Spring 2018

Guardian Condor

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Guardian Condor

3D Printed Glider

Spring 2018

Kevin Bayonnet, Dan Bologna, Jake Stefanick, and Matt Wallace

Senior Design/Honors Project

Faculty Advisor: Dr. Shao Wang, Mechanical Engineering

The University of Akron
Executive Summary

Our group has teamed up with Dr. Williams from Discovery Lab Global to research the capabilities of 3D printed Unmanned Aerial Vehicles (UAVs). The goal of our project is to deliver a 3D printed glider prototype which can later be fitted with electronics for controlled flight. The glider must also carry a payload of 2 to 3 pounds in addition to the electronics. These requirements must be met all while using a basic 3D printer with low cost plastic.

Throughout the Fall 2017 semester, our group made a significant amount of progress by completing the conceptual design portion of the project. A morphological chart was created to organize the various brainstorming ideas and to assist us in coming up with practical combinations of design function which we could incorporate into hand drawn concept sketches. These three different concepts were judged using a weighted decision making matrix to find the most practical solution. The weighted values from the decision making matrix were derived from the objective tree where we chose quality, cost, and safety as our main categories.

As we began the Spring 2018 semester, we continued our project by entering the embodiment design stage. In this stage we decided on which embodiment principles to apply to our design, and began researching planes to base our design off of. As we concluded the embodiment stage, we entered the detailed design portion of the project. Using SolidWorks, our group created multiple parts that would eventually be assembled into an operational glider. As a result of continuous revisions to our models, we reached a point where we felt confident to send our part files to be printed in The University of Akron’s 3D print lab. Once printed, the parts were assembled, glued, and wrapped in packaging tape. The testing of this initial prototype took place at The University of Akron’s InfoCision Stadium which enabled us to toss the glider from a reasonable height. The test flight was unsuccessful, but provided us with important observations to further revise our glider. The newly revised glider has been sent to the print lab to enable us to repeat the testing process.
Acknowledgements

For our Senior Capstone project, we teamed up with Discovery Lab Global to design and test a 3-D Printed Glider. Discovery Lab Global (DLG) is an entrepreneurial STEM lab and concepts incubator to help accelerate innovation in young minds. DLG began as an Air Force research internship program that had an average of over 100 students across the nation. Their goal is to build math, science, and engineering talent in students in later years in high school and earlier years in college. Dr. Rob Williams, executive director of DLG, will be provided guidance to us during the design process. Mike Weaver the 3D printing director of the University of Akron performed the labor of printing each part.
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Chapter 1: Introduction

Background

Unmanned Aerial Vehicles, or UAVs, provide military and rescue personnel with the ability to enter areas that may be too dangerous for a manned aircraft. These UAVs are often assembled in the field where they are used in missions to gain intelligence, survey areas, and deliver supplies. Upon landing, these vehicles have been reported to experience rough landings, where parts become damaged beyond operable. For a military UAV, this could mean a repair cost of $8000 for a broken wing.

With the increase in 3D printing technology, new methods of fabricating parts can be integrated into the military and emergency rescue teams’ UAV programs. 3D printed UAVs would provide an alternative to the high cost devices used in the military today. With access to a 3D printer, military and rescue personnel would be able to print the platform of a UAV to be assembled when needed. When a UAV becomes damaged during a mission, the team can print a new platform to be used on the next mission. This method cuts back on the amount of equipment a team must transport to the field to support a UAV mission.

With the introduction of 3D printed UAVs into the military and emergency rescue branch, end users will have access to a lower cost device that can be transported easily and modified continuously to conform to the requirements of the mission.

Product Definition

Preliminary Design Brief

The purpose of this project is to design a 3D printed glider that can later be integrated with controls for powered flight. The glider will be printed using low cost plastic and packing tape for the outside surface. The design must accommodate a specific payload capacity in addition to the supporting electronics, power, and guidance for a flight. This design must be simple enough to be printed and assembled in the field using a basic 3D printer.
Expanded Design Brief

The goal of the project is to fabricate a 3D printable glider that can later be integrated with controls for powered flight. Since 3D printing material is heavy, producing a glider is the first step towards a controllable UAV. The design should use a minimal amount of material while maintaining structural strength and safety. The design must not require significant modification to achieve controllable maneuverable controlled powered flight. The glider will be printed using low cost polylactic acid (PLA) material and packing tape for the outside surface, and will be printed using a Makerbot 5th Generation printer. The Makerbot printer allows for our design to be printable on most small printers with a print dimension of 10 X 7.8 X 6 inches. The design must allow for the glider to be assembled in the field using simple methods of connections between parts. The glider must be large enough to carry a payload of 2 to 3 pounds in addition to the supporting electronics, power, and guidance for a maximum flight duration of 30 minutes. The total cost of the glider platform will be under $50 and will be later implemented with controls costing approximately $250. These controls are to be widely available, off-shelf commercial parts.

Chapter 2: Conceptual Design

Morphological Chart

To begin the design of the 3D printable glider, many decisions must be met regarding the construction of the platform. UAVs currently used in the military reach takeoff using various methods. Some UAVs use a runway which requires the vehicle to have wheels, while others require the operator to toss the vehicle in the air. In some cases, the vehicles can be placed vertically on the ground to achieve takeoff as a helicopter would. We must consider these methods of takeoff for our design and choose which would best fit our project’s requirements.

The number of propellers can make a significant impact on the flight characteristics of the UAV. A single propeller would allow for easier assembly, however more propellers would allow for a larger payload and quick and easy takeoff. Although the scope of our project does not involve controlled flight, our glider must account for implementation of the electronics and motors necessary for controlled flight.
Since the 3D printer we will be using has a specific print area, the glider will be printed in several pieces and be assembled in the field. Our design must account for connections of each part whether this involves, epoxy, glue, or snap-in-place parts.

The wing placement will have a significant impact on our design. This will dictate where the payload will be located as well as how the controls will eventually be wired into the glider. The placement of the winds can either be on the top, middle, or bottom of the glider relative to its body.

The options mentioned above a a few, but not all, design considerations we must take while designing our glider. These options are organized into a morphological chart in Figure 1 which can then be used to create combinations of design considerations.

<table>
<thead>
<tr>
<th>Morphological Chart of Solutions Generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Method of Takeoff</td>
</tr>
<tr>
<td>Number of Propellers</td>
</tr>
<tr>
<td>Connection Method</td>
</tr>
<tr>
<td>Wing Placement</td>
</tr>
</tbody>
</table>

Figure 1. Morphological Chart

Using this morphological chart, we were able to come up with 3 combinations of designs we decided would be practical to use for our glider. Some methods previously stated in the morphological chart were not included in the combinations because they were decided to be impractical to include in our design. The platform takeoff method would be too complicated to take off in windy conditions. The four propeller method would be add a significant amount of cost, weight, and complexity to the design. Our group decided to use glue rather than epoxy because glue is cheaper and will have enough strength for our purpose. We also decided that placing a wing through the middle of the glider would give us the most room to make a connection point for the wing frames on the body of the glider. In Figure 2, various combinations of design are stated and will be judged using a weighted decision matrix in the later sections of this chapter. Hand sketched concept sketches of these proposals can be found in Appendix A.
### Figure 2. Possible combinations of designs

<table>
<thead>
<tr>
<th>Features</th>
<th>Design Proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Method of Takeoff</td>
<td>Wheels/Runway</td>
</tr>
<tr>
<td>Number of Propellers</td>
<td>1</td>
</tr>
<tr>
<td>Connection Method</td>
<td>Epoxy</td>
</tr>
<tr>
<td>Wing Placement</td>
<td>Top</td>
</tr>
</tbody>
</table>

### Objective Tree

![Objective Tree](image)

To begin our objective tree we broke the 3D Printer down into three main criteria: Cost, Safety, and Quality. It was determined that Quality was the most important factor due to the ease of assembly and performance being important design criterion. Cost was also important.
due to the need for fast and cheap manufacturing, as well as the need for repair if necessary. Lastly, safety is important for any product. The glider not only needs to be safe during flight and not cause harm due to a crash, but also be safe for the person who is launching the glider.

**Weighted Decision Matrix**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>WF</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>0.135</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>1.08</td>
<td>0.945</td>
<td>0.945</td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>0.27</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>1.62</td>
<td>1.89</td>
<td>2.43</td>
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<tr>
<td>Durability</td>
<td>0.045</td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>0.36</td>
<td>0.225</td>
<td>0.27</td>
</tr>
<tr>
<td>Manuf. Cost</td>
<td>0.28</td>
<td>7</td>
<td>6</td>
<td>9</td>
<td>1.96</td>
<td>1.68</td>
<td>2.52</td>
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<tr>
<td>Repair Cost</td>
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<td>7</td>
<td>5</td>
<td>9</td>
<td>0.84</td>
<td>0.6</td>
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<tr>
<td>Operator Safety</td>
<td>0.075</td>
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<td>6</td>
<td>6</td>
<td>0.6</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Flight Safety</td>
<td>0.075</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>0.525</td>
<td>0.6</td>
<td>0.525</td>
</tr>
</tbody>
</table>

Totals: 6.985 6.39 8.22

Figure 4. Weighted Decision Matrix

The weighted decision matrix compares the proposed designs off the glider across the criteria that was outlined within the objective tree. Each concept design was given a score on a 1-10 scale, for each of the given criteria. These values were multiplied by their weight factor (a value that describes the importance of the given criteria) and summed so that each concept design was given a score. Concept drawing A3 received the highest score, so it was chosen as the best of the three concepts.

**Chapter 3: Embodiment Design**

The first prototype of the aircraft consists of nine unique part designs. The goal of the chosen design was to minimize assembly time, material, and the possibility of damage of parts due to the removal of support material, all while ensuring that each individual part fit within the size constraint of the makerbot printer. The following images show detail drawings of each of the nine parts that were designed. The parts are displayed in Appendix B & C as followed: cockpit,
cockpit cover, tail end, left wing frame, right wing frame, wing extension, side rudder, top rudder, foil segment.

In terms of embodiment principles employed during the design process of the glider, simplicity was kept as the main focus. Because the glider was said to be designed for field work, simplicity of assembly and time of assembly were held at the highest importance. That being said, another embodiment rule that had to be followed throughout the design process is reliability. Satisfying the first embodiment rule could not come at the sacrifice of the second rule, and vice versa. This means that the group also had to design the parts for manufacturability, within the means of the makerbot printer. This includes size constraints, material constraints, and support constraints caused by the nature of the makerbot printer. No single part could be larger than the tray in the printer, which measured at 10” x 8” x 6”. Large parts had to be printed separately, and designed so that they could be joined in the assembly process. Tolerances were created for joining members, and they were chosen to fit snugly as not to alter the physics of the glider. For example, airfoils were only given slight tolerances, as any extra wiggle room between joining materials could cause a pitch in the wing, producing undesired results. Flow of force was emphasized in the design of the glider so that stress concentrations could be reduced accordingly with the finite element analysis that was performed on the solidworks model. In the more fragile areas of the glider, corners were modified to fillets to give a reduction in stress. This was especially true for the left and right wing frames of the glider, which was proven to encounter some of the strongest forces by the finite element analysis.

Chapter 4: Detail Design

Once the embodiment principles were decided, our group used SolidWorks to create the final design of our glider. By referencing real world planes, such as the P-51 Mustang, we were able to create the contour of the glider’s body. Throughout multiple revisions, we reached a point where we were satisfied by the shape of the body. The body was then shelled to a thickness of 0.125 inches. Due to the limited space inside the MakerBot 3D printers, the body was cut in half and incorporated with tabs on each end to assist in aligning the two pieces together. Since our glider will be carrying a payload, a hatch was cut out from the top of the body which would later be secured using zip-ties. The wing frames were then created followed by the rudders and airfoils. Since the shapes of the airfoils are crucial in the aerodynamics of the glider, our group referenced a database of airfoil designs posted by the University of Illinois
Department of Aerospace Engineering to find the best design for our purpose. Each connection point in our design had a tolerance of .005 inches to ensure each part would fit into its designated space. Once the parts were complete, our group sent the files to The University of Akron’s 3D print lab. Once the parts were printed, we began assembling the glider. Since the parts were made on a lower quality MakerBot printer, there was a lot of support material that needed to be removed. Upon removal of the support material, we found that there was not enough clearance for the parts to smoothly fit into the connection therefore more sanding and filing were required of the parts. The parts were then glued together using Gorilla Glue and then wrapped with packaging tape. Once assembled, the glider felt slightly heavier than we imagine and was more robust than we intended it to be. While we waiting for a nice day to test the model, we decided to make revisions to the SolidWorks model based on our observations from the assembly of the glider. We decided to increase the tolerances of the connections to ensure each piece fits together without extra filing and sanding. We also decreased the thickness from 0.125 inches to 0.0625 inches to eliminate unneeded weight. More material was removed from the glider as well to decrease the total weight. The price to print the final glider came out to be $60 including labor and materials from the 3D print lab. Figures 5 and 6 show the final revision of the model in an assembly view and exploded view respectively. Individual part drawings of the old and new design can be found in Appendix B and C respectively.

![Final assembly of glider](image)

Figure 5. Final assembly of glider.
Testing was completed at Infocision Stadium. The glider was thrown from the upper level of the bleachers without any payload. The lack of the payload caused the center of gravity of the glider to be imbalanced. This caused the glider to be tail heavy and tip backwards during flight. The glider crashed after an impact to the left wing. The impact caused the wing to snap off at the joint connecting to the body of the glider. Because of this breakage, we were only able to perform one single test. By using FEA, we can prove that adding a larger cross sectional area to the joint connecting the wing to the body will improve strength and allow for multiple tests with the same glider.

By examining the glider after impact, we noticed that the impact occurred at the midpoint of the wing. We wanted to simulate this exact scenario. In the ANSYS software, we imported our 3D model as step file and applied physical properties of PLA plastic. Then we set fixed constraints on the glider’s body next to the wing joint. Next, we applied a force at the midpoint of the wing. We used forces varying from five to twenty-five pounds just as an estimation. Finally, ANSYS was set to solve for deformation and von-mises stress. These steps were done for the model before the fillet and after the 0.5” fillet was added. The following are the properties we used for PLA plastic.
PLA Plastic Properties:
Young’s Modulus: 3.5 GPa
Poisson Ratio: 3.5

Figures 7 through 10 show examples from the FEA analysis. Figure 7 and figure 8 are screenshots analyzing the old design with 5 pounds of force applied to the midpoint of the wing. Figure 7 shows von-mises stress and figure 8 shows deformation. Figures 9 and 10 are analyzing the new design with the 0.5” fillet. Figure nine shows the von-mises stress and figure 10 shows the deformation in the wing.

Figure 11 and figure 12 are graphs that show a comparison between the two designs varying from 5 pounds to 25 pounds. Based on these graphs, one can notice a decrease in von-mises stress and deformation. By adding a fillet the deformation remained almost constant with the varying force applied.

![Image of ANSYS simulation](image)

Figure 7. Max stress in wing - old design
Figure 8. Max deformation in wing - old design

Figure 9. Max stress in wing - new design
Figure 10. Max deformation in wing - new design

Figure 11. Comparison of max stress of both designs
Figure 12. Comparison of max deformation in both designs

Chapter 5: Discussion

Build

The glider was prototyped using a makerbot brand 3D printer. As previously stated, the makerbot was chosen because it is one of the cheaper and more compact models on the market, making it portable relative to many other options. The shell of the plane (as in all the parts listed in Appendix B & C are comprised of PLA, which is a biodegradable and bioactive thermoplastic that makes up the filament in the makerbot printer. The airfoils, side rudders, and tail rudders are wrapped in standard clear packaging tape. The packaging tape was used as the membrane to provide lift and stability to the glider. It was chosen because it is inexpensive, strong, lightweight, and widely available. Gorilla glue was used to join individual parts of the glider during assembly. It was chosen in relation to the parameters for the glider itself. Among 3D printers it is smaller and easily transported. The issues that were run into with the Makerbot was its inaccuracies and its difficult to work with support material. The first prototype took two days to print in total. The majority of the time was actually printing of the material, however time needed to be taken to prep the print surface, replace the material rolls, and remove the printed parts. The inaccuracies of the print was apparent in the wing base. A connection that needed
to be flat to ensure that the wings were straight as well as strong connection. There were several ridges on the connection surface which were an issue during the build. This caused more manpower to be used to sand the part to ensure an acceptable connection. The removal of the support material took quite a bit of time and work to get each part to its proper design. It took about two hours of work by four builders to remove all support material, sand each connection, and build the glider. The most difficult part of removing support material came inside the front and rear sections of the cockpit. There was an abundance of support material in sections that had little to no access from the front or slits in the sides. Needle nose pliers as well as files were used. There was a fine line between breaking away support material and making sure none of the parts were damaged. The sanding of the connections took the most time in the building stage. We underestimated the amount of time it would take to sand each part to get a proper fit. Lastly, packaging tape was used over the wings to create a lightweight, low cost membrane. The packaging tape added about half an hour of build time for one builder. We learned a lot from the difficulties we ran into with build number one.

Adjustments needed to be made to ensure a smoother build for prototype two. We added tolerances of all connections to ensure that a minimal amount of sanding would be needed. We added more slits in the cockpit to give better access to the support material on the inside. The slits were added to reduce weight as well as the shelling of the cockpit was reduced one sixteenth of an inch. See the Testing section for reasoning behind weight reduction. The improvements that we made caused a reduction in build time down to only one hour. The half hour needed for the packing tape did not change.

Testing

The glider was tested at Infocision Stadium at the University of Akron. The location was chosen for the high elevation with a sloping decline that would have a soft landing on the turf field allowing more tests to be made. The test conditions for our first test was a cold overcast day with light precipitation. There were quite a bit of swirling winds which may have not been ideal for a good flight. The first test was not a success. When released from the throwing motion the glider maintained a good flight path for about 10 feet. Due to a long airfoil and the heaviness of the material in the tail of the aircraft, the glider began to backflip out of control. The glider remained intact so a second test was able to be made. The same result occurred with several backflips being made. Several changes needed to be made for prototype two.
number of slits were made to decrease weight in the back half of the plane. A hole was made in the rear of the plane to decrease the build up of material where all the edges come together to decrease weight as well. Prototype number two has been built but yet to be tested. Testing will be performed next week and adjustments will be made to the model before returning the final design to Discovery Lab Global.

Chapter 6: Conclusions

After the completion of all phases of the design process for the 3D printed glider, it was found that many challenges arise when trying to build a glider out of PLA material. Among the materials used to build modern gliders are carbon fiber and fiberglass. Theses materials are used because they are both strong and lightweight. A closer look at fiberglass reveals that it has a flexural strength anywhere from 16,000 - 32,000 psi (the range is dependant on a number of factors). When analyzing the material used to construct the 3D printed glider, PLA plastic, it was found that its range of flexural strength of 6,950 - 16,000 psi. In terms of flexural strength, PLA plastic is only half that fiberglass. This created a challenge of connecting the tail rudders to the cockpit of the glider. Because the PLA material lacks flexural strength, the tail end part of the aircraft had to be designed so that it was thick enough to resist the forces being applied to the tail rudders during flight. The first test of the glider proved that there was too much weight in the rear of the glider, as the tail end swept underneath of the body. It was concluded that weight had to be shifted to the front of the glider to offset the amount of PLA material that was required to keep the rear of the glider structurally sound.

Not only is the PLA plastic inferior to fiberglass with respect to flexural strength, but it also lacks tensile strength that is offered through traditional glider building materials. The tensile strength of PLA, 8840 - 9500 psi, also offers a range that is only about half as strong as the tensile strength of traditional fiberglass, 9000 to 18000 psi. For this reason, more material was needed to create a glider from PLA. This meant that PLA material was reduced in parts where it isn't essential for structure. Rather than building entire wings from PLA as a shell, airfoils were wrapped in packaging tape. The packaging tape created some minor difficulties in assembly as it became creased and dented in some areas. The tape also overlapped in some areas, taking away from the gliders aerodynamic design. It was concluded that an aircraft specific membrane would be a better option for wing wraps, as it would provide an easier assembly and a smoother
Another conclusion that was made from completing this design is that the makerbot printer does not produce the most efficient glider. A number of issues arose because of complications from the makerbot. Although tolerances were included for mating parts, many parts still required fabricating after manufacturing. That is, parts did not fit together as they were designed because of lack of precision by the makerbot. Some parts came out of the printer deformed, and layers of the filament did not properly fuse. This error could possibly be attributed to improper temperatures of the filament as it left the extrusion nozzle. The finish of the manufactured parts also contributed to imperfection for glider flight. Many parts of the glider had a rough finish which has an effect on the aerodynamic properties of the glider. To combat this, parts could be sanded down to have a smoother finish, but there is a tradeoff with field assembly time. A better 3D printer would manufacture parts with a much smoother finish than what is offered by the makerbot.

Future research and testing will include modifications to the existing glider to increase lift and aerodynamic properties. Of these properties, the wing aspect ratio would be of specific emphasis. The wing aspect ratio involves the wingspan and wing width, and can have effects on the gliders ability to generate lift. This glider was designed with a focus on the final product, which ultimately aims to add propulsion and controls to the glider. The wing aspect ratio of the prototype provides that the glider has maneuverability as well as lift. Given more time, different wing aspect ratios would be researched and analyze in order to optimize desired lift and maneuverability for the glider.

References


Appendix A

Concept Sketches

Concept 1

Figure A1
Concept 2

Figure A2
Concept 3

Figure A3
Appendix B - Prototype 1
Appendix C - Prototype 2
Appendix D

Prototype Image