Lockheed Martin
Additive Manufacturing
Introduction to Engineering Design
EDSGN 100 Section 001

James Bond Team 007

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Presented to: Prof. Bereziak
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

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

- \( Q \): Total heat loss
- \( h \): Convective film coefficient \( \left( \frac{W}{m^2 \times ^\circ C} \right) \)
- \( A \): Surface area of each fin \( (m^2) \)
- \( T_f \): Temperature at the base of fin \( (^\circ C) \)
- \( T_a \): Temperature of air \( (^\circ C) \)
- \( e_f \): 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: \( T_a = 25^\circ C \)  \( T_f = 60^\circ C \)  \( e_f = 1 \)
    
    \( A = 1900in^2 = 1.23m^2 \)
    
    \( h = 28.4 \frac{W}{m^2 \times ^\circ C} \)

- **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
    - \( P = \frac{Purchase\ price \times T_b}{0.95 \times 24 \times 365 \times Y_{life}} \) \( Y_{life} \) : 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:**

<table>
<thead>
<tr>
<th>Metals</th>
<th>Cost ($/lbs)</th>
<th>Thermal conductivity at 20°C (W/(m × °C))</th>
<th>Tensile Strength (MPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.74</td>
<td>202</td>
<td>40-50</td>
</tr>
<tr>
<td>Copper</td>
<td>2.28</td>
<td>386</td>
<td>220</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>0.14-0.18</td>
<td>12-45</td>
<td>505</td>
</tr>
<tr>
<td>Aluminum Alloy 6061</td>
<td>0.68</td>
<td>173</td>
<td>310</td>
</tr>
</tbody>
</table>

- **Copper** for highest thermal conductivity \(386 \frac{W}{m \times ^{\circ}C}\) and tensile strength (220 MPA)
Results and Discussion

• Build Time estimation:
  • Our redesign: 34.46 in³ in volume
    \[ T_b = \frac{V}{Building\ rate} = \frac{34.46\text{in}^3}{73\text{in}^3/\text{hour}} \approx 0.47\ hours \]

• Cost Estimation:
  + Overall Cost = P + O + M + L
  + P: Assumed: most modern machine ExOne M-Flex
    Price: $400,000  
    Building rate: 73 in³/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/cm³
    \[ M = volume \times density \times \frac{price}{kg} \approx $26.47 \]
  + O = (machine power) \times T_b = 240V \times 20A \times \frac{10^{-3}kW}{1W} \times 0.47\text{hours} \approx $2.26
  + L is negligible
  \[ \Rightarrow \text{Total cost} = $22.69 + $26.47 + $2.26 = $51.42 \]
  \[ \Rightarrow \text{Not too high, considered the present availability and popularity of additive manufacturing} \]
  \[ \Rightarrow \text{Might not be readily economically efficient now, but plenty of rooms to cut cost in the future} \]
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


