Sensitive Payload Shock Absorber
For Lockheed Martin

Engineering Design 100, Section 025, Dr. Sarah Ritter
May 2, 2016

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Figure 1. The printed prototype for The Outsider’s elevator/shock absorber
**Executive Summary:**

The goal of The Outsider’s project was to redesign the elevator of Lockheed Martin’s Desert Hawk drone to be lighter, stronger, and more durable during landings. The team had to consider various customer needs including 3D printing capabilities of the part, durability, reusability, and strength. Concepts were developed based on materials, structure, and type of additive manufacturing, and then compared using a Design Selection Matrix. The winning design, affectionately named by the team “Elastic Plastic Lattice,” was designed using CAD and the prototype was 3D printed. After printing, the Outsiders tested the prototype and made corrections to the design based on the results. The final design consists of a lattice-structured elevator made of Acrylonitrile Butadiene Styrene by material extrusion.

**Introduction and Problem Statement:**

The Outsiders would like to design a lightweight, reusable shock absorber that will be able to withstand multiple landings of Lockheed Martin’s UAVs, specifically the Desert Hawk III as shown in Figure 2 below. Currently, Lockheed Martin uses a model that consists of too much material and cannot be reused. It does not effectively spread the shock of the landing and cannot be used again. To meet the design goal, the Outsiders will implicate additive manufacturing to create a more efficient and lightweight shock absorber for Lockheed Martin’s UAVs. They will research more reliable shock-dampening material to make the model more effective and design a stronger, more resilient structure.
Figure 2. Digital Representation of Desert Hawk III, the drone for which the new elevator is being designed for [3].

Background:

Lockheed Martin is a company who deals with air defense systems, information, and emerging technologies. Selling to militaries across the world, Lockheed Martin is constantly looking for new improvements and innovative designs for their products (1). One specific product, The Desert Hawk III, is an Unmanned Aerial Vehicle (UAV) that has had problems in the past with landings. The elevator in the tail takes quite a beating everytime the UAV lands, sometimes breaking a connection piece in the tail. What Lockheed Martin needs is a new, innovative design for that connection piece in order to decrease shock throughout the elevator.

In Lockheed Martin’s previous design of the shock absorber, it was composed of high density foam, with an outer coating of Kevlar mixed with a carbon-fiber mixture. This means that the elevator weighs about 0.430 pounds, which can weigh down the small UAV.
**Customer Needs:**

Lockheed Martin wanted a shock absorber that was lighter in weight than their former design. This was the team’s main objective to meet with their design. The product also needed to have additive manufacturing capabilities. Lockheed Martin wanted a design that could be printed anywhere that they were, so the product needed to be made of a common, accessible material and made through a common additive manufacturing process. The product also needed to be strong enough to withstand several landings and be reused in multiple flights. The team also decided that the absorber should be durable enough to withstand the temperature and pressure that the drone endures during flights. The two final needs that the team considered were that the product should be made of a cost efficient material and should be compressible and flexible enough to distribute the shock and not be completely de-shaped. The product would be more likely to be reusable if it was not completely deformed during landings.

The Outsiders then completed an AHP matrix as shown in Table 1 to determine the importance of each customer need. The most important need for the group was the strength of the absorber because it needed to be strong in order to be reused. The next two most important needs were reusability and durability because the product would need to perform well in multiple landing. The final weights about each category were as
follows: strong, 21%; reusable, 20%; durable, 19%; 3D printing capabilities, 14%; cost efficient, 8%; flexible, 7%; and compressible and elastic, each 5%.

**Table 1.** The Analytical Hierarchy Process Matrix used to determine the weights of each customer need.

<table>
<thead>
<tr>
<th></th>
<th>3D Printed</th>
<th>Compressible</th>
<th>Elastic</th>
<th>Strong</th>
<th>Cost Efficient</th>
<th>Reusable</th>
<th>Durability</th>
<th>Total</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printed</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>0.5</td>
<td>2</td>
<td>0.33</td>
<td>0.25</td>
<td>13.08</td>
<td>0.14</td>
</tr>
<tr>
<td>Compressible</td>
<td>0.33</td>
<td>1</td>
<td>1</td>
<td>0.25</td>
<td>1</td>
<td>0.25</td>
<td>0.25</td>
<td>4.58</td>
<td>0.05</td>
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<td>Elastic</td>
<td>0.33</td>
<td>1</td>
<td>1</td>
<td>0.25</td>
<td>1</td>
<td>0.25</td>
<td>0.25</td>
<td>4.58</td>
<td>0.05</td>
</tr>
<tr>
<td>Strong</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>20</td>
<td>0.21</td>
</tr>
<tr>
<td>Flexible</td>
<td>0.33</td>
<td>1</td>
<td>1</td>
<td>0.25</td>
<td>1</td>
<td>0.33</td>
<td>1</td>
<td>6.91</td>
<td>0.07</td>
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<tr>
<td>Cost Efficient</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
<td>0.33</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>7.33</td>
<td>0.08</td>
</tr>
<tr>
<td>Reusable</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>19</td>
<td>0.2</td>
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<tr>
<td>Durability (Temperature/Pressure)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>18</td>
<td>0.18</td>
</tr>
</tbody>
</table>

**Concept Generation:**

The concept generation for this project was very difficult because of the lack of initial information about what the team was to redesign. However, the most important priority was to produce a design for a part that’s purpose was to absorb the force of impact from the plane landing. Therefore, a classification tree, as shown in Figure 4, was created to compare various design factors. The tree branched off into 4 subcategories: materials, systems, structure, and additive manufacturing. For each sub-category, more branches were formulated to further objectify the project. The tree is located below in Figure 4, including all of the different components used for concept generations.

**Figure 4.** The Outsider’s Classification Tree which was used to generate designs for the elevator.
Once the classifying tree was finished six different concepts were made: (1) a completely solid volume composed of rubber, (2) a volume composed of metal pistons, (3) a lattice-structured volume composed of a stiff plastic, (4) a volume metal springs, and (5) a lattice-structured volume composed of elastic plastic.

**Concept Development and Selection:**

For the first prototype, which can be seen below in Figure 5, the team built a connecter that would go between the body of airplane and the elevator. The end of the connecter is a controllable hook that the connector can be easily replaced if it broke during a crash. The initial project description was very vague, and the team felt this design was a good place to start.

![Figure 5. First 3D print of The Outsider's original prototype.](image)

After developing a few designs by using the classification tree for concepts, the team used the design selection matrix, as shown in Table 2, to select that best fit the customer needs. This was used to determine how each concept would perform in consideration of the team’s pre-determined customer needs. The metal piston design performed the worst in the matrix, due to its high cost, inability to flex, and lack of durability. The rubber solid design did quite well in most categories, except for the 3D capabilities of printing a completely solid rubber elevator, which seemed unlikely for this design. The metal spring design did not perform the best, as well. This design was very good in the strength and reusable categories, but not very well in cost efficiency or durability. While the stiff plastic lattice and elastic plastic lattice designs were comparable, the stiff plastic did not prove to be as reusable or flexible as the elastic
plastic design. The “winning” concept was, therefore, the fifth concept, the “elastic plastic lattice.” The group decided that this would be the most efficient design and continued with the design process.

**Table 2.** This is the Design Selection Matrix that was used to weigh each of the original five concepts.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printing</td>
<td>0.14</td>
<td>1</td>
<td>0.14</td>
<td>4</td>
<td>0.56</td>
<td>5</td>
<td>0.7</td>
<td>3</td>
<td>0.42</td>
<td>5</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong</td>
<td>0.21</td>
<td>3</td>
<td>0.63</td>
<td>4.5</td>
<td>0.945</td>
<td>3</td>
<td>0.63</td>
<td>4.5</td>
<td>0.945</td>
<td>4</td>
<td>0.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexible</td>
<td>0.17</td>
<td>4.5</td>
<td>0.765</td>
<td>1</td>
<td>0.17</td>
<td>2</td>
<td>0.34</td>
<td>3</td>
<td>0.51</td>
<td>4.5</td>
<td>0.765</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost Efficient</td>
<td>0.08</td>
<td>3</td>
<td>0.24</td>
<td>1.5</td>
<td>0.12</td>
<td>4</td>
<td>0.32</td>
<td>1.5</td>
<td>0.12</td>
<td>3</td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reusable</td>
<td>0.2</td>
<td>3</td>
<td>0.6</td>
<td>3</td>
<td>0.6</td>
<td>4</td>
<td>0.8</td>
<td>4</td>
<td>0.8</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durable</td>
<td>0.19</td>
<td>4</td>
<td>0.76</td>
<td>2</td>
<td>0.38</td>
<td>3</td>
<td>0.57</td>
<td>2</td>
<td>0.38</td>
<td>3</td>
<td>0.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
<td>3.135</td>
<td>2.715</td>
<td>3.378</td>
<td>3.475</td>
<td>4.12</td>
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</tr>
</tbody>
</table>

**Description of Prototype (3D Model & 3D Printed Model):**

Because of the vague description of the project at the beginning of the design project, the original and second prototypes are very different. After receiving the new information from Lockheed Martin, the team realized they needed to design a new inside for the volume of the elevator. The team decided to use an elastic plastic lattice structure because of the strength and weight of the structure. The lattice structure that the group chose was composed of triangles, due to their structural strength. The triangles were cut out both vertically and horizontally so that the product would be stronger and lighter in weight.

**Figure 6.** The isometric view of the prototype from SolidWorks, showing the vertical and horizontal lattice structure.
Overall this design outdid every other concept that the group had developed. It was able to be 3D printed in little time which also made it more cost efficient to be produced. The lattice structure is strong and durable. Depending on the material chosen, it would also be flexible and reusable.

Design Review:

The Outsiders then consulted with Team 6 to review the design. Team 6 was impressed with the design ideas. They thought that the product fit the requirements given by Lockheed Martin and also felt that the product successfully met the customer needs. Team 6 were uncertain about the material that would be used in the final product. They suggested that The Outsiders figure out which elastic plastic we will be using and that it should be light, but strong. Team 6 also suggested that more support be added to the design because they thought the lattice structure looked weak. They thought it may be useful to research other shapes to see if that structure would be stronger. After that meeting, The Outsiders decided to use the same design and test the strength before moving forward, and also use Acrylonitrile Butadiene Styrene as the material.
Description of Final Design (3D Model):

The final design was more focused on the internal structure of the elevator. To reduce the weight of the shock absorber, The Outsider’s decided to keep the lattice structure composed of vertical and horizontal triangles.

From the test in SolidWorks that can be seen in Figure 8, most of the stress was concentrated on the holes connecting the elevator to the body. Also, the edge of the elevator is bent a lot compared to the other part of the shock absorber. The team assumed that the most force would be applied on the top of the elevator when the plane lands. Therefore, at the instant that the plane lands, the edge of the absorber could bend due to impact.

![Figure 8. The analytical results of the stress test on the prototype on SolidWorks.](image)

The edge was relatively weak and displaced as a result of a force being applied to the top of the elevator, as shown in the Figure 9 below.

![Figure 9. The analytical results of the Displacement test on SolidWorks.](image)
The Outsiders also performed a drop test, shown below in Figure 10, of the 3D printed prototype from six feet and various different angles. The corners where the product is thin chipped and broke, so the team decided to fill in the triangles and make the ends solid in the next design of the product. The damage can be seen below in Figures 11 and 12.

Figure 10. Alec performing the drop test from about six feet.

Figures 11 & 12. Final prototype after the drop test showing broken parts

Compared to the previous model given by the Lockheed Martin, The Outsider’s model was much lighter. The original model weighed 0.43 pounds, while the new design weighs only 0.29 pounds. The new model can also be printed anywhere Lockheed Martin would like to with additive manufacturing capabilities. It will be composed of
Acrylonitrile Butadiene Styrene (ABS) and printed using material extrusion. ABS is broadly used as shock absorber in medical kits and is strong and durable. Moreover, ABS is less dense than the current materials used by Lockheed Martin which helped with weight reduction. The model composed of ABS will behave differently than the 3D printed prototype with is made from PLA, so the real model will be more likely to reshape rather than snap off. The model will also take about four hours to print, which is quicker than it takes to make Lockheed Martin’s current design.

**Figure 13.** The final rendering of The Outsiders’ product

**Conclusions:**

The product has several pros, including being lighter in weight than the original design and being made of a strong material and structure so that it can be reused. The cons would be the weakness of each end of the product, which relates back to the original volume of the elevator. It would also be useful to test out the product in a drone landing to see how the product responds in real-life conditions and continue to iterate after.

The team learned lessons about teamwork and communication while designing the project. It is very effective for everyone to work on individual designs and then come together to decide on the design for the prototype so that everyone has input in the design process.
References: