Sensitive Payload Shock Absorber: Lockheed Martin

EDSGN 100 Section 25
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4/29/16

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**Executive summary:** The option that was chosen by this group for the Lockheed Martin design project was the Sensitive Payload Shock Absorber. The goal of this project was to redesign the UAVs elevator to reduce weight and maintain strength via a design compatible with additive manufacturing. After selecting a design through a design matrix, the group used Solidworks software to generate a digital model which can be 3D printed with high precision. After printing multiple prototypes and finding their flaws, the final design had been prepared.

The final design is an editing of the interior portion of the UAVs elevator. The interior was hollowed to reduce weight and reinforced with rib-like structures. The original material was a high density foam but will now be an extrusion compatible material. The traditional printing material is PLA printing filament, formally known as Polylactic acid, however other, more expensive, materials could be used because of their superior physical properties.

**Introduction and Problem Statement:** Yesh and company would like to create a lightweight, shock absorbing tail fin for UAVs produced by Lockheed Martin in order for their project to be more effective in landing on the field. The product will also be strong and durable for harsh conditions and repeated use.

Currently the design is fairly undefined, so many assumptions are being made with this prototype. The overall exterior dimensions are already established, and this is expected to be effective given the nature of Lockheed Martin’s success in industry. The correct design is expected to be heavy and rigid based on our goals for a prototype.

In order to reach the goal of an effective tail fin prototype, Yesh and company will design a prototype which will follow our guidelines and assumptions, and can easily be created with additive manufacturing. It can also be tested in reference to customer desires.

**Background:** The first place we researched was the website of Lockheed Martin under the unmanned systems to get an idea about the expectations of LM. It went on to researching various types shock absorbers that were produced in the market and how they work to better design our part. In our research we found out one common feature of the shock absorbers, the piston (Sherman, Don). Keeping that as our basis we had an idea of designing our Payload Shock Absorber with a piston inside the fin which receives the shock upon landing. After LM revealed more information about the part, the idea of having a piston was dropped due to space constraints. We started coming up with new ideas as the shock absorbers which we found in our research were not suitable for the part we were making. After we came up with a few designs, we researched on additive manufacturing to see if the designs we came up might be produced
easily with this type of production. The last thing we researched upon were the different type of material we could use to make the shock absorbers depending on our designs and choices varied from metals, plastics, elastic and flexible polymers. Keeping all these research in mind we proceeded with our project iterating our designs.

**Customer Needs:** We proposed various designs for the project and to pick the best one we analyzed each of them in accordance to the most important customer needs. We came up with a list of top 6 customer needs.

- **Lightweight**
  This was the very first customer need we came up with as this was a direct request from the company for the part to be as lightweight as possible as increased weight can cause more drag and fuel for the plane to fly. From our own analysis we weighted it to be 2nd amongst all the other needs.

- **Durable and flexible**
  This was the highest rated need in our matrix. As Lockheed Martin requested it to be used repeatedly and the landing of UAVs are unpredictable, the shock absorber had to be durable and flexible. Therefore amongst all the needs we felt that this was comparably important, just above Lightweight.

- **Compact & Efficient**
  Looking at the dimensions given by Lockheed Martin it was necessary that the part had to be small but efficient for repeated use on the field. Therefore this need was rated after lightweight.

- **Easily Produced**
  Additive manufacturing can be lengthy as only the necessary part is produced without any wastage of the material. The design had to be kept simple to speed up the production time putting it in the 4th place on the matrix.

- **Cost Efficient**
  I well known customer need is for the product to be less expensive. Therefore we took this need into consideration.
Accessible Components

This is a need which has a relation with cost efficiency as easily available parts cost much less than the imported parts. Also more quantity and economies scale can be available if the materials needed are easily accessible.

Concept Generation: Many of Lockheed Martin’s UAV’s presently experience high shock absorbing loads upon landing and due to this, Yesh and company would like to create a sturdy, lightweight, shock absorbing elevator which is located on the tail of the UAV. Our goal is redesign a section of the UAV’s elevator in order to reduce its overall weight while maintaining its strength and durability. This would be accomplished by creating internal members of the fin, which would evenly distribute the shock loads from the tail to the elevator. Our final structure will be able to withstand harsh conditions and multiple landings. At first, many incorrect assumptions of the prototype were made since Lockheed Martin was unclear about their project, however these assumptions were reduced once they fully defined their project. One of our assumptions was that fitting the screws/parts into the holes of the elevator was already taken care of by Lockheed Martin and hence would not be an issue for us.

Below is a diagram of our classification tree, which includes our thought process in selecting our material types that best meet our needs. After the piston idea was dropped, the next best idea we could come up with was to make a part that can retain its shape after the impact acting like a shock absorber. This was our starting point on the concept selection tree. The next thing we
focused was what were the different ways to make a part that can retain its original shape and we came up with 4 different ideas.

**Hard & Stiff Material**

The two materials which can maintain shape on impact are metal and plastics. In metals we found that nitinol has a unique capability of remembering its shape. Many of the plastics come back to shape when they are bent.

**Elastic Material**

Elastic materials like rubber and springs come back to their original shape even after stretching or compressing them. Therefore they were a worthy choice.

**Air Pressure**

Pressurizing stretchable materials can help them act as excellent shock absorbers and retain shape as seen in common items like tires and basketballs.

**Flexible Material**

This was the last in the tree which shows the flexible polymers can come back into shape after impacts. However, while wood is listed as a flexible material, it would not be a viable additive manufacturing material.

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**Concept Generation Classification Tree**

**Concept Development and Selection:** The final concept was developed over a course of events and thinking processes. The final concepts started being developed from the beginning. Our group started off with an idea for the elevator that would allow pressure to be dissipated as the UAV would land, but we later found out that this was the wrong thinking path. Later memos showed our group that we were not allowed to alter any parts other than the inside shell to help
the design. Our initial thoughts in this direction can be seen modeled in the first image below as our first sample part. This first step kind of set back, but it helped us see the problem and how the tail would actually work. Our group’s goal new goal was to take the inner part of an elevator for a small UAV and make it more lightweight and sturdy. Our group knew we wanted to make a uniform set of some unique structure that would be able to meet those demands. After deciding that we needed some unique design we came up with 4 ideas. One was a uniform set of ribs running back the whole way along with design. Our other idea was to simply pressurize the shell with air to make it lightweight and almost act like a bouncy ball. Our third idea was to simply make the inside as rigid as possible. The fourth idea was to use a special material called nitinol which would allow the structure to be rigid when it was at higher velocities and almost limp when relaxed. We looked at the Lockheed memos and presentations, our concept scoring matrix reflected their demands. The first concept was lightweight. A small UAV cannot fly if it is too heavy, and Lockheed stressed this was a priority. The next concept was durability and flexibility. This was the most important concept. If the design was not either of these things the tail would be useless and fall apart on impact on the UAV landing. The next concept was compact and efficient. Our group wanted something simple that could meet the size requirement and would not be a complex structure. This would defeat the purpose of having a new design. The next concept was easily produced. This is where a lot of our ideas struggled. This was the only category that our rib idea truly had a problem. We worried that the small ribs would cause a problem with 3D printing. Another important concept was cost efficient. Lockheed Martin is a business, and businesses want to make money. They do not want to spend all of their funds on additive manufacturing a small elevator for one of their many aircrafts. This was an obvious concept to choose. Each decision came with different pros and cons, also. Lightweight design was one of our biggest concerns, but the lighter the design was the less sturdy it would be. On the other side though, the more lightweight the design was the more efficient and compact it could be and cost efficient. These were the biggest conflicts when picking our initial design. Our concept scoring matrix shown below led us to the rib design based on what our group thought would be most important to Lockheed Martin and their demands. However, each design also had pros and cons. The soft exterior and flexible ribs design was our best option, but it was going to be hard to produce and not the most cost efficient. It excelled in the other areas though. The pressurized model fell into the same problem, but we worried that it would not be as flexible as the other designs. The rigid solid model would be easily produced and cost efficient we believed, but it would not be lightweight, compact, or flexible. That made it an unlikely candidate for our choice. The nitinol design had our lowest scores. It would be extremely flexible and
durable, but it would not be accessible, it would not be cost efficient, and it would not be lightweight.

**Concept selection Matrix**

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<tr>
<th>Criteria</th>
<th>Design 1</th>
<th>Design 2</th>
<th>Design 3</th>
<th>Design 4</th>
<th>Design 5</th>
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<tr>
<td>Total Weighted</td>
<td>19.78</td>
<td>13.72</td>
<td>22.05</td>
<td>18.12</td>
<td>13.72</td>
</tr>
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</table>

**Initial design concept**

**Description of Prototype (3D Model + 3D printed Prototype):**

- **Isometric view first design**
- **Side view first design**
- **Front view first design**
Cross Section View of Prototype 1

The structural supports for the insert components for the tail of the UAV are pieces of bent plastic in a U-shape. They take on some of the forces exerted on the insert components by the UAV landing. They are bent in such a way that they can brace on the structure itself to alleviate some of the forces.

The rounded supports that are the main focus of the prototype extend along the entire structure. They attach to the top and bottom of the outer shell, and will also alleviate pressure to the structure due to their ability to flex and bend with the shell. They are also spaced out to make sure the structure is lightweight while still being structurally sound.
The green component shown was simply the space we had to work with. Lockheed Martin gave us a volume to work with, and our prototype uses the same dimensions to ensure that it will fit and secure the outer shell.

The insert component was another structure that had to be worked around. This was part of the shell. This part could not be altered, but it could be added onto which is how the supports for the insert component came to existence. This is where the tail will actually meet the elevator, and it had to be kept structurally sound.

This design was much better than our initial ideas, because once we had the model made we knew what had to be done to enhance it. We used the general idea of the flexible ribs and rigid outer body with this design, but this initial prototype used one solid material that was all lightweight and semiflexible. This would make it more uniform and lighter so when the UAV lands it would not be straining against itself. Also, we added the insert component supports to help alleviate pressure on the attachments. The most structurally sound part of the elevator should be where it attaches so it does not break off or damage the tail. This was not initially one of our ideas. The prototype had some changes from our initial thoughts, but they turned out to be big decisions.

**Design Review:** Our finding from our design review was that our first prototype wasn’t strong enough to withstand landings from a great height. We physically tested the strength of our design by dropping our prototype on the floor at various heights. As a result, pieces of our design shattered in 2 different locations. Also, we found that the front of our design did not contain enough material (too thin) and hence resulted in it being shattered. Resultantly, we made a couple adjustments to our final design and some of these changes were that we doubled the thickness of the exterior, we added more material such as a rounded support to the front of our project to make it more sturdy to withstand landings and we also printed in 0.4 mm as compared to the 0.2mm which we initially printed in.

**Description of Final Design (3D Model):** The final design is very similar to the original design, however some changes were made to optimize the elevators strength. The interior structure was hollowed out to leave a wall thickness of .04 inches, which is twice as thick as the original design. Ten crescent shaped ribs run the width of the elevator to hold the shell in place when put under stress. An additional rib in the front of the elevator was added to the original nine
Because it was found that the front section was weak in comparison to the rest of the structure. To reduce printing time, the model is specified to be printed with an extrusion thickness of .4mm. The final design is regularly intended to be printed with PLA because it is cheap and relatively flexible and strong.

**Address:** The primary goal of the project was to reduce the weight of the elevator. In order to produce a design which could be lighter but still maintain strength, the manufacturing process was chosen to be extrusion. The interior of our design is fairly complex and could easily be ruined if printed crudely. Other processes which could accurately produce the same geometry, such as digital light processing, and stereolithography, produce models which are very fragile, so extrusion was the best choice for production. The original weight of the Elevators interior structure was .430 pounds and the weight of the final design is .181 points, although if the design was printed with the densest form of PEEK, the final weight would be .219 lbs. This means a range of weight reduction from 49-58%. PEEK, or polyether ether ketone, a potential construction material, is a 3D printing filament with a slightly greater density than that of PLA, but superior figures for physical traits such as elastic modulus and strength to weight ratio (Density 2016). The biggest drawback for the use of PEEK is the cost. Currently, PEEK in a filament form is only available from a limited number of suppliers, and the cost of PEEK is 15 times that of PLA (German 2016). Changes also need to be made to typical extrusion printers to print with PEEK, but if Lockheed Martin wants to spend the money, the design would benefit greatly. The key superior trait of PEEK in comparison to PLA is its greater elastic modulus. This feature allows the elevator to flex more without breaking which means less damage after every impact and an extended life being used on a UAV. In our testing, the low elastic modulus of PLA allowed it to fracture when dropped but PEEK will not be as affected. PEEK also has a higher melting point than PLA which may be important in warfare scenarios.

<table>
<thead>
<tr>
<th></th>
<th>Elastic Modulus (GPa)</th>
<th>Density (g/cm^3)</th>
<th>Strength to Weight Ratio (kN-m/kg)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Melting Onset (C°)</th>
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<tbody>
<tr>
<td><strong>PLA</strong></td>
<td>3.5</td>
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<td>50</td>
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<td><strong>PEEK</strong></td>
<td>4</td>
<td>1.51</td>
<td>70</td>
<td>92</td>
<td>340</td>
</tr>
</tbody>
</table>
Conclusions: Our product has its pros and cons. Our product is very light and streamline. It also boasts a very simple structure that would be able to be manipulated easily. Its support structure is also impressive. It has extensive coverage of the susceptible portions of the initial design. The ribs that will support the attachment structure are very important to the design. The cons of our design are that it may not be strong enough at the very front. Our first prototype shattered when we did a drop test, and despite adding another rib to the very front of the design, our final design may be weak at the very end of the inside edges. It also has a relatively long additive manufacturing period compared to other designs due to the fact that we have to have it printed sideways to allow for the proper manufacturing of the supports. Our design might include a thicker front portion in the future to avoid that weak front structure. Our design could also use a different additive manufacturing concept instead of simple extrusion to make manufacturing time faster. We learned to pay attention and be patient with your customer. The entire beginning of the project was almost a waste because the instructions were not clear on what to do. Also, our group learned that testing and analysis can shed light on your designs actual strength and efficiency to help see if it actually matched your concept selection process.

References:

