Lockheed Martin:

Heat Exchanger

Engineering Design 100 Section 005

Team Hype

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Team Hype

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Section:	**Page #:**
Cover	1
Team Information	2
Index	3
Executive Summary	4
Introduction	5
Mission Statement	6
Customer Needs Analysis	6
External Research	8
Concept Selection	10
Cost Model	11
Design	13
Conclusion	15
Citations	16

Executive Summary:

Lockheed Martin needs a heatsink to be designed such that it can be produced using additive manufacturing. The objective is to minimize the wastage of materials and try to deliver a product which takes up less volume, has less mass, and can deliver the same, or superior, rate of heat exchange from the component to which it is mounted to the surrounding atmosphere. A heat sink is a device that has a specific structure that directs the heat of another system away from said system. By doing so, cools down that system. There are two types of heat sinks, passive and active. Passive heat sinks have no mechanical components, whereas active heat sinks utilize power, having fans with ball-bearing motors.

Through designing the product, multiple steps were required to better modify the heat exchanger. Patent searches and concepts will be scored using a Pugh scoring matrix. Modifications with the design originally chosen occurs to better print the model. Also efficiency was taken into account after the selection and further corrections were made. After reviewing the desirable qualities for a heat sink and the idea designs for additive manufacturing, a simple cubic lattice structure was chosen.

Risks are constant factors that mold the design of the heat exchanger. Some of the risks include creating a design too complex to be manufactured in a reasonable time, and the heat distribution from the exchanger to the atmosphere. This risks can be minimized by analysis of the process to manufacture the product and further research to better understand heat distribution. The final product is expected to be delivered to Lockheed Martin by the end of the Spring semester, 2016.

Introduction:

Purpose:

To redesign the previously existing structure of a heat exchanger. Ultimately, this will reduce production time and material waste.

Background:

A heat exchanger is a device which transfers heat from one system to another, to do work, to facilitate a thermal cycle, or to protect components from overheating. Heat exchangers typically use a fluid as a medium to transfer heat from one system to another. In the case of heat sinks, air is the typical fluid, and the excess heat is ejected to the atmosphere. Team Hype specifically is redesigning a heat sink so that it may be produced using additive manufacturing. Heat sinks are frequently used to dissipate heat generated from electrical losses in electronic devices. These devices are used to prevent electronics found in aircraft, ships, and land based vehicles from overheating. Specifications were given in regards to the dimensions of the heat exchanger.

Method and Investigation:

Initially a customer evaluation was constructed. A Needs Statement aided in the completion of the evaluation. Secondly, in depth research on the previous specifications and models was executed. Upon completion, selections on material, frame, and size were deliberated amongst the team and the final model was chosen. A physical model was then made using CAD software. Minor adjustments were made at this point.

Mission Statement:

It is our mission to alter a previously existing model of a heat exchanger and better adapt it to the needs presented.

Customer Needs Analysis:

Customer needs are specifications given by Lockheed Martin that guide and restrict particular concepts of the heat exchanger. These needs are then converted into needs statements which is another method of identifying the customer needs to make the customer's statements more obvious and quantifiable.

Customer Statements	**Needs Statements**
Redesign an existing HX for AM	Assess HX and reconstruct design to better suit today's lifestyle
Choose a proper AM process for the HX	Select optimal process for HX
Cost taken into account	Cost will be calculated
Build time taken into account	Consistent time to create product established
Choose proper AM material for the HX	Effective and efficient material for HX analyzed and selected
Overall size factor must remain as is	No alteration of dimensions of HX
CCA mating features must remain as is	No alteration of mating features
Surface area must remain constant	Specification for surface area is used in design

Legend	
AM	Additive Manufacturing
HX	Heat Exchanger
CCA	Circuit Card Assembly

To ensure that all of the statements are not overseen, a needs metrics was constructed. This provides steps throughout the process that acknowledge all of the needs statements.

	Metrics	Costs $x to produce	Has a heat exchange rate of yW	Can be constructed in z hours	Chosen material has a thermal conductivity of λW/(m*K)	Has dimensions	Has a surface area of εxσ m^2
Needs							
Assess HX and reconstruct design to better suit today's lifestyle							
Select optimal process for HX			x				
Cost will be calculated		x					
Consistent time to create				x			

product established							
Effective and efficient material for HX analyzed and selected					x		
No alteration of dimensions of HX						x	
No alteration of mating features							
Specification for surface area is used in design							x

External Research:

Material:

The rate at which thermal energy is removed from a system depends principally upon the difference in temperature of two interfaces, the thickness of the boundary between them, the rate at which fluid flows through the heat exchanger, and the thermal conductivity of the boundary material and fluid. The materials most commonly used for the walls and conducting surfaces of

heat exchangers are metals, and for heat sinks in particular aluminum and copper are the most common. The chart below defines the thermal conductivity of various materials. The average conductivity level, which is measured in Watts per meter * Kelvin, signifies the conductivity of the material for the heat exchanger. The optimal material is indicated in bold font, is found when also considering the relative cost of the material and its suitability for use in additive manufacturing.

Material	Bulk Conductivity (W/m*K)
Silver, Pure	418
Copper 11000	388
Aluminum 6063	201
AlSi10Mg	**175**
Aluminum 6061 T6	167
Zinc, Pure	112

Lattice Structure:

A lattice structure has unique geometric properties which are ideal for heat exchange: it maximizes surface area while minimizing volume and increasing the length of the path through which the air must travel. Because heat flow is directly proportional to surface area and inversely proportional to thickness, great gains can potentially be found in finding the best lattice structure for a heat sink. The largest negative to using such a structure is that if the path for airflow becomes too tortuous, a large pressure drop will be induced, reducing the mass flowrate of the

air. Heat transfer is also directly proportional to mass flow rate, so it becomes a balancing act between achieving the ideal surface area/volume ratio without diminishing the air flow.

Dimensions:

The dimensions, were given by Lockheed Martin. While the width and height were given, the length was able to be changed, giving the liberty to change the overall volume and surface area of the heat exchanger. All dimensions were followed precisely as follows:

Device Type	**Discrete**
Width	7 in
Height	0.687 in
Base Thickness	0.187 in
Weight	0.78 lb/ft
Thermal Performance	4.40 ºC/W/3in
Perimeter	12.62 in^2/in

Concept Selection:

The concept selection consisted of combining all of the research conducted and ranking the option. Below is a concept selection matrix. This organized the information and clearly labeled the concepts that were used in the construction of the heat exchanger.

Analyzed concept	Options	Dominick Allen	Tanish Meher	Saulabhya Mundra	Nicole Payung	Tyler Trimble
Material	copper		x		x	
	aluminum	x		x		x
Lattice	square	x	x			x

Structure						
	triangles			x	x	
Length/ Width	177.8 mm	x	x	x	x	x
Surface Area	405,361 mm^2	x	x	x	x	x

From the results gathered above, a final table was created with the final selections made by Team Hype.

Concept type	Concept Selected
Material	Aluminum
Lattice Structure	Simple Cubic
Length/Width	177.8mm
Height from base to top	40mm
Surface Area	405,361 mm^2

Cost Model:

The cost of the heat exchanger will become more precise as it gets closer to the time to create the structure. The cost model is currently created by using the costs of products of mid April. The cost model consists of the cost of the material and electricity. The other factors come from Lockheed Martin's preference.

The cost of industrial electricity ranges from 6 to 10 cents per Kilowatt hour in the United States, excluding New England. (Electricity Data),. Aluminum costs approximately $2 per kilogram ($1.51 as of March 2016, Aluminum). Each heat sink is 158,846 cubic millimeters;

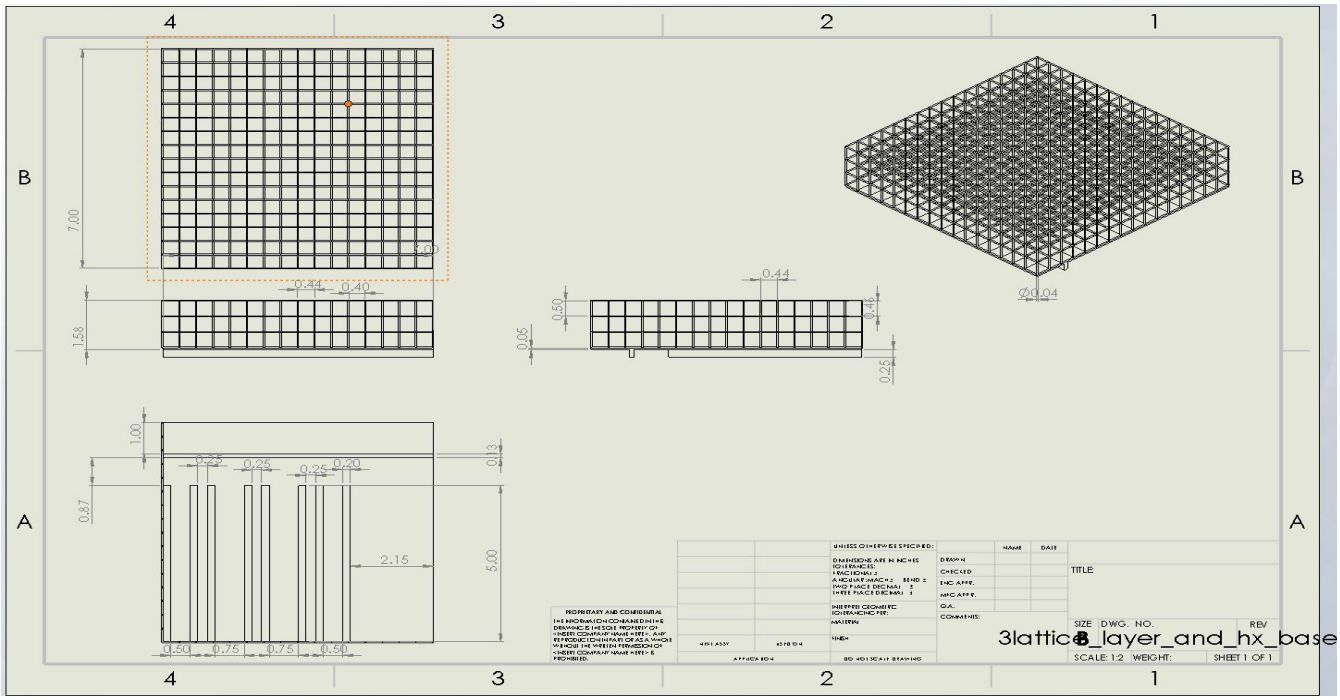
using the density of aluminum (752 kg/m^3), the mass of each object is .12 kg, ergo a cost of 24 cents from material per object. The average power draw of a selective laser sintering machine can be estimated at approximately 4 kilowatts (Telenko). The material deposition rate varies from 2 to 20 cubic millimeters per second (DMLS). The table below was calculated by adding the material cost of each unit to the cost per kilowatt hour of electricity multiplied by the volume of the object and the power draw, divided by the rate at which the material is deposited. (159,000 mm^3 / vol./sec / 3600 sec/hr * cost/kwhr / 100 c/dollar * pwr draw + $.24 = cost for object)

Vol. Material/second	Cents/kWHr	Power Draw (kWHr)	Cost for Object
2	10	5.5	$12.37
2	8	4.5	$8.18
2	6	4	$5.53
5	10	5.5	$5.09
5	8	4.5	$3.42
5	6	4	$2.36
10	10	5.5	$2.66
10	8	4.5	$1.83
10	6	4	$1.30
20	10	5.5	$1.45
20	8	4.5	$0.93
20	6	4	$0.77

Although the cost analysis does not include paying the operator, it's unlikely for the operator to solely be operating one machine performing this work. From this we can gather that in the (naive) worst case scenario, it's likely for a single unit to cost ~$12.50. In the best case scenario, the unit doesn't even cost a dollar.

Design:

The design was based on previously existing heat exchange structures. The rectangular shape creates efficiency of airflow in regards to the lattice structure. This reduces waste as well as increasing the airflow rate. In addition, the structure plus the material creates a more durable heat exchanger. To estimate the rate at which it can transfer heat, using an estimate of 24 cubic feet of air per minute from a 44 mm fan, or 11400 cubic centimeters per second (Delta), a surface temperature of 50 degrees C and an air temperature of 25 degrees C for a delta T of 25 degrees at the entrance, 175 Watts per meter Kelvin for the bulk thermal conductivity of AlSi10Mg, and 405,000 square mm for the area, we can make a gross estimate of the maximum rate of heat transfer using Fourier's law, $Q/t = kAdT/dx$. Using an average dx of 20 mm and averaging the delta T between the entrance and exit, we can get 440kW. Of course, the actual heat transfer rate will be less since the air will encounter resistance inside the heat sink, making the actual flowrate slower, and there will be an unequal heat transfer rate throughout the heat sink.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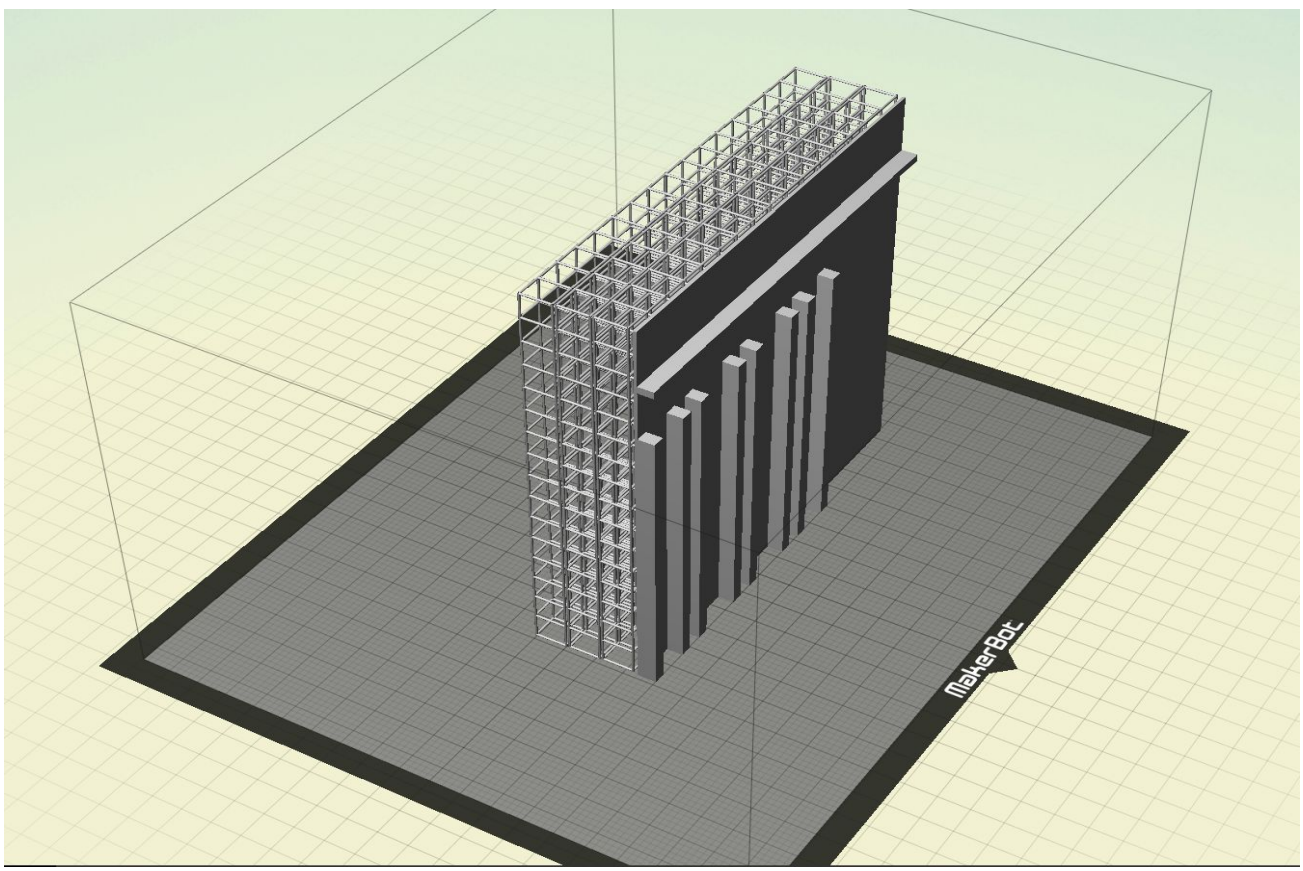
MakerBot

Conclusion:

Overall, the heat exchanger Team Hype created was a modified version of previously existing models. The evaluations conducted presented results which all of the team agreed upon in the end. Discussion and contradiction occurred often which instills the idea that the best options were selected. With the adjustments made, the model has a higher rate of efficiency, while still maintaining the dimensions created by Lockheed Martin.

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