UAV Shock Absorber Design

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Executive Summary:

This project given by Lockheed Martin worked to find a design for an Unmanned Aerial Vehicle (UAV) Elevator Shock Absorber that would reduce weight while reducing stress on the joints of the elevator. In the process, three main designs were created with multiple iterations and concepts for each. Through analysis of customer needs and concepts, one final design was chosen and more iterations were designed specifically to better the entire concept and design overall in order to fit the project goals. The final concept chosen was a mesh gyroidal design to fit the airfoil. The gyroid design was seen to be the most structurally robust design that could be implemented. The mesh iteration allowed for a significant reduction of weight while still maintaining the durability of a solid gyroid structure. Overall, the design created has the potential to meet all customer needs and be implemented in the field for any Lockheed Shock Absorber needs.

Introduction:

The purpose of this project was to develop an unique inner membrane to a UAV elevator that is lower in weight, compared to what is currently used, while still maintaining complete durability and reduction of stress on joints. Lockheed Martin currently has multiple UAV designs that experience very high shock during landings. These UAVs must remain lightweight in order to be aerodynamically favorable yet still be strong enough to be able to endure the harsh landing experience of a deep stall landing of the UAVs. At the same time, the project aims to better the design currently present so that the elevator can withstand multiple harsh landings. Specifically, the major goal became to reduce the weight of the shock absorber. Finding a design for this lowering of weight becomes important when looking into how aerodynamic the UAV is, as mentioned previously. At the same time, lowering weight is also important as the shock absorber
is placed in the rear of the UAV; an increase in weight may disrupt the center of mass and therefore disrupt the balance of the vehicle in flight. Adding weight to the entire vehicle is more problematic than reducing weight; while adding weight may assist in shock absorbing capabilities, it requires more energy for flight and so is not desirable. A reduction of stress on the multiple joints would assist in allowing the UAV to survive multiple flights and landings. The unique design aspect comes from the idea of the free complexity that is available with 3D printing, another specification that falls under this project. In general then, the design would have to take all goals into account to meet customer needs fully while creating a very unique design.

**Problem Statement:**

The purpose of this project as mentioned previously was to create a unique inner membrane for a Lockheed Martin UAV elevator airfoil. The goals and priorities in doing this were to reduce weight of the absorber, maintain or improve durability, be able to manufacture in theater and create a unique design compatible with concepts of 3D printing.

**Research:**

We first looked into Lockheed Martin and the name of their UAV, Desert Hawk III, since we were given no specs of the UAV due to its classified nature. We then looked into the designs of honeycombs, trusses and, gyroids. This led to the original gyroid design off thingiverse being used as the first model. We then were asked to iterate and used thingiverse to get models of a modular cube gyroid, a diamond tessellation, a gyrovoronoid with 2 curved bases, and a gyrovoronoid with 3 curves bases that were thickened for structural integrity. Then we discussed using carbon fiber and found a printer for it that also could print other optimal materials for our shock absorber.
Customer Needs and Target Specification:

Lockheed-Martin had a number of requirements and goals for this project. The main idea of the project was to redesign the shock absorber to be made using additive manufacturing. The priorities for this redesign were to reduce weight and increase durability (the shock absorber should be able to survive multiple landings). Lockheed-Martin also had some secondary needs, including the ability for the part to be manufactured overseas in the theater. The main specification that we were given was that the structure we chose would be able to fit within an airfoil shape.

Concept Generation:

We looked at three different concepts before selecting our final design.

The first concept was a basic honeycomb design. Initially, different shapes were considered for the honeycomb, including hexagons, octagons, and rectangles. For the initial honeycomb concept, we settled on hexagons because hexagons are more widely used and are more stable. This design would reduce a lot of weight and still promote stability and flexibility. It would also be easily added into the airfoil shape.

The second concept was a pyramidal truss design. This design would reduce by far the most weight. This concept includes making a bipyramidal truss design (something we never modeled in SolidWorks). This design would reduce by far the most weight, but it would come at a cost of structural integrity and durability.

The final concept was a gyroid design. The gyroid is a complex mathematical structure that is made essentially by warping a single plane into different shapes, like cubes and spheres.
The gyroid is also modeled around cellular structures. This structure is highly stable, even though it might look fragile. Its main drawback is that wouldn’t reduce as much weight as the pyramidal truss concept, but it would still reduce a significant amount of weight.

**Concept Selection:**

We rated all three concepts on durability, simplicity (how easy the design would be to integrate), weight reduction, and we added another category of Additive Manufacturing (AM) optimized, where each concept would be rated on its ability to take full advantage of the free complexity that comes with additive manufacturing. Weight reduction was the highest priority, followed by durability. Simplicity and AM optimized were rated as the least important.

<table>
<thead>
<tr>
<th></th>
<th>Gyroid</th>
<th>Honeycomb</th>
<th>Trusses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Durability (30%)</strong></td>
<td>5</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Simplicity (10%)</strong></td>
<td>1</td>
<td>.1</td>
<td>5</td>
</tr>
<tr>
<td><strong>AM optimized (10%)</strong></td>
<td>5</td>
<td>.5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Weight reduction (50%)</strong></td>
<td>3</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3.6</td>
<td>2.2</td>
<td>3.0</td>
</tr>
</tbody>
</table>
As you can see, the gyroid is clearly the best design. It is by far the most durable, but doesn’t sacrifice much in the way of weight reduction. Even though the gyroid scored the lowest in the category of simplicity, its complexity makes it the most optimized for additive manufacturing. The honeycomb drifted out of favor with our group because it isn’t a very creative design. Also, it reduces the least weight when compared to the other structures. The pyramidal truss design ended up being not very useful because of its poor durability. The trusses would have easily buckled and/or delaminated (when the 3D printed layers are pulled apart) under the extreme stress of the landing. As a result, the gyroid became our final concept.

**Design Iterations:**

We did four iterations of the gyroid (See Appendix for picture of prints):

First, we tried a diamond tessellation which was stronger but had increased weight and decreased flexibility.

Second, we tried the gyrovoronoid with a two curve base since it should have been as strong and reduce more of weight. However, it turned out extremely fragile.

Third, we attempted a modular spherical gyroid to see how a different shape would work, it was heavier and would be difficult to incorporate.
Fourth, we had a gyrovoronoid based of the original gyroid which essentially was that all the solid walls were changed to a meshy web structure$^3$.

**Final Description:**

After spending a lot of time on generating and selecting concepts and going through customer needs and target specs, we came to a conclusion of choosing the gyrovoronoid as our final design model. A gyrovoronoid is basically the original gyroid with meshed surfaces all over the body. We chose this design as it was the same as the gyroid but the meshed surfaces were better in weight absorption and reduction.

While printing our final design, we had to reduce the resolution in-order to get our design in time, by doing this we got our final design to be smaller. Our final design was made in a makerbot file along with three other models, due to this we were forced to have support structures on each of the four designs. The meshed gyrovoronoid (final design) did not require the support structures as it was strong enough to be additively manufactured by itself.

The drawing (located in the appendix) represents the iteration of the meshed gyroid inside the airfoil. This structure reduces the damage done to the UAV during landing.

**Assessment:**

Assessing the information gathered from Lockheed Martin and our research, we concluded that the requirements for the inner component of the UAV were reduction of weight,
reducing stress on joints to survive multiple deep stall landings, maintaining the durability of the UAV and having the ability to be additively manufactured. We then started to compare each concept and sub-concept with each of the above criteria. The honeycomb was the most basic and common design but not so great with weight reduction, the trusses were ideal for weight reduction but not durable and AM optimized. This gets us to the gyroids, which are highly durable and good for weight reduction. Going deeper into the classification of gyroids, we came up with the meshed gyrovoronoid as our final design; it is perfect for durability and weight reduction due to its complex and convoluted structure.

We then had Andrew stand and jump on the meshed gyrovoronoid to see how much weight it can withstand and by doing this we decided that our product had the capability of withstanding at least 890N (see Appendix for demonstration). But in reality, when the product is made of a different polymer, it would be able to take more weight.

**Economic Viability:**

The Markforged Mark Two\(^7\) would cost $13,499 for the enterprise version and the most expensive replacement spool is carbon fiber which costs $150 directly from them or $80 when bought from wholesale/bulk distributors.

**Comparison with Existing Design:**

Currently, the UAV Elevator Shock Absorber design that Lockheed Martin has in place is completely solid. The airfoil is filled throughout making a solid design for the shock absorber. This does not allow for much shock absorbing capabilities and so improvements were obviously necessary. The mesh gyrovoronoid design that was created not only improves the shock absorbing capacity of the elevator, but also reduces weight. The mesh design specifically is quite lightweight in comparison to other designs and therefore would reduce weight overall, especially
compared to an entirely solid filling in the airfoil. The gyrovoronoid is designed specifically to take impact and shock in all directions, vertical, horizontal, and diagonal; this compared to the entirely solid design already reduces stress on the joints as the solid design was not very conducive to taking multiple harsh landings. In addition, this design can be additively manufactured, allowing for a better in-theater and on-site designing capability compared to the current design. For these reasons, this final gyrovoronoid design would improve the UAV landing capabilities and capacity in comparison to the fully solid design currently available through the Lockheed Martin design.

Conclusions:

The design project developed our skills as Engineers, as doing this project we got better at analyzing problems, coming up with answers, and performing within a team.

Based on all our research, we chose our best design to be the meshed gyrovoronoid as it complemented most of our matrices and our customer needs. The meshed gyrovoronoid when compared to the present design of Lockheed Martin is better at shock absorbing and weight reduction. The honeycomb design was simple and durable but not good in weight reduction and trusses were great in reducing weight in 2D but would break if any torque is applied.

The total cost of 3D printing the meshed gyrovoronoid in carbon fiber would range between came up to $14,000-15,000; it is on the higher side, but it can be printed in many other cheaper and more durable materials and this cost covers many prints rather than just one (the printer alone is $13,499). Even though the complex and the convoluted structure of the meshed gyrovoronoid may be an issue, the strengths and the positives of this design outweigh the drawbacks, making it a good solution for the problem faced by Lockheed martin’s UAV Elevator. This design can be further developed and be made better for the future applications.
References:

7. https://markforged.com/
Appendix

Drawing and Dimensions of Sample Airfoil Design
Picture of Demonstration of Standing on Final Design to Test Impact
Picture of all Final Iterations of Designs Printed
Concept Tree of Design Process for Project