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EML4551-2

Team 19: Creation and Testing of a Force Air-cooled Heatsink

Dustin S. Birchall;Parker N. Harding;Tyler J. Pilet;Lucas M. Pye;Jeffery A. Rutledge

FAMU-FSU College of Engineering 2525 Pottsdamer St. Tallahassee, FL. 32310

Abstract

Heat removal has long been an issue for engineers. In electronics, heat is dissipated as an electric current runs through. In the case of this project, Unison Industries has tasked us with designing a forced-air heat-sink to remove 300W of heat produced by 24 silicon semiconductors in an 85 C environment. These semiconductors will be used to convert AC to DC in order to power the planes electronics. If not removed the heat could build up, and cause the chip to rise above 150 C. That would cause the semiconductors to stop working. This heatsink must maintain a chip temperature below 135C for a factor of safety, and be as light weight as possible. A standard heatsink design was simulated on the computer that put the max temperature well below the previously stated goal of 135 C. To achieve an optimized light-weight heatsink design we will be performing simulations with our prototype. During simulation the semiconductors will be modeled cheaply using resisters of similar size that will dissipate the required heat. A heat camera was used in order see what parts of the heatsink are close to the environments temperature. These areas can be taken off as there is not heat transfer, and this will optimize the weight of our heatsink.

Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

Acknowledgement

Team 19 would like to thank Unison Industries, and more specifically Kevin Walker for all of the help and support they have offered throughout the engineering design process. Mr. Walker was extremely helpful in all stages of the project and even offered advice in career development.

We would also like to thank all of our Advisors: Dr. Juan Ordoñez, Dr. Chiang Shih, and Dr. Shayne McConomy. They have all offered welcomed and priceless feedback throughout the project and help to guide us towards a better design. All advisors offered expert opinions within the realms of their own experience which Team 19 was able to translate into their design.

Table of Contents

List of Tables

List of Figures

Notation

Chapter One: EML 4551C

1.1 Project Scope

Unison Industries needs the heat from 24 semiconductors to be dissipated by a force air-cooled heatsink. The semiconductors output 300 watts in total, and must operate at steady state below 135C while in an ambient temperature of 85C.

1.1.1 Key Goals

Team 19's focus is in-line with the main concerns of Unison Industries, that being the fact that the product will have to cool the circuitry to at least 135C (the colder the better) and also be mounted onto an aerial vehicle. Team 19's key goals for this project are as follows:

- Lightweight design
- Remove heat
- Physically small in size

1.1.2 Markets

This product has applications anywhere high-powered electronics are in use, therefore our primary market would be high powered electronic manufacturers. Cooling of electronic components is a necessity in any company dealing with control systems which places team 19's product in a position of high demand. This specific design would be more tailored to industries where weight is an important design parameter, such as drone manufacturers and other aerial applications. With the growing drone market, this design will be an increasingly viable option over current industry standards.

A potential secondary market would be hobbyists. It is not uncommon currently for people of all walks of life to enter into a situation where a control system would make their lives easier, and therefore there has been an overall increase in hobbyists in this area. With the accessibility of small circuits such as the Arduino or Raspberry Pi lines comes the demand for an efficient and versatile heat sink that would be good for all applications. The products overall light design would make it viable in almost all circumstances, and therefore extremely useful.

1.1.3 Assumptions

In fluid dynamics problems it isn't uncommon to find that there are too many variables in place and not enough information, effectively making the problem impossible to solve. For this reason, assumptions must be made in order to simplify the problem down to what the main concerns are. The following assumptions can be made with confidence that they will not vastly affect the problem at hand, but rather simplify it enough for team 19 to understand what needs to be done:

- Cooling using forced convection
- Mounting onto circuitry is currently out of scope
- Simulate using computer programs (COMSOL, MatLab, etc.)
- Most major components to be specified and ordered rather than designed and fabricated.

These assumptions will allow team 19 to approach the problem with a clearer and fuller understanding of what needs to be done and will help to eliminate time wasted on "re-inventing the wheel."

1.1.4 Stake Holders

Team 19's primary stakeholder is Unison Industries. If team 19 fails to provide efficient cooling at the proper weight constraint, then the company will not have a product to use on their aerial vehicle. Other primary stakeholders include all members of Team 19. If the project is not completed by Engineering Design Day or does not perform properly, this could reflect poorly on all members.

1.2 Customer Needs

Unison is looking to develop a way to reduce the amount of heat on their electrical power conversion products. The customer wants to develop a heatsink to keep the temperature of the silicon chip inside the electrical products operating at a temperature below 135°C. The heatsink will be partnered with fans to force the air through the cold plate or heatsink in order to cool the device more efficiently. Since the electrical components needing cooling are on a small aircraft the customer wants the heatsink to be as small and lightweight as possible to keep the aircraft aloft. The customer has a budget of $2,000 for the design and prototype.

1.3 Functional Decomposition

For Unison Industries LLC, the desired forced-air heatsink needs to have a functional decomposition that emphasizes it being lightweight, small in size, and is able to effectively maintain the temperature of the silicon chips within the power converter at 135 °C. These were the main challenges presented by Unison Industries, LLC; however, our group identified some parameters that would influence the three main functions of our heatsink. The heatsink material will affect the overall weight, size, and heat transfer. Different materials means different densities and heat transfer rates. So depending on the material, a bigger size may be required to obtain the desired temperature. Fin geometry affects size and the effective heat transfer. The length of the fins would affect the overall size and all the parameters that go into fin geometry affect how efficient the fins are. Depending on the size of the fan, it could add considerable weight to the overall design while also influencing heat transfer. The chip arrangement and thermal interface materials affect how well our overall design will distribute the heat. The arrangement could create pockets of intense heat.

Table 1

Functional Decomposition

	Lightweight	Small in Size	Effective Heat Transfer
Heatsink Material	●	●	●
Fin Geometry		●	●
Fan Selection	●		●
Thermal Interface Material			●
Chip Arrangement			●

1.4 Target Summary

In order to find our targets, we used Mersen's R-theta tool to come up with a number of concepts to benchmark for our design. Each member designed at least one concept which allowed us to look at results with various combinations. R-theta allowed us to play with the size and type of components and would give a rough estimate of the thermal map of the overall design. After multiple iterations we were able to find our targets for our design. We can't be the best in everything and still be under budget. We have decided to make size our priority. For the project, that means our heatsink should have the smallest baseplate area and fin length, but still be able to remove the heat effectively. The exact value for width and length of the baseplate haven't been confirmed by our sponsor yet, but we were given an example dimensions of an example heatsink that was designed. The example length given was 215.9 mm and the width was 177.8 mm. So for our target, we are going to use those dimensions as the max allowable dimensions and anything that fits within those bounds would be acceptable. This allows us to possibly use other shapes rather than limiting ourselves to just a rectangular baseplate. The max pressure drop we are aiming for is 28 Pa. This amount is optimized so that we don't need to have a big and heavy fan to force air through the channels. For our concepts, aluminum was the only choice for heatsink material when running the simulations. So for our design, aluminum is the target heatsink material. This material has a high thermal conductivity value so heat moves throughout it well and it is on the cheaper end of the spectrum. For the fin geometry, we got our targets from a mixture of the example dimensions provided from our sponsor and the simulations. Using the fin height from the example dimensions as a baseline, we could see what fin width would give us the optimal cooling. Our targets moving forward for fin geometry is a height of 33 mm and a width of 1.27 mm. The target heatsink weight is 1.4 kg. Since minimum weight is a customer need, we used the concept with the lowest weight as the target for our design. After the concept iterations, we concluded that our target max temperature for the heatsink is 110℃ and a min temperature of 100℃. The max allowable temperature for the silicon chips are 135℃. We have to account that the bottom of the heatsink will be a few degrees cooler than the chips themselves. However, we are a safe distance from the chips max temperature. For the fan, we chose to have a target flow rate of 120 cfm. This value matched with our target pressure drop would keep our fan smaller.

1.5 Concept Generation

Concept 1.

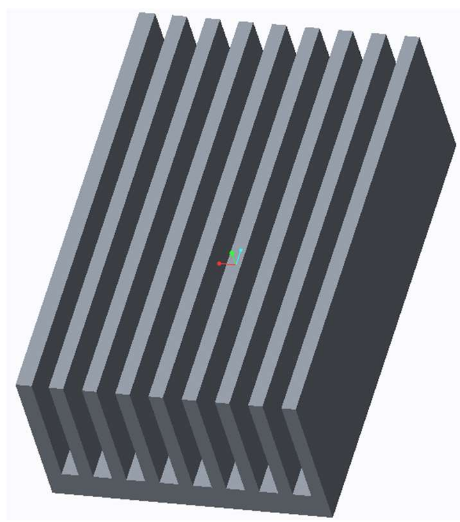

Figure 1: A rectangular fin heat sink with a rectangle shaped baseplate.

Concept 1 is a traditional straight fin rectangular heatsink. This concept is a baseline, as this design is the most common and straightforward to manufacture. The fan would be positioned to blow air through the channels.

Concept 2.

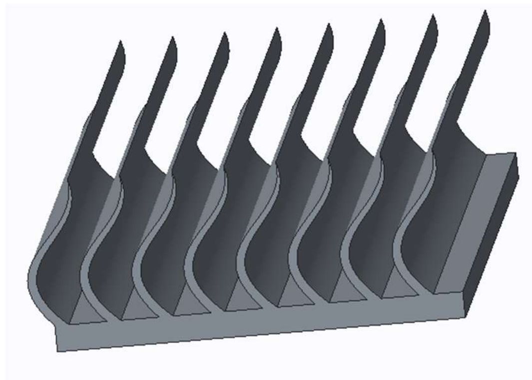

Figure 2: A rectangular heatsink concept with waved fins.

Concept 2 is a rectangular heatsink with waved fins. This design was created to be similar to a rectangular straight fin heatsink, but with an increased fin surface area. The spline shape of the fins may also help hot air escape via buoyant forces.

Concept 3.

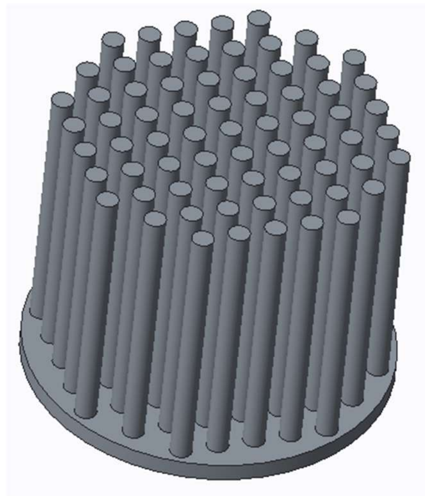

Figure 3: A heat sink with pin fins a circular base.

Concept 3 is a circular heatsink with circular fin tips. This design was created to facilitate diode placement in a circular arrangement. Circular fin tips are also known as the most efficient tip type for heat transfer in heat sinks.

Concept 4.

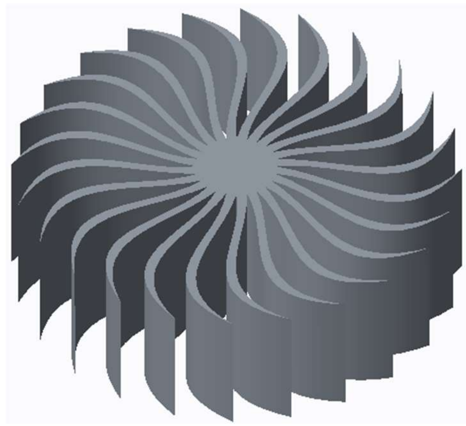

Figure 4: Circular heat sink concept that has wavy fins.

Concept 4 is a circular heatsink with wavy fins. The central portion of the heat sink is meant to also be the central axis of the fan, which would pull air through the channels. The circular arrangement was also chosen to facilitate a uniform temperature of all diodes.

Concept 5.

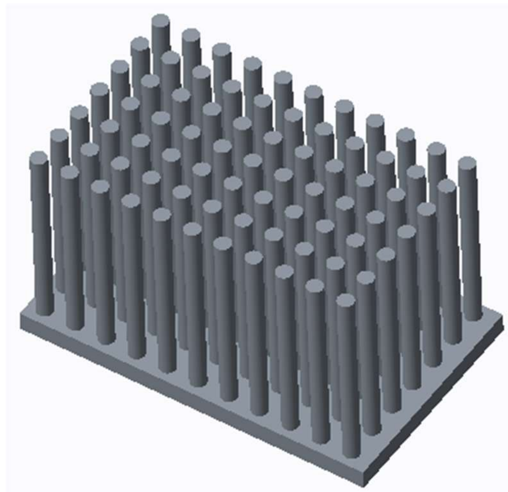

Figure 5: Heatsink with pin fins that has a rectangular base plate.

Concept 5 is a rectangular heatsink with circular fin tips. This concept was chosen because a rectangular baseplate allows for easy diode arrangement. The circular fin tips were chosen because they are known to be the most efficient fin tip geometry for heat transfer in heatsinks.

Concept 6.

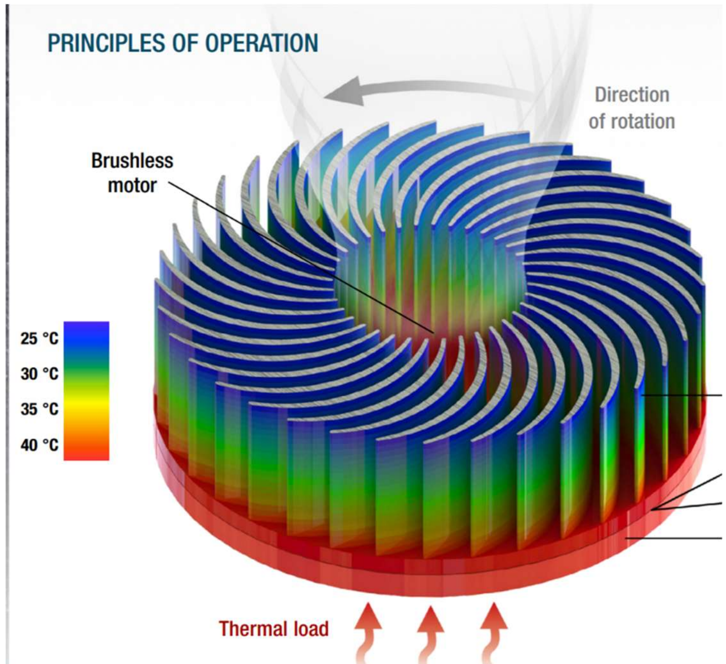

Figure 6: Sandia Labs spinning heatsink design[1].

Sandia labs developed a fanless heatsink. By utilizing a heat sink design that spins using a DC motor, this design generates a low pressure zone in the center of the fin array. This will induce an axial air flow into the heatsink that will impinge on the spinning baseplate below. This design is up to 10x lighter than current CPU heatsink designs, making it a more desirable concept for team 19's project.

Concept 7.

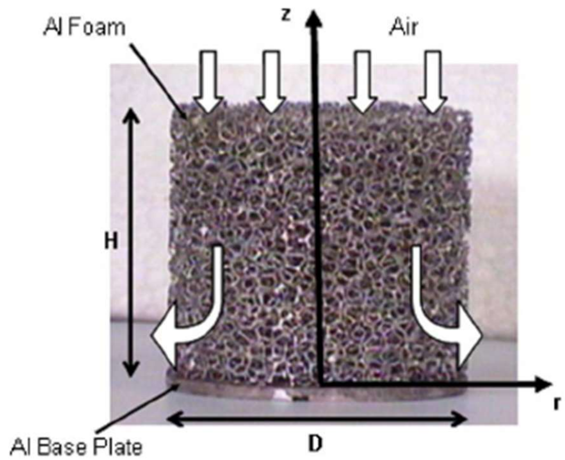

Figure 7: Metal "foam" style heat sink concept found online.

The design in figure 8 would be extremely effective at dispersing heat throughout the heat sink since it provides a multitude of channels for the heat to travel through. It is also very lightweight since the design is mostly foam. This design begins to fall apart when one considers contact resistance from the extremely small cross-section of each foam member to the baseplate. This design would also have a massive pressure drop due to its small flow area.

1.6 Concept Selection

The final decision for which concept team 19 would pursue is based on a series of metrics provided by industry professionals and online research. When considering a heat sink design it is crucial to keep in mind time and money constraints. The current budget for this project is set at $2,000 and the set date to finish is mid-April. Many of the metrics team 19 employs in the decision process are based around these constraints in order to allow enough time for testing and iterative progress. The following criteria was used for concept selection.

1.6.1 Efficiency

The heat flux from a finned heat exchanger is given by the following equation:

$$Q/s = \eta * h * As * (Tb - T\infty)$$

Two variables that team 19 has the ability to influence via geometry are efficiency and surface area of the heat sink. Efficiency is defined as the ratio of heat transferred from a real fin versus the heat transferred from a fin at a uniform temperature. Fin efficiency is a function of the fin's geometry, so a few parameters were held constant between designs. First off, the length and surface area of all heat sink designs was held constant, and pin diameters and fin widths were computed. Utilizing these values, the efficiencies of each fin geometry was calculated using empirical correlations.

1.6.2 Ease of Manufacturing

There are several methods for fabricating a heat sink, some easier than others. The following are the 8 most common methods for heat sink manufacturing: extrusion, stamping, die casting, bonding, folding, forging, skiving, and machining. Extrusion is the most widely used method due to the simplicity of the process. It only involves forcing a heated billet through a 2D plate which has the silhouette of the heat sink cut out of it. Extruded heat sinks are widely available and would allow team 19 to access these designs on a regular basis -- making the iterative process easier and also cutting back on time. Many designs cannot be extruded since this process requires a constant 2D figure. Stamping is a quick process as well, but requires the assembly of all the pieces that have been stamped. Die casting is one of the fastest processes and simply requires a slab of metal being heated and pressed into a mold to create extremely precise parts. The downside to this process is a reduction in heat conductivity through the metal since it creates many pores. The bonding method requires cutting slots into the baseplate of a heat sink where a fin will be slid into place and held by a bonding agent. This creates a thermal barrier and has similar issues to die casting. Folded heat sinks are made of a single piece of sheet metal which is folded back and forth creating a flat-plate spring design. This requires a bonding agent to attach it to a baseplate and has a thermal barrier as well. Forging is another process very similar to die casting with the same drawbacks and advantages. Skiving involves a knife running along the surface of a baseplate to create the fins. This process assumes the geometry of the heat sink to be a rectangular heat sink. Machining is the final process and, depending on the geometry it could be fast or slow. This method is favorable to custom designs, but redundant for easily accessible designs. In the interest of saving time any difficult to fabricate parts will be deducted points in the pugh matrix.

1.6.3 Cost of Manufacturing

Every method of fabrication mentioned in section 1.6.2 has a cost associated with it. The cheapest solutions will be anything involving a repetitive process which can be done by a simple die or stamping process. These heat sinks are readily available and fairly inexpensive. Most custom heat sink designs will involve either having a custom tool made or involve hiring a professional machine shop which will in turn cost a great deal of money. In the interest of saving money, any concepts which require a meticulous fabrication process will be deducted points in the pugh matrix.

1.6.4 Pressure Drop

Pressure drop is a crucial factor for the design since it will determine what fan is required. If the pressure drop it too high then a heavy duty fan might be required which would drive up the overall weight of the design and also the cost. The main thing team 19 will consider when evaluating pressure drop is frictional loss across different geometries. Another factor to keep in mind when considering pressure drop is surface roughness. A high surface roughness will result in a large pressure drop, and so any processes such as forging or casting will result in point deductions in the pugh matrix since these processes typically create parts with a rough surface. Machining would be advantageous since a skilled machinist would be able to create a fine finish on the surface of a part.

1.6.5 Usable Baseplate Area

Another criteria that the heatsinks were graded on was the usable baseplate area. For this project the placement of the semiconductors is within the scope. Since the semiconductors are heat sources the layout of the chips is important as to not develop heat pockets. This was ranked as not that important but something to consider, because if the heatsink can efficiently remove the heat than this is not really a problem, but for the project we want to uniformly remove the heat so it is taken into consideration.

1.6.6 Reliability

Once we generated a few concepts we evaluated the reliability of each concept using a Pugh matrix. After discussing the concepts with our sponsor Kevin Walker at Unison Industries we were able to rate the reliability of each idea. We rated pin fins with a low reliability due to Kevin's experience with them and he stressed that these fins damage easily and are difficult to repair. Also from experience and research we found that wavy fins run into a similar issue as pin fins and damage easily and are difficult to repair.

1.6.7 Pugh Matrix

To select the concept to be implemented for our project a Pugh Matrix was used. To create this matrix the first step was establishing what to rate the concepts on. The criteria and meaning to this project were discussed in the previous sections. After that the baseline was established. The baseline for this matrix was based on our target concept to make sure that the concepts would reach the goals set. The final step in setting up the matrix is to decide the weight factor for the criteria.

After talking to the sponsor of our project it was established that cost is the most important factor, so it has the biggest weight factor. This information made the circular, metal sponge, and the spinning fan unusable for our project as the cost would be too great to produce these. The concepts left remaining were the circle baseplate with pin fin, rectangular base plate with pin fins, rectangular base plate with wavy fins, and rectangular base plate with rectangular fins. The ones with pin fins would take longer to machine due to the amount of material that would need to be removed, so they received a minus sign in cost and the ease of manufacturing. The wavy fin has a complex geometry, so that would take longer to machine and it received a minus in cost and ease of manufacturing. The rectangular fin would be about to same to produce as the target, because it is a rectangular fin as well. This is why it received a zero value. It would cost and be machined about the same as the target.

The next criteria the concepts were judged on was reliability. This is important to the customer, because a damaged heat sink does not work anymore. The pin and wavy shapes are thin and more easily damaged than the rectangular, so that is why a minus was given.

After that the heatsinks were evaluated on the efficiency of their geometries. From formulas found in a book on heat sinks, the pin fins have higher efficiencies so that's why a plus was given to them automatically. A wavy fin has more surface area than a rectangular, so it received a plus. For the rectangular concept the efficiency can be increased by making changes to the geometry, so it received a plus as well.

Pressure drop was the next most important criteria evaluated. The pin fins have no material confining the air the entire length of the heat sink, so the frictional forces would be lower. This gave the pin fins there plus. The wavy fin with its greater surface area has more frictional effects, so it received a minus. Pressure drop can be decreased with design, so the rectangular fin got a plus. This is because the pressure drop will be lower than the targets.

Lastly, the usable baseplate area was evaluated in our concepts. Dues to geometry since the chips are rectangular, they can fit more evenly spaced on a rectangular baseplate. The circles received minuses as our chips would be closer. This could create heat pockets on our heat sink, and one of the goals for this project was uniform heat distribution. The rectangular baseplate concepts received zeros as these concepts take the same shape as the target.

Based upon these criteria and weight the winning concept was the rectangular baseplate with rectangular fins. This design has the fewest minuses so it won. This design meets all the customer needs and can be designed to meet or be better than the targets in place for this project. Below the pugh matrix can be seen with all the scores of the concepts.

Table 2

Pugh Matrix for Concept Selection

Criteria	Weight	Circle Base w/ Circle Fin	Rectangular Base w/ Circle Fin	Rectangular Base w/ Wavy Fins	Rectangular Base w/ Rectangle fin
Efficiency	4	+	+	+	+
Ease of Manufacturing	1	-	-	-	0
Cost	6	-	-	-	0
Pressure Drop	3	+	+	-	+
Usable Baseplate Area	2	-	0	0	0
Reliability	5	-	-	-	0
	Plus	**2**	**2**	**1**	**2**
	Minus	**4**	**3**	**4**	**0**

Chapter Two: EML 4552C

2.1 Spring Plan

The fall semester ends on December 15th and the spring semester will start on January 8th; however, work on this project will be continuous. The project sponsor stated that a heat sink can take up to 10 weeks to manufacture and ship, and with the semester being 14 weeks long there is not a lot of room for error. The first thing necessary to accomplish is to finalize the dimensions of the heatsink. This includes deciding the fin width, fin spacing, and the location for the tapped holes that will allow the resistors and the duct to attach to the heatsink. After that has been finalized a fan will be selected. The fan is the last thing to select because pressure drop must be known. The goal is to have the design finalized by January 5th. This portion of the project has been taken on by Parker Harding and Dustin Birchall.

The next major goal for this project is to decide a testing set up. Resistors will be used to model the semiconductor. The resistors can be used to output the same heat wattage as the semiconductors that will be used by Unison. This testing set up should be decided by at the latest January 17th. Lucas Pye has taken it upon himself to design the setup of this experiment.

After the setup has been decided all the parts that are needed to complete the project will be ordered. All the parts should be ordered by January 21st. This should give plenty of time to receive all the parts that are needed. The financial officer will be performing this task and will ensure that the budget is kept in mind.

The parts will take a while to machine, so for the next goal of prototype construction plenty of time has been allocated. The prototype should be constructed by March 25th. The final goal is to finish testing, and that should be done before the Engineering Design Day April 12th. This completes the plan for project completion and the plan is shown in the following Gantt Chart for easy viewing. Prototyping and testing will involve the whole group, but Tyler Pilet has decided to take this part upon himself as he has experimental set up experience.

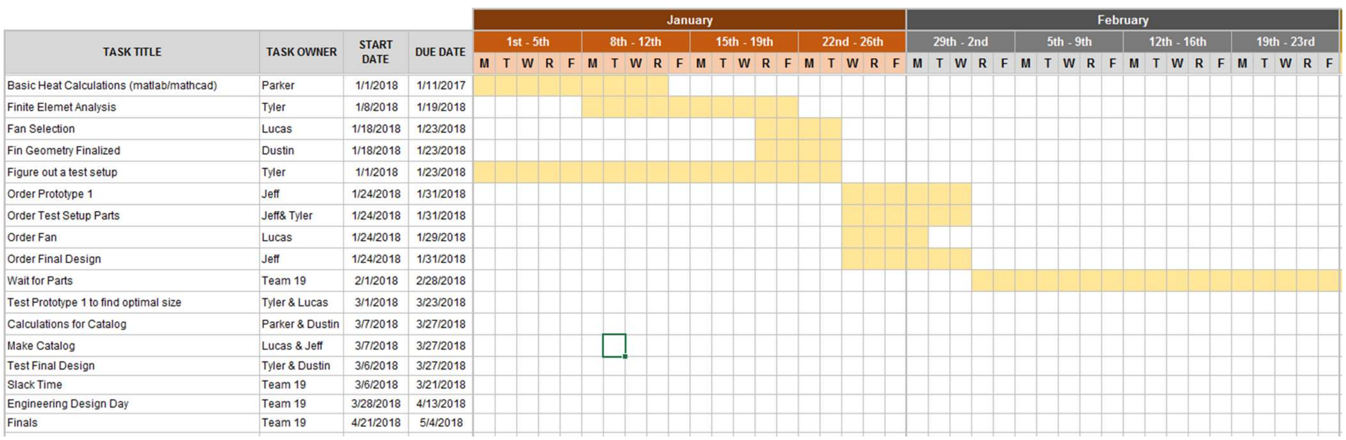

Figure 8: Gannt chart showing the project plan for the months of January and February.

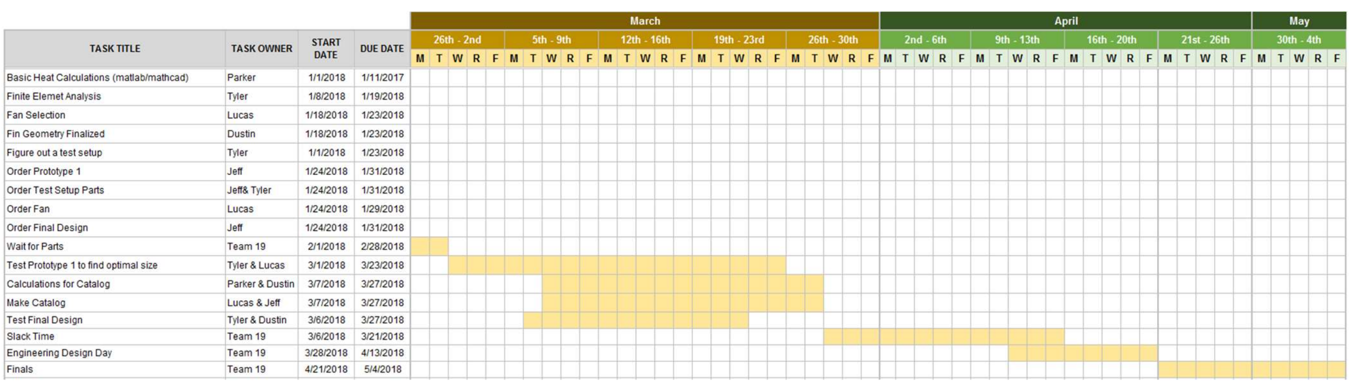

Figure 9: Gannt chart showing the project plan for the months of March, April, and May.

2.1.1 Budget Plan

Unison Industries has provided our team with a $2,000 budget to design, build, test, and optimize our heatsink. Our budget will be spent on material to create our heatsink, resistors to act as semiconductors during testing, fans for the heatsink, and machine work to build our heatsink. The resistors have been priced out and at $1.74 per part and we have purchased 30 parts at a total of $52.20. We have priced out the aluminum blocks needed to fabricate our heatsink at $81.41 per block and if we have two heatsinks machined the total cost for the aluminum blocks would be $162.82. For the fans we will need to purchase two fans at approximately $74.00 per part coming to a total of $148.00. We contacted FSU FAMU College of Engineering machine shop to have our heatsink machined however the shop lacked the tools necessary to create it. In light of this we had to outsource and now we are working with Velocity Machine Works in Tallahassee. We are looking at purchasing two heatsinks at $792.12 per unit for a total of $1,584.38. This brings our total cost to $1,947.40 of our $2,000 budget.

Some potential problems have been brought forward to us with machining of our heatsink. The machinist we have talked to noticed that the gaps between our fins are approximately .135" which is not a standard number used for machine work and we were asked to change it to .125" due to it being a more standard value for drill bits. Although this change will increase the pressure drop through the heatsink the change in cost was significant enough to pursue this change. The original cost of our heatsink with .135" gaps was approximately $1,173 per unit and with the change to .125" gaps the price reduced to $959 per unit. With this change we will need to increase the CFM of our fans in order to account for the increase in pressure drop. We are also looking for a more cost effective way to have the heatsink machined and are currently looking into the possibility of purchasing the tools necessary for the machine shop at FSU-FAMU College of Engineering to machine our design.

Appendices

Appendix A: Code of Conduct

A.1 Mission Statement

Team 19 is dedicated to providing exceptional service to our customers through our combined experience and cultivating a friendly environment based around inclusion and communication. In order to provide the best possible outcomes and product designs, each member of team 19 will contribute their greatest efforts.

A.2 Roles

Each team member has agreed to serve the group as one of the five following roles: Team Leader, Lead ME, Financial Advisor, Record Keeper, and Skeptic. The nature of each role will be discussed in detail.

A.2.1 Team Leader

Parker Harding has agreed to be the team leader. This position entails delegating tasks to team members and ensuring that each member is meeting their requirements. This person will also be the main line of communication between the client (Unison Industries) and the contractor (Group 19). In most cases, the team leader will function as the arbiter of team related issues. The team leader will also be in control of setting up meeting times with the client.

A.2.2 Lead ME

Tyler Pilet has agreed to be the lead ME for group 20. The lead ME is responsible for understanding all design choices of the project and presenting the options to the group in a clear, concise way. The lead ME will also be in charge of providing detailed drawings of the product for the records.

A.2.3 Financial Advisor

Jeffery Rutledge has agreed to be the financial advisor for group 19. The financial advisor's main responsibility is to monitor the credits and debits to the project account. He must also review alternative options in order to determine the best route financially for the team.

A.2.4 Records Keeper

Lucas Pye has agreed to be the records keeper for group 19. The record keeper's responsibility is to acquire all notes taken, design drawings made, and other information provided by the group and place it in a folder that all members have access to. The records keeper will take notes at all meetings.

A.2.5 Skeptic

Dustin Birchall has agreed to be the skeptic for group 19. The skeptic will work very closely with the lead ME and play "Devil's Advocate" for each design solution. His main responsibility is to determine flaws with all of the designs and design options. This will ensure that most, if not all, design failures are thought of in advance.

A.3 Communication

The main form of communication for the team will be through GroupMe, an application found in both the Apple and Microsoft store. This will allow all members of the group to be included, as per the group's mission statement. Email is a secondary form of communication. The group has decided that any communication done orally or through meetings will be recorded electronically so that there is a record of it.

All files will be transferred through the group’s google drive which is a shared folder that all members have access to. This ensures that no matter where a member is they will always have access to all documents as long as they have wifi. The google drive is also available through the google drive application found in both the Apple and Microsoft store for mobile phones, which all members have agreed to download. Team meetings will be held directly after Professor McConomy releases EML4551 on Tuesdays and Thursdays since the course never runs its full time. This way no member will be busy since this time slot has already been freed up in their schedule. Any member that is not available to meet during this period for whatever reason is responsible for checking the google drive to fill themselves in on what they missed.

A.4 Team Dynamic

All members of the team regardless of role are expected and encouraged to contribute ideas to the design. In engineering it is fundamental to realize that no design is too wild in the conceptual phase and all design ideas should be treated equally. All members of the team are to adopt a personality of acceptance and open mindedness when it comes to the project, and are highly encouraged to take this personality with them outside of the project setting as well. If during a meeting an argument breaks out and no forward progress is being made, the meeting will be cancelled and re-scheduled within 24 hours. Reason shall prevail in order to benefit the team, client, and design.

A.5 Ethics

Team members are required to be familiar with the NSPE Engineering Code of ethics as they are responsible for their obligations to the public, the client, the employer, and the profession, as well as their teammates. Each member will follow the NSPE Engineering Code of Conduct. If there is any question of unethical behavior or choices, the group will discuss with said teammate. If no change occurs after the meeting, the team will discuss with instructor.

A.6 Dress Code

Team meetings will be held in casual attire. Group presentations will be business casual attire. Sponsor meetings will be business casual or formal attire and will be decided as a group before meetings.

A.7 Weekly and Biweekly Meetings

Team members will participate in all meetings with the sponsor, adviser, and instructor via in person or through skype/facetime. These meetings will focus on discussing ideas, project progress, budget, conflicts, timelines, and due dates. In addition, tasks will be delegated to team members during these meetings. Repeat absences will not be tolerated unless they provide a reasonable excuse before the meeting time.

A.8 Decision Making

Decisions will be made based upon a simple majority ruling. Group members should abstain from voting if there is an ethical dilemma with the decision being made. If a group member has a conflict of interest in regards to a decision, the conflict does not need to be stated. Completion of the project should be the priority of each group member, and every decision should be a productive step towards the intended end product.

Decisions should be made with the following process:

- Problem Statement The problem should be adequately defined, with each team member having an basic understanding. Members with deeper understandings of the problem should explain their unbiased knowledge aloud to the group
- Brainstorming Members should propose possible solutions to the problem. All suggestions will be equally ranked in importance.
- Data Acquisition and Analysis Team members will be asked to acquire data in different subject areas to aid in the decision making process. The brainstormed solutions will be revisited following this stem.
- Design A design will be created based upon the following steps.
- Testing and Simulation The design will be simulated or calculated for effectiveness prior to physical testing. Physical testing may not be required if out of the project scope highlighted by sponsors
- Evaluation Results of the previous phase will be utilized to better the design if time and budget allows.

A.9 Conflict Resolution

Conflict Resolution In the event of a conflict, the following steps can be employed:

- The team leader may be asked to intervene and solve group conflicts if involving more than two individuals.
- Points of interest will be communicated by both conflicting parties. If deemed necessary, a formal mediation with listening and speaking times will be utilized to come to an understanding.

- In extreme cases of group conflict, the team leader has the power to call team meetings at alternative, casual venues. Venues may include bars or restaurants. All purchases made during these meetings will be made with personal funds.
- If all other steps fail, the course instructor may be asked to intervene into conflicts.

Appendix B: Functional Decomposition

	Lightweight	Small in Size	Effective Heat Transfer
Heatsink Material	●	●	●
Fin Geometry		●	●
Fan Selection	●		●
Thermal Interface Material			●
Chip Arrangement			●

Appendix C: Target Catalog

		Lucas	Lucas	Lucas	Dust	Tyler	Parker	Jeff	
Metrics	**Units**	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**	**Concept 7**	**Target**
Material		Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Baseplate Width	mm	240.000	240.000	240.000	177.800	177.800	185.000	184.120	177.8
Baseplate Length	mm	160.000	160.000	160.000	215.900	215.900	178.000	203.200	215.9
Fin Height	mm	35.000	35.000	35.000	35.000	33.320	38.000	35.000	33
Fin Width	mm	1.270	1.270	1.270	1.280	1.280	1.270	1.270	1.27
Pressure Drop	Pa	45.203	45.203	21.840	27.402	27.402	35.800	38.451	28
Heat Sink Weight	kg	2.128	2.128	1.891	2.165	1.434	2.360	2.550	1.4
Flow Rate	cfm	210.0	210.0	96.0	96.0	96.0	96.0	96.0	120
Max. Temperature	°C	104.0	104.0	109.0	113.0	128.0	109.0	112.0	110
Min.Temperature	°C	97.6	97.6	97.6	103.0	112.0	103.0	102.0	100

References

There are no sources in the current document.