

Lockheed Martin

Additive Manufacturing

Introduction to Engineering Design

EDSGN 100 Section 001

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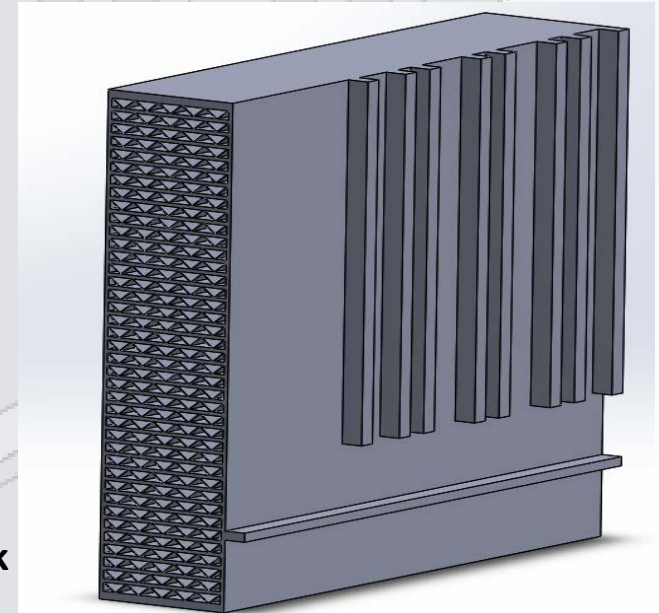
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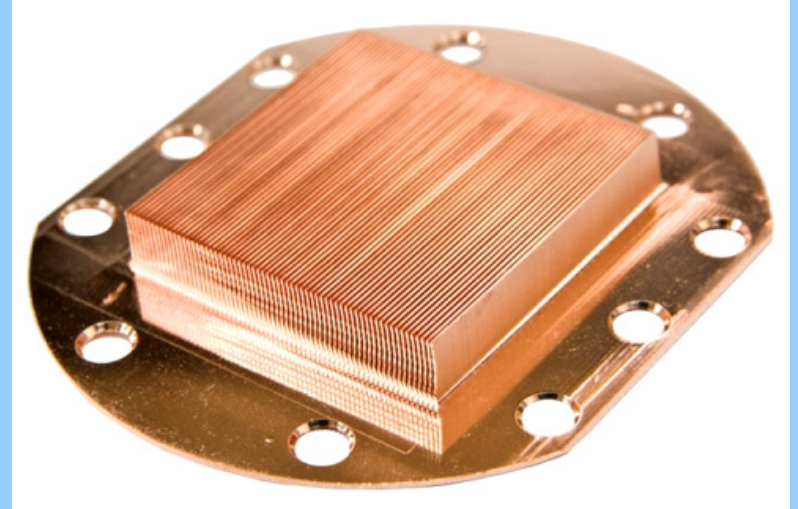


Presented to: Prof. Berezniak

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Purpose

- To redesign the heat exchanger for circuit card assembly (CCA) that incorporates additive manufacturing
- Preserve limited resources
- Decrease cost



Background

- **Additive manufacturing constructs the object in layers**
 - + Minimize waste
 - + Achieve highly complex geometry
- **Heat exchanger's material must have**
 - high conductivity
 - high corrosion resistance
 - high tensile strength
 - economic efficiency
- **Equation to calculate the total heat loss through the heat exchanger**

$$Q = h \times A \times (T_f - T_a) \times e_f$$

h : convective film coefficient ($\frac{W}{m^2 \times ^\circ C}$)

T_f : temperature at the base of fin ($^\circ C$)

e_f : fin efficiency

A : surface area of each fin (m^2)

T_a : temperature of air ($^\circ C$)

Sponsor

- **Lockheed Martin** is a global security and aerospace company
- Headquarter: Washington D.C
- Leading in all of its five main business segments:
 - Aeronautics
 - Information Systems and Global Solutions
 - Missile and Fire Control
 - Mission Systems and Training
 - Space Systems
- Branches in various countries



Project Description

❖ Why Heat Exchanger?

Among the five options, the heat exchanger has the most far-reaching applications.

Most related project to teammates' majors

❖ Criteria

- Can be additively manufactured
- Reasonable cost and build time for mass production
- Overall size factor and CCA mating features must remain as-is
- Internal air flow thru geometry can change, but surface area should remain constant

Procedures (1 of 2)

❖ Redesign heat exchanger

- Drawing tool – SolidWorks 2015 x64 edition
- Change slot pattern to increase the surface area of the fin and promote the total heat transfer efficiency
- $Q = h \times A \times (T_f - T_a) \times e_f$

Assumed: $T_a = 25^\circ\text{C}$

$$A = 1900 \text{ in}^2 = 1.23 \text{ m}^2$$

$$T_f = 60^\circ\text{C}$$

$$e_f = 1$$

$$h = 28.4 \frac{\text{W}}{\text{m}^2 \times ^\circ\text{C}}$$

❖ Choose an AM technique that can:

- Work with the selected metal, low cost, and reasonable product quality

❖ Select a material for the heat exchanger based on:

- Thermal Conductivity
- Tensile Strength
- Price per pound

Procedures (2 of 2)

❖ Using the model proposed of Yim & Rosen (2012) to estimate:

❖ Build time $T_b = \frac{\text{Volume}}{\text{Building rate of a chosen machine}}$

❖ Overall Cost = P + O + M + L

- P: Machine Purchase Cost

- $P = \frac{\text{Purchase price} \times T_b}{0.95 \times 24 \times 365 \times Y_{\text{life}}}$ Y_{life} : take the warranty

- O: Machine Operation Cost

- $O = (\text{machine power}) \times T_b$

- M: Material Cost

- $M = \text{volume} \times \text{density} \times \frac{\text{price}}{\text{kg}}$

- L: Labor Cost

- Usually ignored

Results and Discussion

- Design change: on internal geometry and surface area

+ Original design: basic horizontal patterns

➔ Add in the **zigzag patterns** in between the basic fins (0.01in thick)

➔ Reduce little air flow but almost double surface area

$$Q = h \times A \times (T_f - T_a) \times e_f \approx 1218 \text{ W}$$

- Additive Manufacturing Process:

+ Consider powder bed fusion, binder jetting, and direct energy deposition for printing with metal and present availability

➔ **Powder bed fusion** (esp. direct metal laser sintering) for least post processing & high accuracy

- Material:

Metals	Cost (\$/lbs)	Thermal conductivity at 20°C (W/(m × °C))	Tensile Strength (MPa)
Aluminum	0.74	202	40-50
Copper	2.28	386	220
Stainless Steel	0.14-0.18	12-45	505
Aluminum Alloy 6061	0.68	173	310

➔ **Copper** for highest thermal conductivity $\left(386 \frac{\text{W}}{\text{m} \times ^\circ\text{C}}\right)$ and tensile strength (220 MPA)

Results and Discussion

- Build Time estimation:

- Our redesign: 34.46 in³ in volume

$$T_b = \frac{V}{\text{Building rate}} = \frac{34.46 \text{ in}^3}{73 \frac{\text{in}^3}{\text{hour}}} \approx 0.47 \text{ hours}$$

- Cost Estimation:

+ Overall Cost = P + O + M + L

+ P: Assumed: most modern machine ExOne M-Flex

Price: \$400,000

Building rate: 73 in³/hr

Normal voltage: 240V

$$P = \frac{\text{Purchase price} \times T_b}{0.95 \times 24 \times 365 \times Y_{\text{life}}} \approx \$22.69$$

+ M: Copper: \$5.23/kg

Copper density: 8.96g/cm³

$$M = \text{volume} \times \text{density} \times \frac{\text{price}}{\text{kg}} \approx \$26.47$$

$$+ O = (\text{machine power}) \times T_b = 240V \times 20A \times \frac{10^{-3} \text{ kW}}{1W} \times 0.47 \text{ hours} \approx \$2.26$$

+ L is negligible

➔ Total cost = \$22.69 + \$26.47 + \$2.26 = \$51.42

➔ Not too high, considered the present availability and popularity of additive manufacturing

➔ Might not be readily economically efficient now, but plenty of rooms to cut cost in the future

Conclusions and Recommendations

- Our heat exchanger for CCA has its internal geometry, materials, and manufacturing process changed for the purpose of additive manufacturing.
 - Added zigzag patterns between the basic horizontal fins
 - Made from copper using powder bed fusion
 - Reasonable cost
- Thank Lockheed Martin for such an opportunity
- Additional clarifications of the project's results or further questions on any details can be reached via any member

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