Lockheed Martin Project
Project #2: Sensitive Payload Shock Absorber

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Dr. Ritter

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Executive summary

The Sensitive Payload Shock Absorber Project, sponsored by Lockheed Martin, sought to redesign an aircraft elevator for additive manufacturing. The specific elevator was originally designed for a small unmanned aerial vehicle, or UAV. Lockheed Martin manufactures these UAV’s for military applications ranging from weather monitoring to reconnaissance. An example can be found in Figure 2.

The elevator needed to be lightweight and easily manufactured in the field. After considering many options, the team designed a triangular mesh to extrude through the provided airfoil shape that reduced weight by 56% when prototyped in PLA. The final product could be printed with a typical plastic material extruding 3-D printer with the designed infill wherever it is needed to support UAV operations.
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1 Introduction

1.1 Background

Airplane elevators control vertical pitch in most fixed wing aircraft, including unmanned aerial vehicle, or UAV’s. As you can see in Figure 1, the small airfoil “flaps” move up and down on the tail of aircraft by the cockpit controls. A traditional airplane elevator is typically manufactured via subtractive manufacturing methods like machining. The given elevator was originally designed for a specific small UAV. Lockheed Martin manufactures these UAV’s for military applications ranging from weather monitoring to reconnaissance. An example can be found in Figure 2.

![Aircraft Elevator Diagram](image1.png)  
**Figure 1: Aircraft Elevator Diagram [1]**

![Lockheed Martin UAV](image2.png)  
**Figure 2: Lockheed Martin UAV [2]**

1.2 Problem Statement

The team’s ultimate goal was to decrease the UAV elevator’s weight while preserving the structural integrity of the original design. The final product must be manufactured by an additive manufacturing method of our choice that is available in-house at Lockheed Martin. Due to the lack of landing gear, UAV’s commonly experience numerous high stress landings. The current elevator is hard to replace in the field if damage occurs. Knowing this, the team moved forward by investigating methods of reducing weight in the final elevator. Through
the iterative design process, the team will incorporate the best solution features into the final product.

2 Design Process

2.1 Customer Needs

Our main goal was to design an elevator or pitch controller through additive manufacturing that is lighter and can withstand 25 crashes before needing to be repaired or replaced. Our primary customer needs were determined to be weight, durability and ease of repairs. Secondary needs were cost, ease of manufacturing and on-site production. Using the requirements needed for the final product, we completed an Analytic Hierarchy Process (AHP) table (See Figure 3) to determine the relative importance of the properties.

We made weight a top priority because with anything related to flight, weight always has to have special attention. The importance of weight in such a small aircraft can make all the difference in if it functions efficiently or not. These UAVs are not equipped with landing gear in order to reduce weight, so adding on a dense elevator would not be ideal for the plane’s main functions.

Our team determined that durability plays a major role in this design. The whole purpose of our project was to develop an elevator capable of withstanding 25 crashes, which was the standard we set for ourselves. Durability plays a big part in the full practicality of our design, the part must be able to stay intact with crash landings. As one may see from the AHP table, we rated Reparability at 15%, because we need the design to avoid being easily totaled. It’s crucial that the mechanics and engineers of Lockheed Martin can easily repair the part. The same weight was given to “Ease of Manufacturing” because we need to mass produce our prototype with the rapidly growing drone market.

Our group placed cost as a low priority just to enhance all that all other primary goals were completed. Then, with the data we calculated from the AHP table we utilized the Design Selection Matrix (see Figure 4). We used material extrusion as opposed to the other forms of additive manufacturing due to material extrusion’s adaptive properties and inexpensive processing.
2.2 Concept Generation

Creating a classification tree was a great way to narrow down ideas. Our concept generation phase consisted of a couple different techniques to design the elevator. We had to think of feasible methods of redesigning the pitch controller of the UAV. The first sublevel of the tree, underneath redesigning elevator, is structures (Figure 4). Our team considered a hallowed out elevator, along with a triangle and hexagon mesh designs. We thought of just adding supports or maybe even making the entire inside of the elevator with rubber or aluminum.

In our classification tree, our team had to look at what material we want going into the design. We had to consider weight and durability here while reviewing what materials would be the most efficient in the making of a shock absorber. Some materials we thought of were rubber, metals, PLA and “Ninja Flex” PLA. Underneath, metals we looked at maybe adding steel or aluminum structure, we also included two different types of rubber.

A pressures aerosol can idea was part of our concept generation summery. Our team thought of filling the hollow elevator with a pressurized compressible gas to absorb the crushing blow of a crash landing. As one can see from the classification tree, we pondered upon the idea of a hydraulic shock absorber which involved installing a system of fluid reservoirs that activate upon impact, and cushion the blow imposed on the elevator.

Material extrusion was the best option for how we would physically produce our object. Powder Bed Fusion could have been a good option for our use due to its precision laser production, but this is not an in-house capability that Lockheed Martin’s customers likely have. So, popular 3-D printing was the best option due to its relatively inexpensive operating costs and availability.
2.3 Concept Development and Selection

Using our weight from the AHP, we used the concept selection matrix (See Figure 5) to determine what design would fit our customer needs. We came up with 5 feasible designs, each with their own benefits and drawbacks. They were triangle mesh, hexagon mesh, solid rubber, solid steel and a pressurized system.

As you can see, the durability is the most important criteria in our matrix which weighs 30 percent in total. The weight of our product and ease of manufacturing are the second most important qualities weighing 20 percent each. Cost, reparability and ease of deploying are less important criteria in matrix which only weigh 10 percent.

When we discussed our design, we mainly talked about the mesh structure since solid structures and pressurized systems do not actually satisfy our customer needs.

We came up with two types of mesh structures, triangular and hexagonal. We choose the triangular one because hexagon structure is more complicated structure, which will make it more difficult to repair and manufacture. So our final design was a triangular mesh structure.
2.4 Description of Prototype (3D Model + 3D printed Prototype)

The final design selected was significantly better than any of the previous thought of designs. The pressurized system, solid rubber, and solid steel designs would not be able to be modeled at all in SolidWorks because two of them are completely and one of them was empty space. The only viable design besides the one we chose was the hexagonal lattice. The hexagonal lattice would’ve been several degrees harder to produce because of the difficulties of hexagonal prisms fitting together.

Our initial design was a very early stage prototype. There were two designs, one being a singular tetrahedron and one being four tetrahedrons combined into a basic lattice structure (see Figure 6). While this was a very early model it was a good proof of concept. The weight would be reduced because it is mostly empty space. Tetrahedrons are the strongest 3D shape so it passes the durability criteria. Since the design consists of only tetrahedrons it would be very easy to repair and the cost of mass production of a consistent shape would drop the cost down. Its ease of manufacturing is slightly good, slightly bad because there is one basic structure that has to be repeated but that one basic structure is slightly difficult to produce.

3 Design Iteration

3.1 Design Review

The design review was very helpful in understanding our own design. There main concern was actually visualizing the lattice structure inside the elevator and the fact that our printed prototypes were too small (see Figure 7). They also pointed out that with only a single pyramid showing they couldn’t successfully visualize what our final product would actually look like. We took all this into consideration when building our final design.
First off, we scaled up everything in size so that it could be easier to view and hold if printed. When we printed two second iteration models, they were much larger and you could actually see where everything would go (see Figures 8 & 9). As you can see from the models on either side of the page they are much more developed.

![Figure 8: 3D printed elevator](image)
![Figure 9: Screenshot of Tetrahedron to be printed](image)

3.2 Description of Final Design (3D Model)

![Figure 10: Screenshot of Final SolidWorks Model](image)

Pictured above is our final model (Figure 10). There are several differences from the earlier prototypes presented. The main difference is that we finally combined our lattice structure with the elevator that was provided to us. It can also be noted that each lattice isn’t complete in the design. Each pyramid would be the same height except when they reach the elevator walls they are cut off. Having incomplete pyramids as the supports slightly decreases the structural strength of the entire elevator. Another key difference from the original lattice is that we replaced the triangular base with a square base. While this may seem counterproductive to the strength of the model because going from a triangle to a square reduces strength, this change was necessary. Looking at the back of the elevator you can see that it has a 90 degree angle. If the triangle base was kept then it couldn’t be lined up with this corner which would make the entire internal structure unsound.

Lockheed had several requirements for this project. They were, the structure had to survive multiple landings, designed for additive manufacturing, must fit within the provided
volume, and must be as light as possible. Due to the fact that the structure was initially imported and the lattice structure consisted of so many parts it was impossible to stress test the design because SolidWorks would repeatedly crash. Our design is significantly lighter than if the elevator was completely filled. Using Makerbot Desktop to weigh both designs we found a weight reduction of 56%. Our design has also been optimized for additive manufacturing. While subtractive manufacturing would be difficult because of all the small internal holes, additive manufacturing would be easy because it is just a constantly repeating structure throughout the inside of the elevator.

We would advise Lockheed Martin to use material extrusion for the creation of this design. That is because material extrusion is the simplest form of additive manufacturing. It is also because the repetitive nature of the design along with the simplicity of each individual lattice would be easy to produce. We recommend the use of a plastic because metal extrusion would be rather difficult given the constraints. The type of plastic is more up to debate because we want a plastic that is both rigid and has some flexibility to withstand an impact. Ninja flex for example is very flexible but it doesn’t have the necessary rigidity for our design. Further research would be required to see what type of plastic would be best for use, but we would recommend PLA because it has the rigidity to not let the elevator collapse in on itself and the legs of the lattice are thin enough that they can bend slightly without breaking thereby allowing some energy from impact to be dissipated through their elasticity.

4 Conclusions

Overall our product can be considered a success. We fulfilled all of Lockheed’s requirements. The pros of our design is that it uses an easily replicable lattice structure, and that the design is very light weight due to the low amount of material needed. These being two of Lockheed’s main requirements we feel that us meeting them is very important. The main con of our design is the current implementation of the lattice structure. Currently our design uses pyramids that are all the same dimensions. Since the elevator is curved not all the pyramids are complete when the reach the top and bottom surface. These incomplete pyramids reduce the strength of the design slightly. If the model went through continued to go through more iterations this problem would be addressed. We would fix this by going into SolidWorks and individually measuring what the height of each pyramid should be to get the design to be as accurate as possible.

This project taught us several lessons. One important lesson we learned was division of labor. Every member of our group had their own separate but important role in the project and we would constantly communicate our progress with each other. We also learned the importance of prototyping. Throughout the project, even up until the last week, we were constantly redesigning our project to better fit our needs. We learned that the design process isn’t just several steps, it is a very fluid process and you need to be thinking about all parts of it simultaneously.

5 Acknowledgements and References

5.1 Acknowledgements
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5.2 References

1. NASA. https://www.grc.nasa.gov/www/k-12/airplane/elv.html

All other photos supplied by group members