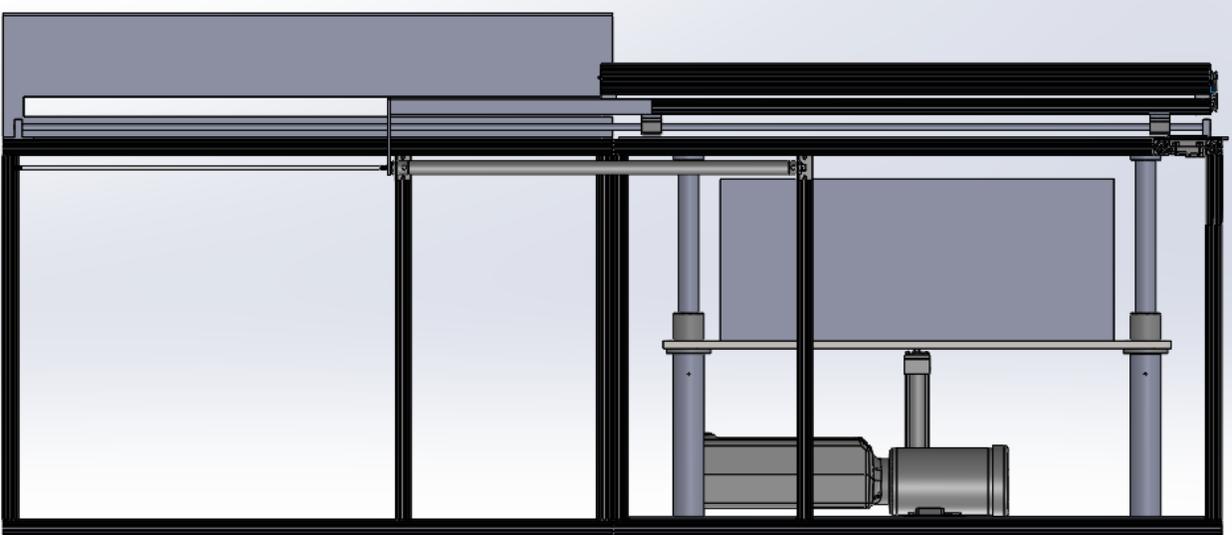


Figure 10

This is a picture of the final design, left side view. The vacuum pump can be seen on the bottom, it is laying horizontally. The vertical pipe in the middle of the tool support is the hydraulic.

## Finite Element Analysis

### Tool Support

When looking at the model, an easy way to see how stress will affect it is to complete a stress test. To do this, we used an engineering simulation software called ANSYS in order to check for critical errors in our design's structure. This program can predict the model's deformation and stress based on the applied boundary conditions. For the tool support portion of the design, a statical structure analysis was completed so we could see how the model would react under force. The test was run with a force that was pointed downward at 5338N (five thousand three hundred and thirty-eight newtons) which reflects the max tool size. The material that the assembly is made of is structural steel. This is so that

there is a less likely chance of the vacuum form deforming. The assembly has many contact regions. Each leg is connected to the bottom base plate. The plate in the middle of the structure is connected to all 4 (four) shaft mounts. Each leg is also connected to its corresponding shaft mount. At the top of the legs are two beams, the tops of the legs and the beams are connected. Each connection is bonded to each other, so it will not move. There is also a fixed support on the bottom plate since that is where the ground would be if the vacuum form were built.

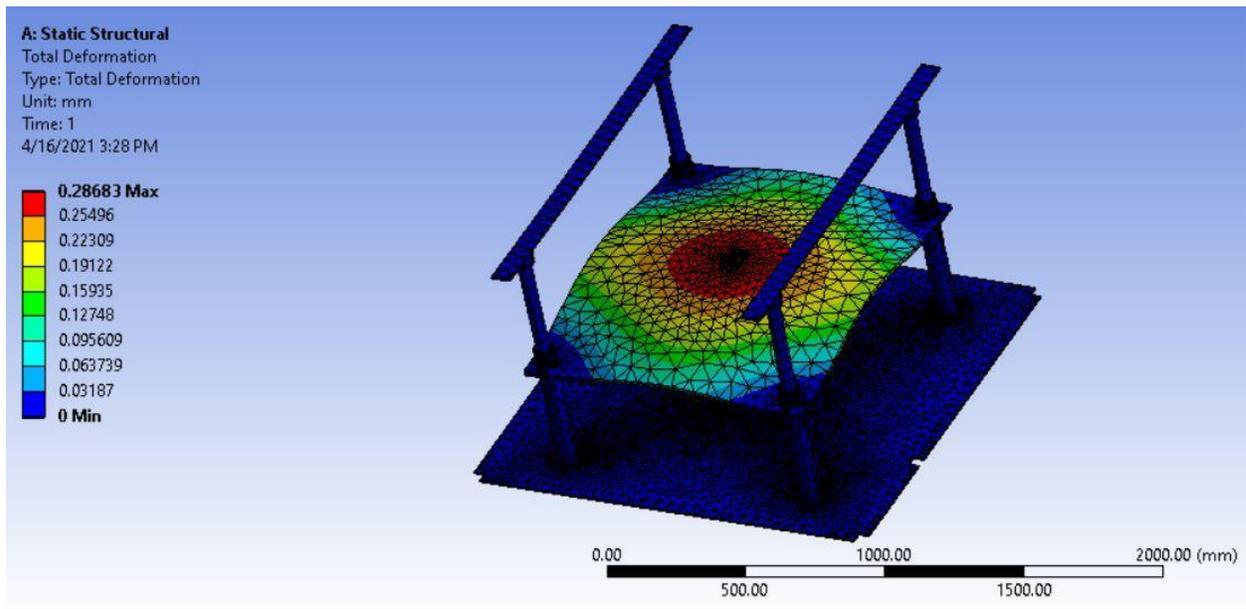


Figure 11

Pictured here is the total deformation of the tool support taken from the ANSYS software.

From figure 11, the deformation can be seen in the middle of the plate that supports the tool. The force is evenly distributed, however, there is more deformation at the center because the center is not as supported as the sides are where the legs hold up the middle plate. The deformation seems to be very high in the middle of the plate because it's colored red, which reflects the highest deformation.

However, if you look at the diagram's key shown on the left of Figure 11, the units are in mm (millimeters), which is very small.

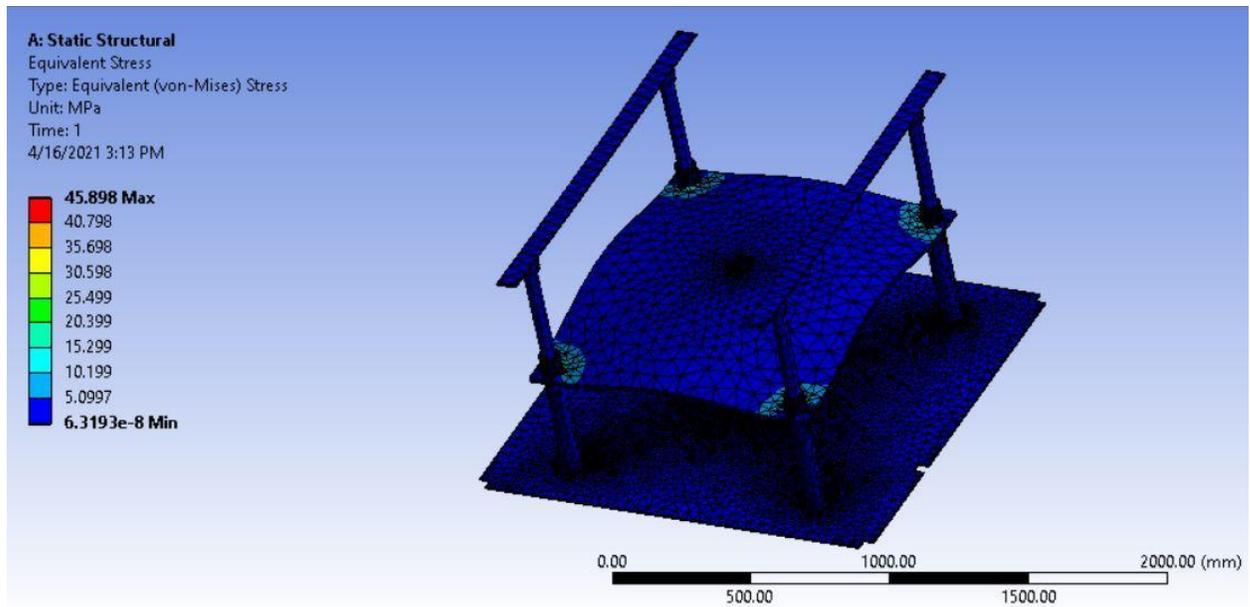


Figure 12

This is equivalent stress of the tool support captured from ANSYS

From Figure 12, the stress can be seen where the middle plate is connected to the shaft mounts. This is a result of them being bonded, which causes them to pull at each other. Because the figure only reflects the stress values of light and dark blues throughout, this means it does not have that much stress. The colored key to the left in Figure 12 is where you find out how much stress there is at any point on the figure by matching it to the color's value shown on the key. The value next to the color is the deformation value, a little above that is where the units are. The unit for stress is MPa (megapascals). The value at the highest point on the form is 45.898 MPa (forty-five point eight ninety-eight). This is not a large number compared to the stress that the structural steel material can withstand.

As one could see from this stress and deformation test, the structural steel will do well to hold up the tools that will be used in the vacuum former.

## Oven

When looking at the oven stress test done in ANSYS, the first thing to look at would be the connections. All of the sides of the oven need to be connected to one another to make the space usable to heat up the material. This includes the top plate, the bottom plate, and both sides, which are all bonded. There is a fixed support on the bottom plate since the bottom plate will be connected to the top of the model. However, this was not done in ANSYS because the file was too large when trying to solve for the whole model. There is also a force on the bottom of the plate that is pushing upwards to simulate the force of the rest of the structure pushing up on the oven to hold it. The force applied to the oven is 100N (one hundred).

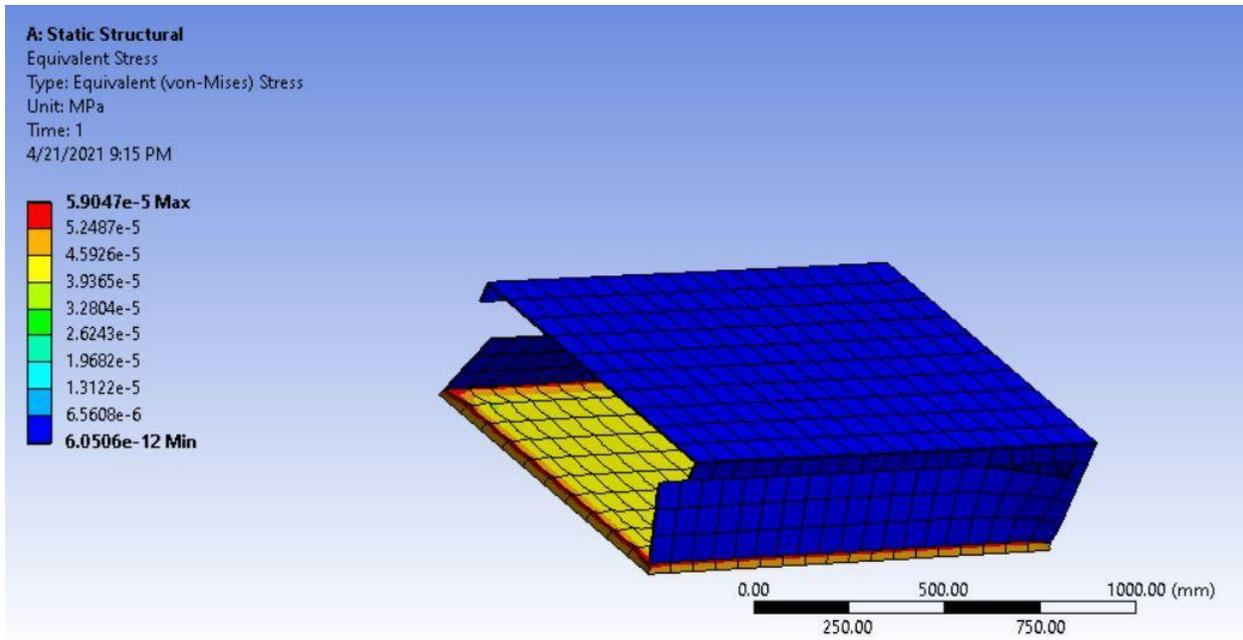


Figure 13

This is the picture of the oven under equivalent stress in ANSYS.

Figure 13 shows the equivalent stress results on the oven from ANSYS. Here the top part of the oven seems to be unaffected by any forces. However, the bottom plate shows some stress throughout, as the majority of it is yellow with red on the very edges. This would be a cause for concern, but based on the key in Figure 13, the values are to a power of -5 (negative five) MPa, which is a small value. Also, when looking at the results of the stress test one can see that the sides are bowing into the oven. This will not actually occur because of the weld fillets holding the oven together and the rest of the structure being there would prevent that from happening.

## Budget

The table called “Actual Cost” is the final list of parts that the team came up with that would be needed to complete the small industrial vacuum former. The “Actual Cost” table includes all of the parts the company would need to purchase. It does not include the parts they already have. The total cost is \$12,983.47, which is below our maximum budget of \$15,000 by \$2,016.53.

### Actual Cost

| Source        | Part Number | Description                       | Unit Price | Quantity | Units | Extended Price |
|---------------|-------------|-----------------------------------|------------|----------|-------|----------------|
| McMaster Carr | 47065T979   | Aluminum Framing, 10' sections    | \$57.82    | 16       | Each  | 925.12         |
| McMaster      | 6674K14     | Linear Bearing                    | \$58.46    | 4        | Each  | 233.84         |
| McMaster      | 1586A22     | Hinges                            | \$7.65     | 2        | Each  | 15.30          |
| McMaster      | 6682A330    | Latch                             | \$30.06    | 2        | Each  | 60.12          |
| McMaster      | 6818T21     | Steel Shaft, 12' length 5/8" dia. | \$52.99    | 2        | Each  | 105.98         |
| McMaster      | 6498K485    | Air Cylinder                      | \$224.09   | 1        | Each  | 224.09         |
| McMaster      | 6498K340    | Air Cylinder Mounting Bracket     | \$8.98     | 2        | Each  | 17.96          |

|                      |                             |                                       |            |     |      |          |
|----------------------|-----------------------------|---------------------------------------|------------|-----|------|----------|
| McMaster             | 1351T190                    | Hydraulic<br>Cylinder                 | \$667.94   | 1   | Each | 667.94   |
| McMaster             | 6483K590                    | Linear Bearing,<br>Flange<br>4Mounted | \$185.63   | 4   | Each | 742.52   |
| McMaster             | 6061K680                    | Shaft, 3' length<br>2" dia.           | \$172.87   | 4   | Each | 691.48   |
| Automation<br>Direct | PLC Custom<br>Configuration | Productivity<br>2000 PLC with<br>I/O  | \$803.25   | 1   | Each | 803.25   |
| Metals<br>Depot      |                             | ¼" A36 Plate,<br>5'x10'               | \$689.00   | 1   | Each | 689.00   |
| Metals<br>Depot      |                             | 3" A36 Square<br>Stock, 8'            | \$989.20   | 1   | Each | 989.20   |
| Metals<br>Depot      | Custom Size                 | ¾" A36 Steel<br>Plate, 50"x44"        | \$1,007.67 | 1   | Each | 1,007.67 |
| Metals<br>Depot      |                             | ¼" 6061<br>Aluminum<br>Plate, 4'x8'   | \$632.32   | 2   | Each | 1,264.64 |
| McMaster             | 47065T327                   | Framing Nuts                          | \$1.31     | 230 | Each | 301.30   |
| McMaster             | 6419k31                     | Vacuum Pump                           | \$2,502.50 | 1   | Each | 2,502.50 |

|              |               |                           |          |    |      |             |
|--------------|---------------|---------------------------|----------|----|------|-------------|
| McMaster     | 1593N7        | Vacuum Hose               | \$35.59  | 1  | Each | 35.59       |
| McMaster     | 5169K73       | Air Filter                | \$83.63  | 1  | Each | \$83.63     |
| MOR Electric | QIH240-1600/2 | Quartz Heater             | \$50.38  | 20 | Each | \$1,007.60  |
| McMaster     | 7277K45       | Three (25<br>@hp240 V AC) | \$173.45 | 1  | Each | \$173.45    |
| McMaster     | 9235K347      | 2 On (Normally<br>Closed) | \$96.29  | 1  | Each | \$96.29     |
| McMaster     | 6849T58       | Powder-Coated<br>10'      | \$23.00  | 15 | Each | \$345.00    |
| Total        |               |                           |          |    |      | \$12,983.47 |

## Conclusion

We as a team have concluded that all the necessary components of a vacuum form have been researched and are included in the part list. We believe that this was an excellent senior design project because of the level of difficulty as well as the opportunity to learn and grow from this experience. While the team faced some challenges along the way we managed to pull through and put together our best effort to come up with a design that met all requirements.

We were given a maximum budget of \$15,000 along with some required design specifications. The machine needed to accept their current tooling, be operated by one person, include safety guards, and be adjustable allowing for future modifications. Following much research, we created a design and complete parts list that met all of their requirements. We also completed Finite Element Analysis tests on specific sections of the machine to see how the model would react to force and to determine the stresses at various points throughout. Our final design was approved by the company, but they decided not to build at this time. They plan to implement it on their own in the future.

When the company builds the design, they should have all necessary materials to have a fully functioning vacuum form with all the safety features for less than \$15,000. When the vacuum form is completed it is expected to take less than a few hours to change out the tools and begin production, increasing the productivity of the company. This will help the company when smaller orders, around 100 (one-hundred), of prior model parts are ordered. Their current vacuum formers can continue to handle the mass production parts without the interruption of these smaller orders and prototype parts because the vacuum former we designed will run

these. Something the company can add once built could be a trimming station. A trimming station is an area where the extra plastic would be trimmed from the formed plastic to complete the tooling. A trimming station is on the big vacuum formers already in use.

## References

1. Automation Direct. Automationdirect.com. [Web]. 1999-2020. [Cited 09-18-2020]. <https://www.automationdirect.com/adc/home/home>
2. Automation, Sibe, director. *SIBE Automation - Vacuum-Forming Machine Automatic Loading and Unloading*. YouTube, 19 Oct. 2018, www.youtube.com/watch?v=-kTnZJd8mxM.
3. Automation, Sibe, director. *Sibe Automation Model SBS2436 Vacuum Forming Pre Printed Material*. YouTube, 17 Apr. 2019, www.youtube.com/watch?v=Wn7A8UNQsUs.
4. Best Buy. BestBuy.com. Web. 2021. [Cited 01-04-2021]. [Quartz Infrared Heaters - Best Buy](#)
5. Brisk Heating. Web. 2021. [Cited 01-12-2021]. [BriskHeat - Your Heating Specialist Since 1949 - BriskHeat](#)
6. Bringsjord, Norman, director. *Sibe Automation Vacuum Forming Machine*. YouTube, 12 Dec. 2012, www.youtube.com/watch?v=z\_n\_8leNVUc.
7. Bulb Town. Bulbtown.com. [Web]. 2021. [Cited 01-04-2021]. [Quartz Infrared Bulbs, Quartz Infrared Lamps, Tubular Quartz Heat Lamps, QIR Heating Lamps, QIR Heat Bulbs, Quartz Tubular Heat Lamps, QIH Heat Lamps, QIH Quartz Infrared Heater, QIH Heating Lamps \(bulbtown.com\)](#)
8. Ceramicx. Ceramicxsolutions.com. [Web]. [Cited 01-04-2021]. [About Ceramicx | Infrared Heating Elements & Components \(ceramicxsolutions.com\)](#)
9. Ceramicx. ceramicxsolutions.com. [Web]. [Cited 01-04-2021]. [Full Quartz Element \(FQE\) | Ceramicx](#)
10. Cubic Feet Per Minute (CFM). Techopedia.com. [Web]. [Cited 04-21-2021]. [What is Cubic Feet Per Minute \(CFM\)? - Definition from Techopedia](#)
11. Grainger. grainger.com. [Web]. 1994-2020. [Cited 09-18-2020]. <https://www.grainger.com/category/pneumatics/air-compressors-vacuum-pumps-and-blowers/vacuum-pumps>
12. HVAC Tools. [Web]. 2020. [Cited 01-04-2021]. [Quartz Heater Vs Ceramic Heater \[6 Considerable Factors\] | HVAC TOOLS](#)
13. Hydraulic Cylinder Area. theengineeringtoolbox.com [Web]. [Cited 03-29-2021]. [https://www.engineeringtoolbox.com/hydraulic-cylinder-area-d\\_1467.html](https://www.engineeringtoolbox.com/hydraulic-cylinder-area-d_1467.html) .
14. IQS Directory. Iqsdirectory.com. [Web]. [Cited 01-04-2021]. [Ohio Heating Element Manufacturers | IQS \(iqsdirectory.com\)](#)
15. McMaster-Carr. McMaster.com. [Web]. 2020. [Cited 09-18-2020]. <https://www.mcmaster.com/>

16. Micropyretics Heater International (MHI). mhi-inc.com. [Web]. [Cited 01-04-2021]. .  
[Micropyretics Heaters International \(MHI Inc\) - Quality Engineering and Energy Efficiency- Since 1991 \(mhi-inc.com\)](http://mhi-inc.com)
17. Mor Electric Heating. morelectricheating.com. [Web]. [Cited 01-10-2021]. [Industrial Infrared Radiant Heaters | Electric Infrared Process Heaters \(morelectricheating.com\)](http://morelectricheating.com)
18. Quartz Infrared Inc. [Web]. [Cited 01-04-2021]. [Quartz Infrared Electric Heating Elements.](http://quartzinfrared.com)
19. Tech, Sabula, director. *1yr Review SIBE Automation Thermoforming Machine.* YouTube, 20 July 2018, [www.youtube.com/watch?v=ZWHXs5xYA1A](https://www.youtube.com/watch?v=ZWHXs5xYA1A).
20. Throne, James L. *Thermo Forming.* Hanser, 1987.
21. Ushio. Ushio.com. [Web]. [Cited 04-21-2021]. [QIH Quartz Infrared Heater | Ushio America, Inc.](http://ushio.com)
22. VAC Aero International. vacaero.com. [Web]. Jan. 13, 2016. [Cited 10-10-2020].  
<https://vacaero.com/information-resources/vacuum-pump-technology-education-and-training/1039-an-introduction-to-vacuum-pumps.html#:~:text=The%20different%20types%20of%20pumps%20for%20these%20vacuum,High%2C%20very%20high%20and%20ultra-high%20vacuum%20pressure%20ranges.>
23. "Vacuum Forming Machines." *Sibe Automation*,  
[sibeautomation.com/products/vacuum-forming-machines/](http://sibeautomation.com/products/vacuum-forming-machines/).
24. Wattco. [Web]. 2021. [Cited 01-04-2021]. [Infrared Radiant Heaters - Wattco](http://wattco.com)
25. Workshop Publishing. Build-stuff. [Web]. 1997-2016. [Cited 01-10-2021]. [Infrared Radiant Heaters - Wattco](http://buildstuff.com)
26. Youtube. Youtube.com. [Web]. 2016. [Cited 01-12-2021]. [DIY Thermoforming Easy Heating Element Solution, No Space Heater - Bing video](https://www.youtube.com/watch?v=ZWHXs5xYA1A)

## Appendix A: Meeting Journals



MIAMI  
UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 2

Meeting Date: 9-3-20 Meeting Time: 7pm  
Advisor: Rob Speckert Present:

Team Members: \_\_\_\_\_ Present:

Mindy Bach Present:

Danielle Gagliano Present:

---

### Topics discussed:

This week the meeting was centered on getting to know the team members strengths. At the meeting as a team it was decided that every Thursday after class to meet via online meeting. Further discussed the project.

### Action Items (what, who, when):

Research vacuum formers, get more information regarding vacuum former.

Next meeting (date/time/location): 9-10-20/ 7:00pm/ online meeting



MIAMI  
UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 3

Meeting Date: 9-10-20

Meeting Time: 7pm

Advisor: Rob Speckert

Present:

Team Members:

Present:

Mindy Bach

Present:

Danielle Gagliano

Present:

Topics discussed:

This week the meeting consisted of talking to the company, the manager, on the details of the project. The manager gave a background on what the company does and what the vacuum form is needed for.

Action Items (what, who, when):

Get details as to what specs are needed.

Next meeting (date/time/location): 9-17-20/ 7:00pm/ online meeting









# MIAMI UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 7

Meeting Date: 10-15-20 Meeting Time: 7pm

Advisor: Rob Speckert Present:

Team Members:

Present:

Mindy Bach Present:

Danielle Gagliano Present:

---

Topics discussed:

Discussed the proposal for the final touches to be ready to turn in. Spicically where should certain accepts of the proposal should go in the proposal. Discussed safety parts and where to find them. We then proceeded to discuss what we should do for next week.

Action Items (what, who, when):

The team will be working further on the CAD model, as well as, schedule a pre meeting for the proposal for to make sure we have what is needed. Danielle and Mindy will narrow down what components are actually needed.

Next meeting (date/time/location): 10-22-20/ 7:00pm/ online meeting











# MIAMI UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 12

Meeting Date: 11-12-20 Meeting Time: 4pm  
Advisor: Rob Speckert Present:

Team Members:  Present:

Mindy Bach Present:

Danielle Gagliano Present:

---

### Topics discussed:

The whole group got together before class to put finishing touches on the powerpoint

### Action Items (what, who, when):

Mindy and Danielle will continue to work on the part list. This is continued for the foreseeable future. And the group will work on the Final proposal that is due 12-03.

Next meeting (date/time/location): 11-25-20/ 5:00pm/ online meeting















# MIAMI UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 19

Meeting Date: 01-18-2021

Meeting Time: 4:30pm

Advisor: Rob Speckert

Present:

Team Members:

Present:

Mindy Bach

Present:

Danielle Gagliano

Present:

---

Topics discussed:

We as a group discussed when we can meet starting next week ( it will remain the same Monday's at 4:30). We also discussed what still needs to be done.

Action Items (what, who, when):

Danielle will look into safety measures and try to draw the HMI in CAD. Mindy will also try to draw the HMI in CAD.

Next meeting (date/time/location): 01-25-21/ 4:30pm/ online meeting









MIAMI  
UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 23

Meeting Date: 02-15-2021 Meeting Time: 4:30  
Advisor: \_\_\_\_\_ Present:

Team Members:  
\_\_\_\_\_ Present:

Mindy Bach Present:

Danielle Gagliano Present:

-----  
Topics discussed:

There are a few updates needed on the model but other than that it is good.  
The group as a whole talked about what is still needed to be done.

Action Items (what, who, when):

Danielle will start on making the poster. Mindy will start on the report.

Next meeting (date/time/location): 02-18-2021 5:00 Online





















# MIAMI UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 33

Meeting Date: 04-07-2021 Meeting Time: 3:00pm  
Advisor: Rob Speckert Present:

Team Members: \_\_\_\_\_ Present:

Mindy Bach Present:

Danielle Gagliano Present:

---

### Topics discussed:

Mindy and Danielle discussed what to do about the presentation due on April 23rd, not completely figured out yet. Made a final plan for what to put on the poster.

### Action Items (what, who, when):

Mindy will continue the poster work. Danielle will continue to work on the final report.

Next meeting (date/time/location): 04-13-2021, 4:30pm, online.





# MIAMI UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 35

Meeting Date: 04-13-2021 Meeting Time: 4:30pm  
Advisor: Rob Speckert Present:

Team Members:

Mindy Bach Present:

Danielle Gagliano Present:

Present:

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Topics discussed:

During the meeting Mindy and Danielle discussed what needs to get done by Thursday, the little speech Mindy has to make. Discussed the FEA report that Yu emailed, as well as, the ANSYS report we already had. Emailed professor Yu the ANSYS report that was created. Made a check list of what needs to go on the poster.

Action Items (what, who, when):

Make a new gantz chart, Mindy will try to finish this by tomorrow (04-14-2021).  
Make a new parts list, Danielle will try to get most of this done by Thursday (04-15-2021).

Next meeting (date/time/location): 04-19-2021 4:30 online



MIAMI  
UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 36

Meeting Date: 04-15-2021 Meeting Time: 5:20  
Advisor: Rob Speckert, Zhiuyan Yu Present:

Team Members:  
Mindy Bach Present:

Danielle Gagliano Present:

Present:

---

Topics discussed:

Mindy gave an update on how far she got on the powerpoint. Mindy and Danielle discussed what was still needed on the powerpoint. Still need to add the new design, budget, FEA report, gantz chart, and conclusion. Rob and Yu gave advice on how to incorporate the FEA report into the presentation.

Action Items (what, who, when):

Danielle will go through the FEA report and make it to go into the presentation. Mindy will try to make the gantz chart and will continue to work on the presentation. We will get the recording done by Wednesday (04-21-21)

Next meeting (date/time/location): 04-19-2021 4:30pm, online



# MIAMI UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 37

Meeting Date: 04-21-2021 Meeting Time: 12:00pm  
Advisor: Rob Speckert, Zhiyuan Yu Present:

Team Members:  
Mindy Bach Present:

Danielle Gagliano Present:

Present:

---

### Topics discussed:

Mindy and Danielle talked about what the Powerpoint needed and went over what Mindy already had on the Powerpoint. Mindy and Danielle also looked over the model and figured out how the vacuum form works. They also discussed what the poster needed, Danielle showed what she had already done on the poster. Danielle and Mindy planned to meet tomorrow to record the oral presentation.

### Action Items (what, who, when):

Mindy will finish up the powerpoint by tomorrow (04-22-2021). Danielle will finish the poster by tomorrow as well.

Next meeting (date/time/location): 04-22-2021, online





# MIAMI UNIVERSITY

Miami University  
Department of Engineering Technology  
ENT 497-498 Senior Design

Journal Entry # 39

Meeting Date: 04-23-2021 Meeting Time: 1:26pm  
Advisor: Robet, Zhiyuan Present:

Team Members:  
Mindy Bach Present:

Danielle Gagliano Present:

Present:

---

### Topics discussed:

We got to together and did a few trial runs on the oral pnsentation. We also recorded the oral presentation and uploaded it to Youtube.

### Action Items (what, who, when):

Danielle and Mindy will finish up the final report.

Next meeting (date/time/location):

## Appendix B: Gantt Chart

| ID | Task Name                        | Duration | Start        | Finish       | August     | September | October   |
|----|----------------------------------|----------|--------------|--------------|------------|-----------|-----------|
|    |                                  |          |              |              | SVAFSTTSVA | FAFSTTSVA | FAFSTTSVA |
| 1  | ENT497/498 Senior Design Project | 261 days | Wed 8/19/20  | Wed 8/18/21  |            |           |           |
| 2  | Select Group                     | 7 days   | Thu 3/4/21   | Fri 3/12/21  |            |           |           |
| 3  | Determine Project Idea           | 7 days   | Mon 3/15/21  | Tue 3/23/21  |            |           |           |
| 4  | Get Project Approval             | 7 days   | Wed 3/24/21  | Thu 4/1/21   |            |           |           |
| 5  | Project Kickoff Meeting          | 7 days   | Thu 9/24/20  | Fri 10/2/20  |            |           |           |
| 6  | Research                         | 21 days  | Fri 10/2/20  | Fri 10/30/20 |            |           |           |
| 7  | Draft Design                     | 10 days  | Fri 10/30/20 | Thu 11/12/20 |            |           |           |
| 8  | Finalize Part Selection          | 14 days  | Thu 11/12/20 | Tue 12/1/20  |            |           |           |
| 9  | Submit Proposal                  | 3 days   | Tue 12/1/20  | Thu 12/3/20  |            |           |           |
| 10 | Finalize Design                  | 40 days  | Thu 12/3/20  | Wed 1/27/21  |            |           |           |
| 11 | Present Design for Approval      | 7 days   | Wed 1/27/21  | Thu 2/4/21   |            |           |           |
| 12 | Complete Design Changes          | 14 days  | Thu 2/4/21   | Tue 2/23/21  |            |           |           |
| 13 | Final Design Approval            | 7 days   | Tue 2/23/21  | Wed 3/3/21   |            |           |           |
| 14 | Design FEA                       | 21 days  | Wed 3/3/21   | Wed 3/31/21  |            |           |           |

