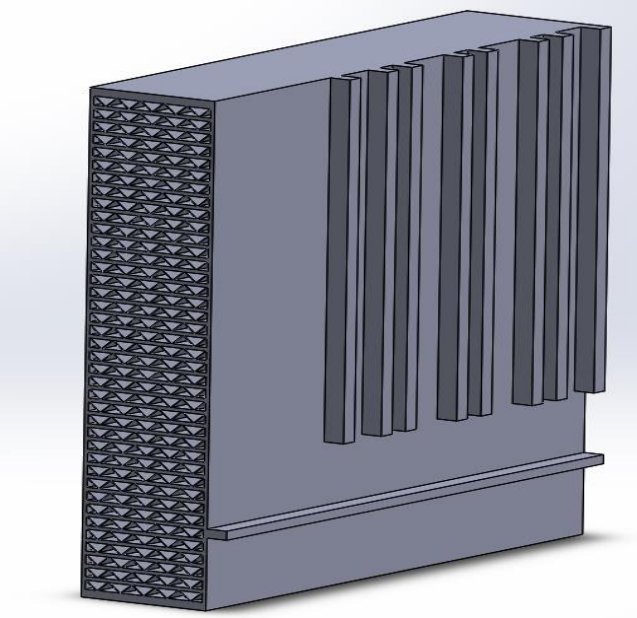
Lockheed Martin
Additive Manufacturing

Introduction to Engineering Design

EDSGN 100 Section 001

James Bond Team 007

- Aashish Nair personal.psu.edu/amn5482 amn5482@psu.edu
- Hyeokjun Choi personal.psu.edu/hpc5084 hpc5084@psu.edu
- Han Tran personal.psu.edu/hgt5011 hgt5011@psu.edu
- Tanner Quiggle personal.psu.edu/tfq5003 tfq5003@psu.edu



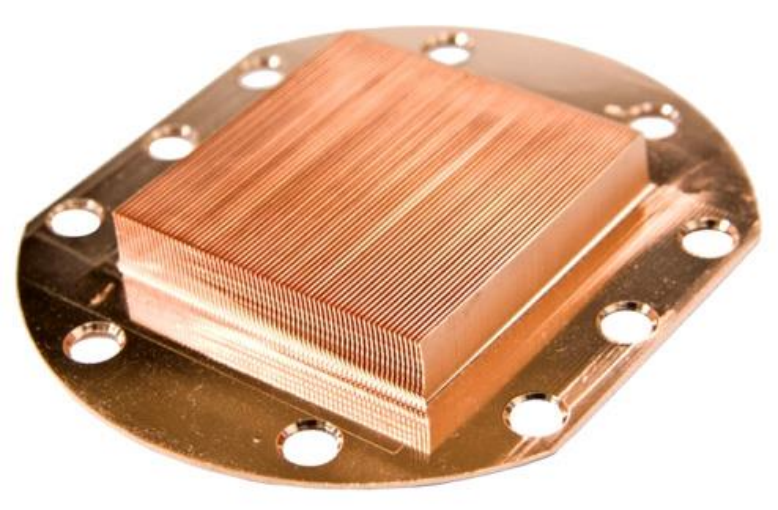
Presented to: Prof. Berezniak
Date: 04/29/2016

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**

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

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

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

T_f: temperature at the base of fin (^oC)

T_a: temperature of air (^oC)

e_f : fin efficiency

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°C T_f=60°C e_f=1

A=$1900in^2 = 1.23\mathrm{m}^2$ h=$28.4\frac{W}{m^2 \times °\mathrm{C}}$

- **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 $T_b = \frac{Volume}{Building\ rate\ of\ a\ chosen\ machine}$
  - Overall Cost = P+ O +M +L
    - P: Machine Purchase Cost
      - $\mathrm{P} = \frac{Purchase\ price \times T_b}{0.95 \times 24 \times 365 \times Y_{life}}$ Y_{life}: take the warranty
    - O: Machine Operation Cost
      - O = $(machine\ power) \times T_b$
    - M: Material Cost
      - M = $volume \times density \times \frac{price}{kg}$
    - 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

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

- 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 ($/lbs)	Thermal conductivity at 20℃ (W/($m \times$ ℃))	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 $\left(386\ \frac{W}{m \times ℃}\right)$ and tensile strength (220 MPA)

Results and Discussion

- Build Time estimation:
  - Our redesign: 34.46 in^3 in volume

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

- Cost Estimation:

+ Overall Cost = P + O + M + L

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

Price: $400,000 Building rate: 73 in^3/hr Normal voltage: 240V

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

+ M: Copper: $5.23/kg Copper density: 8.96g/cm^3

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

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

+ 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

Reference

- Additively. (n.d). Overview over 3D printing technologies. Retrieved from https://www.additively.com/en/
- Amazing's Additive Manufacturing. (2013). ExOne- Rapid Growth of Additive Manufacturing (AM) Disrupts Traditional Manufacturing Process. Retrieved from http://additivemanufacturing.com/2013/06/06/exone-rapid-growth-of-additive-manufacturing-am-disrupts-traditional-manufacturing-process/
- Bryn Mawr College. (n.d). Operating Cost Formula. Retrieved from http://www.brynmawr.edu/geology/206/operating%20cost%20formula.htm
- Foster, W. (1992, Jan 21). Thermal Verification Testing of Commercial Printed-Circuit Boards for Spaceflight. *Reliability and Maintainability Symposium, 1992,189-195*. Doi: 10.1109/ARMS.1992.187821
- Lockheed Martin Corporation. (2016). PSU Freshman Design Effort Lockheed Martin Overview [PowerPoint slides]. Retrieved from http://sites.psu.edu/engineeringdesignproject/wp-content/uploads/sites/41537/2016/03/PSU-Freshman-Design-Effort-LM-Overview-v2.pdf
- Lockheed Martin Corporation. (2016). *Statement of Work* [PDF document]. Retrieved from http://sites.psu.edu/engineeringdesignproject/wp-content/uploads/sites/41537/2016/03/PennState_LM_Project_Listing-v2.pdf
- Loughborough University. (n.d). About Additive Manufacturing. Retrieved from http://www.lboro.ac.uk/research/amrg/about/
- M. Vincent & Associates. (n.d). Retrieved on April 23rd,2016 from http://vincentmetals.com/
- Sculpteo. (2014). Guide to Professional 3D Printers. Retrieved from http://www.sculpteo.com/blog/2014/07/22/list-of-professional-3d-printers/
- Thomas, D. S., & Gilbert, S. W. (2014). Cost and Cost Effectiveness of Additive Manufacturing. *NIST Special Publication 1176.* http://dx.doi.org/10.6028/NIST.SP.1176
- Yim, S., & Rosen, D. (2012). Build Time and Cost Models for Additive Manufacturing Process Selection. *Proceedings of the 2012 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*. Doi: 10.1115/DETC2012-70940