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Heat Exchanger

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**Executive Summary:**
Lockheed Martin sponsored this semester’s design competition and provided four different in depth project ideas with a fifth option to improve any product manufactured by the aerospace company. The goal of each project was to improve designs while attempting to decrease weight using the process of additive manufacturing. Our group collectively decided to redesign Lockheed Martin’s heat exchanger that is responsible for dissipating heat on an aircraft’s CPU. If done incorrectly, the computer could overheat and either slow its abilities or cease to function altogether. Altogether six concepts were created with a large emphasis on the idea that maximized surface area. Each concept was reviewed by the group and one was decided upon based on its ability to perform its task of dissipating heat. The chosen design has been predicted to perform excellently in the field and is expected to help aircraft CPU’s run in an optimum temperature setting.

**Introduction:**
The purpose of this project is to create a more efficient and redesigned heat exchanger’s internal geometry while attempting to reduce the overall weight of the object. A heat exchanger transfers heat from a component to prevent it from overheating. We chose to focus our design on increasing the surface area of the internal parts in order to draw the maximum amount of heat out of the computer. We also attempted to redesign the heat exchanger to allow it to be more additively manufactured which allows for more creativity and freedom when creating the design.

**Problem Statement:**
In an attempt to make the design for a circuit chip heat exchanger more efficient, we have sought to increase surface area, maximize airflow, and promote heat dissipation through an innovative, iterated, additively manufactured design.
**Research:**

A heat exchanger is a device that is used for transferring heat from one medium to another. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid, known as engine coolant, flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

Additive manufacturing can be used to produce complex geometries that are a lot more difficult to produce individually and assemble. A few more needs include additive manufacturable part, metal or material that can be used in additive manufacturing that also transfers heat well, and a clean, precisely dimensioned product.

There are a number of technologies used in additive manufacturing available today. Of the major ones, the main two types are power-bed systems and power-fed systems. We chose to work on our project with type power-bed as it is one of the most common methods used in today’s world for additive manufacturing. This type uses a powder deposition method consisting of a coating mechanism to spread the design across the plate. We also found this to be a better type as the design process is always accurate and it is, on a scale, less expensive than the other type.

We also did research on which material should be used for the heat exchanger. We came up with materials like Copper, Aluminium and Iron for the heat exchanger. After doing few more research on these metals, we concluded on using Aluminium as it tops charts on conductivity and malleability.

We struggled when choosing between the various different types of aluminum. We found Aluminium-1050 and Aluminium-1100. The reason being, Al-1100 is the best when it comes to strength and formability of work whereas Al-1050 is a much better conductor and had less density compared to Al-1100. Al-1050 had a density of 2710kg/m$^3$ whereas 1100 had a density of 2720kg/m$^3$. So we decided to go ahead with Aluminium-1050 as it is a better conductor and is a better material for transferring of heat.
**Customer Needs:**

Lockheed Martin requested that the redesigned heat exchanger have the same mounts, same dimensions, and same external surface area, but be more ideal for additive manufacturing and for dissipating heat. Lockheed Martin would also like the new heat exchanger to be lighter while still utilizing maximum surface area and airflow within the component. From the product description, they are looking for a redesigned heat exchanger better for additive manufacturing, proper material for high heat, proper size, and surface area of the inside.

Customers look for products that are reliable, user friendly, responsive and ensure security. Lockheed Martin ideally wants a component that will last for a significant amount of time (at least a decade) and will not deteriorate with excessive use. A heat exchanger prevents the electronics from overheating and ultimately becoming unusable. Lockheed Martin stresses that the design is reliable, especially in different temperature and pressure conditions. Because the component will be used in military and defense aircraft, the part cannot fail.

**Concept Generation:**

We started our design by placing rods with a height of 1.5 inches in a staggered pattern that encompassed the entire area with a total of 576 rods. After the design was complete, we found that we had reduced the surface area to an eighth of the original as opposed to our goal of increasing surface area. Our main idea on the heat exchanger was to increase the surface area while keeping the geometry of airflow constant and not altering any of the external surface area. We also hope to either decrease the weight or keep it relatively similar to the original.

Our second phase of concept generation settled on a triangular honeycomb so that the exchanger had an increased surface area as opposed to our initial failed attempt. We successfully more than doubled the original design’s surface area, but did add a significant increase in weight. This design also had excellent air-flow and the group felt satisfied that it would have an increased performance in the field.

We redesigned the model and all the members of the group came up with different designs so that we have a clearer picture of how to conclude on the main design and also increase the surface area. We all pooled up our ideas and came up with total of four designs. Three of them concentrated more on the surface area while one of them was more on airflow.
We put all our designs together and came up with one main design which met all our criteria.

**Concept Selection:**

![Concept Selection Diagram]

Above are the factors we came up with for a good Heat Exchanger. We analysed and evaluated our concept designs with respect to customer needs and compared the relative strength and weakness of the concepts. We finally concluded on a design that met all the above criterias.

**Design Iterations:**

Our final design (seen below) consists of a triangle honeycomb with 367.5 triangles spanning the depth of the heat exchanger, having their openings on both ends. With all of these triangles, our surface area ended up being $1929 \text{ in}^2$ which is $1110 \text{ in}^2$ more than Lockheed Martin’s given design. Seeing as the surface area was so much greater, it allows for heat to conduct throughout the exchanger and cover more surface of the metal.

With this heat spread out, and fairly direct air paths due to the design of the triangles, the exchanger can more easily be cooled because the air running through has more area to come into contact with and absorb this heat, carrying it out as it goes.
(Above) This is the final model that the group collectively created based on the idea of optimizing surface area while making sure air flow is not impeded. It is composed of a series of 367.5 equilateral triangular prisms that run the length of the heat exchanger.

(Above) This model was created by Garrett Rabian using previous model as examples in order to increase surface area while also keeping weight and air-flow in mind. It contains slats similar to those in the original heat exchanger, but has added a series of small cubes to each slat that run the length of the exchanger in order to increase the surface area while adding minimal weight.
This model was created by Oscar Manjerovic and actually incorporated the very first model with a twist to drastically increase surface area. It is made up of 576 rods that are staggered vertically through the length of the heat exchanger while eleven plates run horizontally taking up the entire area of the exchanger. The idea is that the rods will help transfer heat from one plate to the next while allowing a great deal of air flow and adding a massive amount of surface area.

This model was created by John Buckley in an attempt to improve the original design without subtracting any materials. Similarly to Oscar’s design he created a series of horizontal plates that run the entire length and width of the exchanger. However these are extremely thin in order to keep weight in mind while increasing surface area greatly.

**Material:**

We determined that the alloy, Aluminum 1050, would be the best material for our design because it is highly efficient at transferring heat. Aluminum 1050 is commonly used in manufacturing processes and is an overall good material to use for heat purposes. It has a thermal
conductivity of 222 W/m*K whereas normal Aluminum only has a conductivity of 205 W/m*K. This alloy costs slightly more as well, being $1.15 / lb and Aluminum is just $0.70 / lb.

Although it costs more, it has a higher conductivity, which we find to be very valuable when talking about improving this product. The other important thing to compare with our design is that using Aluminum 1050 instead of just aluminum would give our design a weight of 4.18 lbs. Their design using Aluminum 1050 would weigh 2.88 lbs. Given that this difference in weight is very small and that it does not take up a significant portion of the electronics in the airplane, we didn’t see this as a downside. The benefits of the increased surface area and airflow definitely make this design worth it as well as the thermal conductivity of aluminum 1050.

Projected Results

With the new design, there were three basic factors that were altered: air-flow, surface area, and total weight. When comparing the altered design to the original, there was a large increase in surface area as well as weight, while the air flow was slightly restricted. If this new model were to be implemented using additive manufacturing methods then a slight increase in cost would be expected in materials as well in manufacturing. However, once this increased cost was endured the part would have an seemingly endless life expectancy and would well make up for itself by dissipating heat much more effectively than its dated counterpart. The triangular prism honeycomb is predicted to be more effective because of its excellent ratio of surface area to air-flow.

The only long term drawback is an increase in weight by about 1.3 lbs. This could be viewed as a small or large hindrance based on the size of the aircraft and the general duration of the flights that the aircraft will be taking. Our group saw it as a necessary sacrifice in creating a model that was much more capable of completing the task that it was created for.

Economic viability:

Additive manufacturing helps make the cost of each part cheaper since you are not buying the whole block of aluminum and cutting it out, but only using the material you need. Our design, using Aluminum 1050, would cost $4.81 for just the raw material. This does not
include cost of manufacturing. Their design would cost $3.31 for just the material used in additive manufacturing. The cost of this type of manufacturing would be cheaper than subtractive manufacturing anyway, so they are already going to save money. Therefore we believe it would be best to use these savings to afford a finer form of Aluminum with better thermal conductivity and one that is used commonly in manufacturing. Also, this is not an item they would be mass producing, so the cost does not greatly increase seeing as they are not creating many of them or replacing them often.

**Comparison with Existing Design:**

When taking a final view of each exchangers statistics our design was heavier than the existing one. Our design had a mass of 4.18 lbs whereas the existing one had a mass of 2.88 lbs. The main reason being that with an increase in surface area there was a virtually unavoidable increase in weight as well. This also increased the overall cost. Our model has an overall cost of $4.81 and the existing model had an overall cost of $3.31. Our design also had more than double the surface area compared to the existing design. Overall, our model dissipated more heat compared the existing model.

**Conclusion:**

The concept of a heat exchanger is fairly simple. It needs to be a block with inner workings that allow for the rapid and efficient dissipation of heat without impeding air flow or using too much energy. While it sounds simple, it is quite complex when you look at the what goes into determining those factors. We had to go through many iterations and ideas in order to arrive at the one we decided would be most effective. All of this in mind, our project takes all of the knowledge we have on the subjects and applies them to our final design for the heat exchanger.

Our final design used an array of triangles, 367.5 of them, and increased the surface area of the heat exchanger greatly from the original design. It required increasing weight to do so, but we also greatly increased surface area, direct air flow, and thermal conductivity. Our design implements aluminum 1050’s high thermal conductivity to increase the effectiveness of the part.
The part would cost $4.81 for just the raw material and end up weighing 4.18 lbs. Both of these are very low considering the effectiveness of the part and they are not much different from Lockheed Martin’s original values for both.

This project was a valuable look into how a design team works and what big corporations go through in order to get the well designed products that they have. While working on this project, we had to learn to evaluate our past choices, learn from mistakes, reassess the problem to refocus our goal, and use many different ideas to arrive at one final one. As a result, we have all learned the valuability of iterated designs and additive manufacturing.