Barker Bird Animatronic Senior Project Report

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Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.
Abstract
This document describes how our F71 Senior Design Project team developed a 3D printed, electronic bird that mimics Disneyland’s first animatronic, the Barker Bird. An animatronic is a mechanical puppet that replicates real life movement with robotic parts. Disney’s Barker Bird is a well-known animatronic that replicates a talking macaw with multiple moving systems. The final prototype completed by our team serves as a teaching tool for CAPED (Cal Poly Amusement Park Engineers and Designers) club members that are interested in the field of animated robots. Throughout the preliminary stages of the project, we researched background information about animatronics and determined the needs of our stakeholders and sponsors, Kai Quizon and CAPED. We used this information to design a model of the bird, which then went through several iterations before arriving to the current, final design of the project. We found out how to correctly size and orient parts when 3D printing to compensate for shrinkage and maximize strength available. We also determined the minimum amount of material required to provide enough strength at the joints, and we have learned about techniques for reducing friction at joints and its impact on the motor size required. Additionally, we created a custom PCB board which integrated seven motors and a speaker with an Arduino board so it can operate separately from a computer. The successes and failures we experienced in this project helped lead us to this final project that can accurately instruct future students how to make their own working animatronic. Students will also be able to learn from our mistakes and gain insight on how they how customize this project to their own specifications.
1. Introduction

The objective of this project is to create an autonomous, animatronic bird from 3D printed and easily purchased parts that will interact with people nearby and attract members to the CAPED club. In addition to providing life-like motion in a portable design, this project will be a well-documented teaching tool to assist future students to understand the engineering required to make a functioning animatronic from easily accessible materials.

In this document, we detail the design, manufacturing, and verification steps that we have taken to create the final product we sent to our sponsors at CAPED. Specifically, this document is separated into four distinct parts:

1. Scope of Work (SOW)
2. Preliminary Design Review (PDR)
3. Critical Design Review (CDR)

Each report was prepared separately during different times throughout the year to document different aspects of the project development process. The first document (SOW) focuses on accurately describing the purpose of our project and is where we discuss what functions the bird will have. In the second report (PDR), we documented our selected design directive and outline how we planned for each function of the bird to operate. With the third report (CDR), we had a fully designed CAD model of the bird along with physical models of various linkages used for prototyping. We outlined our completion of the first design process along with our plans for manufacturing the rest of the bird and testing the manufactured components. This is followed by the fourth report (FDR), which discusses the manufacturing that has occurred and the results gained from testing the project. Within each report you will find various chapters describing design and manufacturing processes, along with appendices containing important documents related to the project development and management.

This complete senior project report serves to summarize our work during the last three quarters and to present a holistic understanding of our project to the CAPED club. This document can be referenced by future students who are building their own Barker Bird so they can learn from the successes and failures we have had designing with 3D printed parts and Arduino boards.
Barker Bird Animatronic Project Scope of Work

October 18, 2021

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Abstract
This document describes how the F71 Senior Design Project team will begin development of a 3D printed, electronic bird that will mimic Disneyland’s first animatronic, the Barker Bird. An animatronic is a mechanical puppet that replicates real life movement with robotic parts. Disney’s Barker Bird is a well known animatronic that replicates a talking Macaw with multiple moving systems.

The final prototype will serve as a teaching tool to CAPEd (Cal Poly Amusement Park Engineers and Designers) club members that are interested in the field of animated robots. Throughout the preliminary stages of the project, the team researched background about animatronics and looked at similar products. Additionally, the wants and needs of stakeholders and sponsors, Kai and CAPEd, were determined. The SOW outlines the group’s objectives, project scope, deadlines, and the specifications outlined by the sponsors.
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Chapter 1: Introduction

Animatronics such as Disney’s Barker Bird, Shaman of Songs (from Avatar), Rosita (talking Cockatoo) are staples of the themed entertainment industry that have been used to delight guests at theme parks all over the world. Traditionally, animatronics have been too expensive to be built and used by hobbyists. Senior Project Team F71 will create an autonomous, affordable, replicable animatronic that resembles the “Barker Bird” that formerly resided outside of Disneyland’s Enchanted Tiki Room. This animatronic is intended to attract members to an interdisciplinary club on campus called **CAPED** (Cal Poly Amusement Park Engineers and Designers), that consists of students interested in all aspects of the themed entertainment industry. This product requires system integration of multiple subsystems consisting of servo motors, linkage designs, and microcontroller implementation to make the bird mimic real-life motion. Additionally, the product will serve as a teaching tool for members of the club with a desire to learn about and develop animatronic robots.

This team consists of three mechanical engineering students concentrating in mechatronics, Ishan Jandaur, Marcus Monroe, and Nolan Clapp, who are accompanied by a computer engineering student, Jonathan Ogden. Each team member has unique experience that they will bring to the team. These contributions include machining, finite element analysis, 3D printing, programming, and a collective passion for the themed entertainment industry. The sponsors for this project are Kai Quizon, Melinda Keller, and the members of the CAPED Club. This report will document the background research, project objectives, and future design processes used to develop the “Barker Bird” animatronic.
Chapter 2: Background

2.1 Stake Holder Research
To determine what the objectives of the final product are, the team met with Kai Quizon, who is the sponsor for the club and an important member of the CAPED club. The budget for this project is $500 and consists of both development and the final product (skeleton and parts). The product should be the size of a bird and able to be transported easily by at most two people. The skeleton parts should be 3D printed, preferably by FDM and via printers that other Cal Poly mechanical engineering students have access to. The bird is going to be showcased at the WOW Club showcase, Open House Weekend, and various club events to attract the attention of potential members. Meetings with Kai will start off being every other week and can be more frequent if deemed necessary.

The final deliverable should include a working skeleton with moving parts, open-source code, documentation, and prepared kits with off-the-shelf parts. There are many aspects of the final prototype that is up to interpretation and discretion. These includes, but are not limited to: stand geometry, motion/voice capabilities, and power delivery.

Future stakeholder research will include interviews and surveys with the younger CAPED club members that would potentially be using the final prototype/kits.

2.2 Existing Products
The Barker Bird at Disneyland was among the first animatronics created according to Fanning (2018). This animatronic, seen in Figure 1, is called an Audio-Animatronic because it was preprogramed to speak and move as part of a show according to the trademark by Disney. The mechanical motion of the bird is supplied by a complex system of hydraulics according to Fickley-Baker (2011). A replica of the original Barker Bird is currently residing at the Walt Disney Family Museum in San Francisco according to Wu (2020).

![Figure 1: Original Barker Bird outside of Disney's The Enchanted Tiki Room, 1963](image-url)
The Barker Bird’s capabilities include:

- Synchronized jaw movement with audio
- Pumping of chest to simulate breathing
- Movement of head in two degrees of rotation
- Pivoting at the hips
- Rotation at the base

The original Barker Bird, Juan, used digital controls to control the pneumatics. The design was driven by air pressure, which limited the animation movements to either on or off. Therefore, it looked less realistic than animatronics implemented presently.

Disneyland has recently replaced Juan, the bird the team is modeling, with a newer Barker Bird animatronic named Rosita. Rosita, seen in Figure 2, has all the capabilities and movements of Juan except her movements are less robotic and her jaw moves in perfect coordination with her speech and whistling. Rosita is seen preforming outside of the Tropical Hideaway seen in the link in the caption of the picture.

![Figure 2: Rosita, the Replacement to the Original Barker Bird](image)
The Barker Bird represents some of the first animatronics ever made at a theme park, and since then the technology has continued to evolve. In the ride Na'vi River Journey at Disney’s Animal Kingdom there is an animatronic called the Shaman of Songs. This state-of-the-art animatronic feature hyper-realistic, life-like movement seen in Figure 3, is reported to cost 10 million dollars which is a common price for high-end animatronics, according to a Theme Park Insider article written by R. Niles. This high price tag demonstrates the inaccessibility to animatronics for hobbyists.

![Figure 3: Shaman of Songs, Disney's Animal Kingdom (Pandora) state of the art animatronic technology](image)

A project is a similar scope to this project would be a 3D printed robotic spider made by Leung, seen in Figure 4, is designed so that it can be easy manufactured and cost around $100 dollars. This spider uses eight SG90 servo, is remote controlled using an app, and the electronics are LinkIt 7697 with Robot Shield and a built-in battery.

![Figure 4: 3D printed animatronic spider, similar to the manufacturing process that the team will be using](image)
2.3 Motion Sensing/Motor Implementation
“Mechanical Design and Control Calibration for an Interactive Animatronic System” from the ASME Digital Collection describes a control system and assembly made by Brian Burns and Biswanath Samanta (2015) from Georgia Southern University. They developed a dragon animatronic that interacted with human motion/response. By using a depth camera similar to the one developed for the Xbox Kinect, they were able to develop an autonomous animatronic system that interacted with its environment. This technology can be applied to the team’s design to implement motion detection from human interaction.

Steve Koci from Servo Magazine (2015) describes his experience and expertise building animatronics. In his article, “Animatronics for the Do-It-Yourselfer,” he describes the components he used to develop his animatronic parrot, named Bandit. He used four HiTec 425BB servos, to move the jaws, wings, body, and neck of the robot. He also details how he implemented the servos in his design to obtain certain movements. Lastly, he made his code open source which is appended to the end of his article. This code would be used as a baseline to start programming different subsystems.

2.4 Form Factor Research
The species of parrot the final product will be modeled after a macaw. An article on the osteology of macaws written by S. J. Olsen (1967) will be useful in making sure that the final product will share many characteristics of an actual macaw’s bone structure. This article and mimicking the macaw’s skeleton will help the team to create linkage design and kinematics of the final product to produce a movement that is truly life-like. Joints of the macaw skeleton will be replaced by equivalent bearing and bushing systems, and the muscular system will be replaced with mechanical linkages and electronics to produce the desired movement.

In addition to modeling the general structure based on the anatomy of a macaw, an article on the design, modeling and manufacturing of wing structure written by Seung Wan Ryu, Jong Gu Lee, Hyon Jin Kim (2020), will help the team in designing proper linkages and gearing to develop correct motion in the wings on the animatronic bird. This article also contains helpful information in the mathematical modeling of the bird wings as a four-bar mechanism, which will be helpful in creating a mathematical simulation of the bird wings flapping.

2.5 Standards
National and international safety standards create requirements for electrical products to ensure safety. For designing the animatronic Barker bird, robotics codes such as UL 1740 in addition to amusement ride and device manufacturing codes in ASTM (Committee F24) are to be referenced. All components will be IEEE and UL compliant which will add a degree of safety past the legally mandated NFPA 70E codes. Following these standards is not expected to be an issue as most processors, motors, and small electrical components come with these forms of certification. The main safety, the team’s responsibility will be properly insulating all wire connections from any flammable costumes the CAPED may dress the bird in.
2.6 Applicable Technology
The skeleton will be made from 3D printed parts from the print shops available on campus. The most readily available printers produce models with PLA filament and small parts are usually completed within a few hours. PLA components are known for their low cost, but also lack in strength and texture when compared to other manufacturing methods. Since there are no outside forces on the moving components and the skeleton parts will be covered by a costume, there are not limiting tolerances relating to strength or surface finish. A major post-printing alteration that will be made to the printed components is cleaning out acceptors for bearings and pins. Rough connection points will create excess force on both the motors and the 3D printed structures, so testing will be required to ensure the PLA filament can be sanded down to an adequate hinge type.

Electric motors, servos, and microcontrollers that are abundant in the modern market are well designed for this animatronic project. One of the first project design decisions will be to choose which type of microcontroller to run the Barker bird from. Products such as Arduino®, Maestro®, Raspberry Pi®, and Nucleo® are considered by the team for their easy accessibility and known compatibility with common software languages. The selection of which products to use will be made from balancing the cost, performance, and abundance of open-source code. The desired performance for this project is the ability to reliably run the electric motors and servos at varying speeds to imitate life like motion.

Additional electronics can assist in more complicated forms of user input and output. One of the main functions of a barker bird is giving stories and jokes to the spectators, or in its most simple form, talking. In addition to a hinged jaw connected to a servo, the bird will need a speaker to relay its narrative, and a way to connect jaw motion to audio output in a realistic fashion. Meter audio level indicators take input from an audio jack and converts it to an output based on the sound intensity. This is accomplished using the same software that produces the dynamic sound graphs on common music streaming platforms. Meter audio level indicators are affordable, accessible, and conducive with program development making them a desirable solution to create realistic and coordinated talking mechanisms.

There are a multitude of patents that describe different ways systems are implemented to animate robots. Disney Enterprises Inc. filed a patent in 2015 that describes the use of a system to create a 3D mesh of the character before determining range of motion. From the desired ranges of motion, poses are identified, and the designers can create a system of actuators to simulate poses. The team hopes to use the ideas from this patent to model a linkage that will serve a similar purpose. With the help of a textbook, sufficient linkage design and testing should help obtain movements we desire our robot to have. Another patent from Pixar, Patent US8368700B1, details a software model that has a similar purpose. Pixar developed a force-based software model for the animatronic and makes specifications for the animatronic based on the driving signals from the model.

There are several patents that give instruction on how to make our animatronic have speech. A patent from Dreamation Inc. (Patent US7439699B1), outlines the use of a storage device with pre-programmed audio to make a robot talk. This system uses a microcontroller to create synchronized sound and movement. Another patent from Jeremiah William Balik, describes using a speaker
inside robotic toys, in conjunction with an app, to store sounds, sayings, and music in the toys. Use of both patents would help the team develop methods of giving our animatronic bird the ability to speak. Additionally, the product’s goal is to have the bird’s beak move synchronously with its speech.
Chapter 3: Project Scope

3.1 Boundary Sketch

The boundary sketch in Figure 5 details what the team is responsible for in design. Encapsulated in the boundary is the bird’s design, open-source code, and microcontroller configuration. User interaction with the bird cannot be controlled; thus, they are outside the boundary of what the team can control. Human interaction in the boundary sketch is shown with a person waving to the robot and having the robot speak and move due to the interaction. Additionally, the team will be writing code that will be included with the final deliverable, but the goal is to have CAPED club members be able to alter the code. Altering of the code is not controlled and is shown with a person outside the boundary sketch that is typing on a keyboard connected to a computer monitor. Lastly, the team is responsible for picking materials for the product and assembling a kit that other people can use alongside the code to assemble their animatronic.
Table 1 below demonstrates the wants and needs of the customer, which fall inside the boundary on our diagram sketch. The wants and needs listed in the table will be the primary focus of the project.

<table>
<thead>
<tr>
<th>Wants</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pivot at head and base</td>
<td>• Easily Manufactured/ Majority of parts are 3D printed</td>
</tr>
<tr>
<td>• Sense motion</td>
<td>• Electrically powered</td>
</tr>
<tr>
<td>• Intuitive user interface</td>
<td>• Commercially available parts</td>
</tr>
<tr>
<td>• Realistic/Bird-like movement</td>
<td>• Open-source code</td>
</tr>
<tr>
<td>• Plug into an outlet</td>
<td>• Teaching documentation/media</td>
</tr>
<tr>
<td>• Minimize machined parts</td>
<td>• Realistic Size</td>
</tr>
<tr>
<td>• Low Cost</td>
<td></td>
</tr>
<tr>
<td>• Scalable</td>
<td></td>
</tr>
<tr>
<td>• Easily Adaptable</td>
<td></td>
</tr>
<tr>
<td>• Easily Transported</td>
<td></td>
</tr>
</tbody>
</table>

### 3.2 Functional Decomposition

This project is fundamentally about the promotion of animatronics and can be divided into two subcategories, its utility as a teaching tool, and its ability to attract members to the CAPED club; this break down is seen in the functional decomposition model in Appendix A.

As a teaching tool, it should be easily programmable by a variety of students with different technical backgrounds. In addition, the processes for manufacturing will be well documented and accessible. This means that it will be able to be constructed with a mechanical engineering student with the help of an adviser. To this end it will be possible to replicate the bird using off-the-shelf and 3D-printed parts at minimal cost.

To attract new CAPED member the Barker bird shall have the following attributes. The team’s Barker bird will be able to move in a similar manner to the Barker Bird found at Disneyland. This will include moving the beak in time with sound, 2 degrees of rotation in the head, rotating base, and pivoting at the hip. In addition, the project will include blinking eyes, and wings that open and extend. The bird will also have multiple sensory inputs. These are motion sensing, speech recognition, and registering button presses. Finally, the bird will be able to talk using built in speakers. This will allow the bird to put on an impressive show and attract interested parties.

The sponsor expects a fully functioning skeleton that is 3D printed and electrically powered. As a teaching tool, the final deliverable should include open-source code that is easy to read and manipulate for users. A bill of materials detailing fully assembled animatronic with the correct parts and number of parts is necessary for users to be able to build the animatronic with ease. A method of teaching through video demonstration/tutorial or written guides is necessary to help users with the building process.
Chapter 4: Objectives

4.1 Problem Statement
The CAPED Club needs a replicable design for an animatronic bird that will actively engage with club members as well as generate excitement in other students, parents, and faculty that pass by at the club showcase and welcome night. They want the design process to be well documented so that the animatronic bird can be used as a teaching tool, in order to teach animatronic design and function to people who are interested in theme park design and animatronic functionality.

4.2 QFD Process
To ensure the correct problem is being solved, and meeting the desired specifications, a Quality Function Deployment (QFD) was performed. In this process, potential customers were identified in addition to the wants and needs that are important to the sponsor and other customers. These wants and needs were then weighted based on their importance to each customer. Then, percentage related to how important each want and need was to the design was calculated. A list of engineering specifications were then decided (Table 2) and the correlation between these specifications and the customer wants and needs was identified. Competitor products, such as the actual Disney Barker Bird, and consumer grade robotics kit were included, to see how the final product would match up against these. Lastly the engineering specifications were compared against each other to show interactions between the specifications. The full copy of the House of Quality is in Appendix B.

The results of the QFD showed that the most important customer wants and needs are:

(11%) Life-like movement
(9%) The ability to be used as a teaching tool
(9%) Similarity to Disney’s Barker Bird
(9%) The ability to be easily manufactured

In addition, the QFD shows how to ensure the final product will be desirable in comparison to the competition. The most important engineering specifications to compare with other products are:

(17%) Keeping cost as low as possible
(14%) Minimizing the number of parts
(11%) Ensuring code is easy to follow and reuse
Table 2. Engineering Specification Table

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Similarity to Real Birds</td>
<td>Pass/Fail, Survey</td>
<td>NA</td>
<td>H</td>
<td>S, I, T</td>
</tr>
<tr>
<td>2</td>
<td>Replicated Disney’s Barker Bird</td>
<td>Pass/Fail</td>
<td>Minimum</td>
<td>L</td>
<td>S, I, T</td>
</tr>
<tr>
<td>3</td>
<td>Cost</td>
<td>Under $150</td>
<td>Maximum</td>
<td>H</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>Student Interest</td>
<td>Pass/Fail</td>
<td>NA</td>
<td>L</td>
<td>S, I</td>
</tr>
<tr>
<td>5</td>
<td>Ability to Follow Design Process</td>
<td>Survey/Case Study</td>
<td>Minimum</td>
<td>H</td>
<td>S, T</td>
</tr>
<tr>
<td>6</td>
<td>Volume</td>
<td>7x7x35 Inches</td>
<td>±5in³</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>7</td>
<td>Weight</td>
<td>50lbs</td>
<td>Maximum</td>
<td>L</td>
<td>I, T</td>
</tr>
<tr>
<td>8</td>
<td>Number of Parts</td>
<td>100</td>
<td>Maximum</td>
<td>M</td>
<td>I</td>
</tr>
<tr>
<td>9</td>
<td>Aesthetic</td>
<td>Survey</td>
<td>NA</td>
<td>M</td>
<td>S, I</td>
</tr>
<tr>
<td>10</td>
<td>Reusable Code</td>
<td>Survey</td>
<td>Minimum</td>
<td>H</td>
<td>S, I, T</td>
</tr>
<tr>
<td>11</td>
<td>Easy to Manipulate CAD</td>
<td>Survey</td>
<td>Minimum</td>
<td>H</td>
<td>I</td>
</tr>
</tbody>
</table>

[1] Risk Level: High (H), Medium (M), Low (L)

[2] Compliance Method: Analysis (A), Survey (S), Inspection (I), Test (T)

4.3 Description of Specifications

1. Similarity to Real Birds

This Specification will test how similar the final product moves like a real bird. This specification will be tested by inspecting the final product, comparing its movements to videos of macaws, and preforming a customer survey. This is a high-risk goal specification because there will have to be significant testing and tweaking of the final product.

2. Replicated Disney’s Barker Bird

This specification is the benchmark for the design. The original Disney Barker Bird shows the minimum requirements for the final product. The final product will likely have some movements that are more advanced than that of the original bird.

3. Cost

The cost specification should be minimized, with the final product being no more than $150. A budget spreadsheet will be used to ensure the maximum budget is not exceeded, and that the cost of the final product does not exceed $150. This is a high-risk specification because the budget is relatively tight when compared to existing animatronics.
4. Student Interest

This specification is crucial to the final product. The final product should generate more club involvement. The level of interest will be gauged by sending out a survey to a variety of people, many of whom have different backgrounds, to verify that the final product is interesting, and will generate more club involvement. This is a high-risk specification because although the final product will likely be interesting to mechanical engineers, it is important that the product is also interesting to other students.

5. Ability to Follow Design Process

This specification is important because a large part of the final deliverable is the ability to use the final product as a teaching tool for CAPED club members to learn more about animatronic design. This is a high-risk specification because it is a possibility that the final product will become very complex, making it difficult to follow; minimizing complexity will allow the final product to be effectively used as a teaching tool.

6. Volume

This specification is a generalization for the overall size of the final product. The final product is intended to be roughly the size of a macaw. This size does not necessarily include the base that the animatronic rests on, where many of the electronics are intended to go.

7. Weight

This is a low-risk specification because the size and material of the final product will lead to a weight that is much below the maximum 50lbs. This will be tested by weighing the final product.

8. Number of Parts

This specification will be important to the complexity of the final product. Minimizing the number of parts will allow for the final product to be better utilized as a teaching tool. This is a medium-risk specification because the complex movements that are intended for the final product will require some significant design considerations to simplify into the fewest number of parts possible. The final product is estimated to have less than 100 parts total, this goal will be kept track of by keeping an up-to-date bill of materials as parts are used.

9. Aesthetic

This specification describes how the animatronic skeleton and linkages work. A survey will be sent out to ensure potential customers thing that the final product is aesthetically pleasing. This is a medium risk goal because it will take additional planning to ensure that the linkage design can be altered to look like the actual bones of a macaw.

10. Reusable Code

This specification is important because the final product will be used as a teaching tool. One desire that potential customers had was that the code be written in such a way that
students with little coding experience would be able to change the lines that the bird speaks, and the order of the actions it preforms. This is a high-risk specification because it will be very easy to overcomplicate the code. To be effectively used as a teaching tool, the code must be well documented and easy to reuse to change the bird’s actions. This specification will be verified by preforming a case study where the code is presented to CAPED members who are interested in animatronics, and the intuitiveness of the code is assessed.

11. Easy to Manipulate CAD

Accessible CAD design is important to the final product because this animatronic bird is meant to be adaptable and expandable. If the CAD file has many different parametric dimensions, the CAPED members should be able to easily scale the animatronic up and down to create animatronic birds of many different sizes with relative ease. Similar to the reusable code, the CAD will be presented to CAPED members to alter, to see if they can produce a similar product that is a different size. This is a high-risk goal because the CAD dimensions may not necessarily relate to each other in an intuitive way.
Chapter 5: Project Management

5.1 Design Process
In the future, this project will include preliminary prototyping, concept CAD design, 3D printed concept prototype, a final CAD design, and a final prototype. The team plans on utilizing popsicle sticks, string, and hot glue to complete our preliminary prototype. In addition, the team will use GrabCad® to store all CAD models in SolidWorks® models that are created in the design process. The concept and final prototype will both be 3D printed, although the exact material is in the analysis process. The likely material will be PLA, PETG, or ABS, where the material properties and print quality will be weighed to determine the optimal material. The final prototype will also utilize tools such as electrically actuated parts (servo and other motors) and linkage design to achieve the desired movement.

5.2 Gantt Chart Development
The Gantt chart is an incredibly helpful tool used to help groups plan long term projects, and is a critical tool used for the modular barker bird team. Located in Appendix C the chart shows the project flow, important dependencies, and deadlines required to keep the group from falling behind. Team members volunteered to hold responsibility for certain tasks based on their strengths, this accountability for each task helps prevent assignments from missing their deadline.

After laying out the Gantt chart, it was surprising to see how soon electronic equipment will need to be selected and ordered. After laying out a basic structural design for the bird skeleton, purchasing the appropriate components will be the top priority.

5.3 Key Deliverables

<table>
<thead>
<tr>
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5.4 Next Steps
The next steps in terms of the deliverables will be coming up with preliminary design and CAD models to present in the PDR report. Following that, structural CAD models and prototypes will be created for presentation in the CDR. Lastly, the final model and prototype will be finished for visual presentation in the senior project expo, and full presentation in the FDR. The dates and description of these next steps is outlined in Table 3 above.
Conclusion
Developing an animated robot is an expensive task that requires significant time and money. The F71 Senior Design Project team will be developing an animatronic macaw that mimics the first animatronic that was developed by Disney. Additionally, this robot will attract members to the CAPED club at Cal Poly and teach others how to make animatronics. The final deliverable includes a functioning robot, a method to teach others, and a final assembly parts list. The background research has given us confidence that the project is capable of being fulfilled to the sponsor’s specifications. Furthermore, careful planning and project management allows the team to have quantifiable goals. The team strives to use the details of this document to satisfy the sponsor’s needs. Although researching will continue throughout this process, the next deliverable will be a concept prototype and CAD models of the final product.
References


YouTube, Laughingplace, 19 Dec. 2018, youtu.be/6iQ8W0Qt4Pc.
Appendices

Appendix A: Functional Decomposition

Diagram: Functional Decomposition

- Attract Members
  - Showcase Bird
  - Attract text

- Teach Animatronics
  - Early Programmed
  - Document Processor
  - Train Empty

- Sense Input
  - Detect Motion
  - Voice Recognition
  - Detect Button Press

- Maneuver Sound

- Move Redirectionally
  - Spin Eyes
  - Move Head
  - Move Neck
  - Open Wings
  - Extend Wings
  - Fist Flip
  - Tilt Ears
Appendix B: House Of Quality (QFD)

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Barker Bird Animatronic Project Preliminary Design

Review

November 12, 2021

Presented By Team F71:

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CAPED (Cal Poly Amusement Park Engineers and Designers) Club

Lauren Cooper, Senior Project Advisor
Abstract
This document describes how our F71 Senior Design Project team will begin development of a 3D printed, electronic bird that will mimic Disneyland’s first animatronic, the Barker Bird. An animatronic is a mechanical puppet that replicates real life movement with robotic parts. Disney’s Barker Bird is a well-known animatronic that replicates a talking macaw with multiple moving systems.

The final prototype will serve as a teaching tool to CAPEd (Cal Poly Amusement Park Engineers and Designers) club members that are interested in the field of animated robots. Throughout the preliminary stages of the project, we researched background about animatronics and looked at similar products. Additionally, the wants and needs of stakeholders and sponsors, Kai and CAPEd, were determined. The Scope of Work outlined our group’s objectives, project scope, deadlines, and the specifications outlined by the sponsors. This preliminary design review focuses on our team’s design directives, initial ideation models, and project management strategy.
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1. Introduction

The objective of this project is to create an autonomous animatronic bird from 3D printed and easily purchased parts that will interact with people nearby and attract members to the CAPED club. In addition to providing life-like motion in a portable design, this project will be a well-documented teaching tool to assist future students to understand engineering required to make a functioning animatronic from accessible materials.

In this document, we show the timeline that we will follow to design, manufacture, and test various functions of the robotic bird to ensure timely project completion. We will also show our project management plan, which organizes functions and components into subsystems which will be managed by a team member. Subsystems include the eight different functions, program development, costume integration, and wiring. This organization is necessary for managing the seven distinct types of movements requiring nine different motors and actuators. These functions must all move in unison, and the physical components required must fit within our 3D printed structure without collisions. Updates since our scope of work includes narrowing the number of functions we plan to include with the bird, establishing member responsibilities for certain subsystems, and further establishing the timeline for completing our work. In this document, our preliminary design review, we focus primarily on linkage design and establishing interaction with motors. Packaging all functions into the compact macaw body will be focused on during the next design review, after the basic functions and project organization have been described in this document.
2. Concept Development

The concept ideation process began with a functional decomposition of the Baker Bird to determine the necessary movements. From these movements, we identified the corresponding subsystems, and created several ideation prototypes. We used Pugh matrices to determine out best ideas to move forward with. The system level design was then evaluated with a weighted decision matrix that compared the top subsystems ideas from each Pugh matrix.

2.1 Functional Decomposition
As seen in the Functional Decomposition Diagram (Appendix A) our barker bird will be able to move in a similar manner to the Barker Bird found at Disneyland. This will include moving the beak synchronously with audio output from speaker, 2 degrees of rotation in the head, rotating base, and pivoting at the hip. Additionally, the project will include blinking eyes along with wings that open and extend. Each of the eight functions was then assigned as a subsystem.

2.2 Ideation Prototypes
To begin the ideation prototype process, a brainstorm session was organized. This session was structured such that each subsystem was highlighted, and each member of the team would give their ideas on how that subsystem could be designed. Once this brainstorming session was complete, each member of the team made several quick prototypes of their favorite ideas generated from the brainstorming session. A few of the ideation prototypes are described below.

The favorite for the shrugging mechanism involved a rotating wheel linked with two rods that cause the wings of the bird to rise as seen in Figure 1. This would allow wings to flap up and down with a single servo motor.

Figure 1: Shrug Ideation Model shown in the resting position (left) and shrugged position (right)
Our wing extension prototype involved a linkage that could extend a 3-section wing from a collapsed state to a fully extended state using a pinching force from the end of the structure. These would allow a complex motion from a single point of force as seen in Figure 2. The rest can be found in the Appendix D.

![Figure 2: Wing Extension Ideation Model in the retracted position (left) and the fully extended position (right)](image)

### 2.3 Pugh Matrices
To determine what design generated from the ideation processes would be used in the concept model Pugh matrices were created. Each Pugh matrix was assigned a datum, the model that was assumed to be the best, and several other models that would be compared to that datum. Then on another axis the design specifications from the quality function deployment (QFD) were listed. Each model was evaluated against the datum for each of these criteria. If the system was deemed to be the same as the datum it would be marked with an “S”, if better it would be marked with a “+”, and finally if worse it would be Assigned a “-”. Then each “S”, “+”, and “-” was scored “S” being 0, “+” being 1 and “-” being negative 1. This allowed us to find the two best system models. These Pugh matrices can be found in Appendix E.

### 2.4 Morphological Matrix
Once the two best subsystems were found using the Pugh matrix. They were added to a morphologic matrix shown in Appendix B. This morphological matrix is table with each level being a list of the top subsystem designs. Then several system level designs were created by picking a one subsystem form each category starting from the top of the table being careful to choose to make sure that no two complete system level designs are the same. This was done so that there were 5 different system level designs to compare against each other. Our team felt that system one was the best combination for our design. however, we worked to keep this matrix as unbiased as possible. Additionally, we included system 3 which was the opposite selections from our favored system 1.

### 2.5 Weighted Decision Matrix
With the five system level designs generated from the morphological matrix a weighted decision matrix was created to compare them. This Weighted Decision Matrix is used to score system level designs and then compare the results. The weights for the Weighted Decision Matrix were determined from a pairwise comparison of the system specifications found in the QFD. These processes confirmed our early suspicion that System One was the ideal system. Weighted Decision Matrix and pairwise comparison can be found in Appendix C.
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3. Concept Design

3.1 Selected Design

Our selected design aims to fulfill our four primary functions of head/neck rotation, base rotation, wing opening/closing, and beak opening/closing.

Head/Neck Rotation

We decided to use two servo motors, each capable of rotation in a specific plane. One of the servo motors will sit at the neck so that the head will rotate. This motor will rotate in the “z” axis. This servo motor will be attached to another that rotates to allow the head to tilt up and down. This mechanism is shown below in Figure 3.

![Figure 3: Concept design of 2 DOF neck rotation](image)

Base Rotation

We will use a servo motor in conjunction with a wheel and Lazy Susan mechanism. The servo motor will be located to the side of the Lazy Susan and will have a wheel attached to it. The Lazy Susan mechanism (Figure 4) will be sandwiched between two circular plates. This wheel will be in contact with the top of Lazy Susan, which will be a plate that can rotate. The rotation of the wheel will cause the free top piece of the Lazy Susan to rotate. Another plate will be on the bottom and will be fixed.
The base prototype is in the shape of a T-perch stand. We created the prototype using ¾” plywood, a ¾” dowel, lazy Susan bearing, and wood screws is shown below in Figure 5.

Opening/Closing Wings
The opening and closing of the wings will be done with pinching of linkages. Attaching the linkages to a servo motor will allow rotational motion to be translated to linear motion. The rotational motion will cause the pinching of our linkage design, which will cause the wings to open like a birds’. The wing mechanism is shown below in Figure 6.
Figure 6: Concept design of wing extension linkages
Opening/Closing Beak
The beak needs to open and close to mimic the speech of a real-life bird. We will be using a servo motor with a linkage to create this hinging motion. The top beak of the bird is stationary, while the bottom beak will be moved up and down. The servo motor will be attached to a linkage that can move up and down. This linkage will be attached to another linkage, which is attached to the bottom jaw. The hinging point for the lower beak is determined to make it as realistic as possible (Figure 7).

![Figure 7: Beak movement concept design](image)

3.3 Concept Prototype
Our concept prototype consists of four CAD animations and a physical foam model. Each of the CAD animations are meant to show the motion described previously in section 3.1. They are shown below in Figures 9-12.

![Figure 8: Physical Foam Model](image)

Additionally, a foam model was made to depict the size of the bird and envision how our parts will fit inside the robot. The foam model is attached to a Lazy Susan to demonstrate that spinning of the base was achieved.
3.4 Geometry, Materials, Manufacturing Processes
A macaw has various contours and shapes on its body and thus is a challenge to design. Preliminary steps included importing pictures of the macaw into SolidWorks as a canvas to model from. We are using surface modeling techniques with loft features to model the complex curves. All modeling of geometry and shape is being done in SolidWorks.

A requirement of our project is that all parts are 3-D printed for others to have easy access to the materials. As a result, we are using PLA material with a FDM printer, both of which are available on campus. Our rapid prototyping will be done with Nolan’s personal 3D printer, so that we are not limited by other senior projects that require 3D printing.

Based on our primary functions and system-level design, we need five servo motors, but we are assuming we will need more as the design process continues and we start building. Apart from 3D printing supplies and servo motors, there are more items we intend to use:

- Speaker
- Motion Sensors
- Metal Pins
- Brackets
- Lazy Susan(s)
- Wood
- Microcontroller
- Power Supply

3.5 Concepts in Progress
Blinking, power supply, microcontroller

Two main aspects of the robot that have not been determined are how we are going to power the robot and what microcontroller is going to be used. There are a variety of microcontrollers we can use which include Nucleo® STM32s, Arduino®, and Pololu Maestro®. Currently, we expect our robot to be plugged in to supply power but will also consider using a battery.

To make the bird more life-like, we want to create a blinking mechanism for the eyes. We can use a mechanism like the beak opening motion, using a servo motor and linkages. Additionally, we are considering using LED screens for the eyes that we can program to blink at random times.
4. Concept Justification

This system model will allow us to verify that the most important functions of our final prototype will work as we intend. The individual subsystems will be justified through judgement, comparison to existing products, preliminary analyses, and tests.

4.1 Barker Bird Base
We determined the base shown in the concept design section of this document to be the optimal design primarily through judgement. We looked at several possibilities, shown with a Pugh matrix in Appendix E and determined that this base prototype would adequately demonstrate the motion of our final model and allow for ample space for the electronics we want to move out of the torso of the bird. Our preliminary design was to have a motor in the middle of a Lazy Susan to rotate directly. However, we decided against it since a motor on the side will allow for more power transmission. Additionally, a motor connected to the dowel the bird is spinning on will cause a structural force acting axially along the motor. Another design we considered was in the shape of a hanging, open bird cage. This design is aesthetically pleasing but we anticipated that the curved sides of the bird cage would interfere with the wing movement. The tubular perch that the animatronic bird will physically rest on, will allow us to route wires seamlessly into the base to provide power and communications from the microcontroller. The use of wood instead of 3D printed PLA will allow for easy manufacturing and assembly using commercial parts. This allows for the simplest design and manufacturing method, as well as the fewest number of custom parts.

We have modeled this base in SolidWorks® as well as created a physical model to demonstrate the desired movement, size, and shape of the base subsystem. The motion analysis is shown below in Figure 9.

![Figure 9: CAD Model of the base prototype, the series of pictures shows the rotation of the base mechanism](image-url)
4.2 Barker Bird Head and Neck
The concept design we came up with for the head and neck of our animatronic bird is a two degree of freedom neck rotation and bending. We determined that the best way to complete this movement was with servo motors, so we could precisely control the head and neck angles of the bird. When we implement the code, we plan to have both neck motors moving simultaneously, which we believe will produce a lifelike movement. The movement of this mechanism is seen below in Figure 9.

Datum position
Assembly composed of Head, Pin, and Neck
Servo motor at the pin allows the bird's head to tilt up and down in a “nodding” motion
Servo motor at neck allows for 180° rotation like a realistic bird

Figure 10: Timeline of CAD Animation for Head/Neck Rotation

Five ideation models were created and compared against each other in a Pugh matrix in Appendix E to determine the top designs. The runner-up design was a ball joint, which is ideal since it allows for three degrees of rotation. The capability of three degrees of rotation would make the bird more life-like. However, there is no good option off-the-shelf for a mechanism to hold the head in a certain position. Since no mechanism is readily available, a ball joint would cause the head to drop down when not actively held up. Of the several ideas that we came up with during ideation, we determined that this was the most achievable design that would produce the desired movement. Although this design has quite a few parts, we feel that it is the easiest to follow and 3D print, which are key specifications of our project. Once we produce a physical model of this mechanism, we will begin testing it with servo motors to ensure the motion we are seeing in CAD will fit adequately with the other subsystems.
4.3 Barker Bird Beak

We determined the model we will be producing for the beak will be a rotating lower beak with a fixed upper beak. Although macaws have a unique beak movement where their upper beak moves independently of their lower beak, we decided that the opening of just the lower beak would produce the desired expressiveness when the bird is “talking.” Appendix E shows a Pugh matrix that determined the next best design would use a linear actuator. We chose not to use a linear actuator to create the movement since they are expensive and may cause size complications. Instead, we chose to incorporate a linkage design that allows for flexibility with space and part constraints. We came up with a motion analysis in SolidWorks® to show how the servo motor will produce the talking motion of the bird. This motion analysis is shown below in Figure 9.

![Figure 11: CAD of beak model, where the rotation of the lower link connected to the top link causes the beak to open](image)

This design utilizes the fewest number of parts, and the parts that it does use are all able to be 3D printed, fulfilling some of our main design specifications that we developed in the Scope of Work document.
4.4 Barker Bird Wings
The wing model we have developed uses linkages to turn a rotary motion (from a servo motor) into a linear motion to create the motion of the wings opening. We first developed and tested this model using Legos until we achieved some of the desired movement. We then moved into SolidWorks® to create a more exact model to verify that we will be able to get the desired wing extension from a single servo motor. This model has quite a few moving parts, and is complex, but we felt that the ability to 3D print, and use a single servo motor to produce this motion outweighed the complexity. This CAD model is shown below in Figure 10.

![Figure 12: CAD of Wing Linkages](image)

As of right now, we are still discussing how we will generate a pinching motion with a servo motor. We have come up with rough ideas of the best way to complete this using a servo motors, and we think this will be more efficient than linear actuators. We also compared this to using motors at each joint, as seen in Appendix E, and this light-weight mechanical design provided clear economic and space savings.
4.5 Other Systems

Four of the main systems that we have not yet created concept prototypes or CAD models of are the blinking, bowing, shrugging, and electronics subsystem. The blinking, bowing, and shrugging CAD models and concept models will be created once the four main systems outlined above are created, that way we can account for the interaction between the systems. For example, the shrugging mechanism will need to be attached directly to the wing mechanism to allow us to generate the motion of the wings flapping. Although we do not yet have CAD or physical models of these systems, we do have an idea of what we are going to do. We are not creating the models yet because they are highly dependent on their integration with the four main systems listed above. In addition, we have talked about the electronics we plan to use, such as servo motors and maestro microcontroller, but we have not completed any purchases or written any code to integrate with the mechanical systems yet. A main function of our robot is that it would be able to speak, and we have not yet decided what speaker system to use to accomplish this task. Blinking, bowing, shrugging and electronic subsystems are much lower risk, because their integration with the rest of the system is relatively straight forward, but relies heavily on the design of the four main systems.

4.6 Design Hazards and Safety

Assuming the model is used as intended, the main risks are injury due to sharp edges and electrical shock. The sharp edges on the bird will be mostly on the beak, but will be there only for aesthetic reasons, so we will do our best to round any possible edges. The bird will be powered with an onboard battery, and all the wires contained within the bird itself, so the risk of electrical shock is very low, but none of the electrical components are technically connected to ground. The electronics we will be using is low voltage and low current, so the possible injury associated with electrical shock will be very minimal.
5. Project Management

Before CDR, our team plans to have a complete model all subsystems packaged together in a CAD file. Our team has set a timeline for completing the large number of tasks required to for this system. These tasks include incorporating the nine different motors operating within this system along with designing linkages, wiring, and costume integration.

5.1 Subsystem Organization
Design tasks have been grouped into subsystems which are then individually managed by a team member. The responsibility assigned to each team member for a subsystem is for ensuring tasks are completed on time, however every member of the team will be contributing to work required for each subsystem. As our only computer engineering student, Jonathan will be responsible for all code writing, sensor interaction, and costume integration. For the physical design of subsystems, responsibility is split amongst the mechanical engineering students. Nolan will oversee the blinking, beak movement, and bowing motion. Marcus is responsible for the shrugging, wing extension, and coordinating all wiring. Ishan will manage the neck movement, base rotation, along with speaker purchasing and integration. All non-moving parts will be handled by relevant subsystems as determined by the team. For example, printing the head will be included with blinking and beak movement, the rib cage is connected to shrugging, and pelvis is connected to the hips. Any space or integration conflicts between two subsystems will be mitigated by the third, unbiased team member with a mechanical engineering background. In the Gantt chart (Appendix G), many deadlines apply to multiple subsystems. Instead of writing new tasks for each function in the chart, each subsystem manager will work to have their functions meeting these deadlines.

5.2 Next Steps
The next design review for our team is CDR (Critical Design Review) in February. Before then, we plan to have all electrical components selected and purchased, along with a full system CAD model to present.

Planned analyses of the complete system includes creating a full assembly CAD model within SolidWorks® to test for system interference and testing motion of 3D printed parts and their respective components. These preliminary tests will show the packaging requirements and to ensure all motors will have adequate torque.

Planned purchases for our project includes filament for 3D printed parts, a microcontroller, necessary motors and servos, wiring, joint components, along with wood supplies for base and perch. With the nature of 3D printing, these components are adequate for both initial prototyping and final design. Current transportation delays in chip manufacturing may make create a longer lead time for microcontroller board, but at this time supplies can be shipped within a week. Each subsystem manager is responsible for the ordering of components necessary for their functions.
Conclusion

By dividing the functions of our animatronic barker bird into subsystems, our team has outlined a timeline, management plan, and ideation models for this project. We utilized Pugh matrices and pairwise comparison methods to optimize the design selection of each function we analyzed. Additionally, we established roles within the team to manage each subsystem and create structure for system integration. Physical prototypes and CAD models are produced for the beak movement, wing extension, shrugging motion, and base rotation. The work illustrated in this document lays out the foundation on which we will work from in the rest of this project to build our device and establishes our project management.

Our goal is to make an autonomous animatronic device that exceeds your expectations. We request your specific feedback on this document, and any detailed comments on our design directive that we can use to improve our performance on this project.
References

*Arduino*, https://www.arduino.cc/.


# Appendix B: Morphological Matrix

<table>
<thead>
<tr>
<th>Function</th>
<th>Importance</th>
<th>Possible Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head/Neck Movement</td>
<td>9</td>
<td>Ball Joint 2 DOF Motor</td>
</tr>
<tr>
<td>Base Rotation</td>
<td>8</td>
<td>side motor middle motor</td>
</tr>
<tr>
<td>Wing Movement</td>
<td>7</td>
<td>Parallel Linkage Design Motors at each joint</td>
</tr>
<tr>
<td>Beak Opening/Closing</td>
<td>9</td>
<td>Servo and Linkage Linear Actuator</td>
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</tbody>
</table>
## Appendix C: Weighted Decision Matrix and Pairwise Comparison

### Weighted Decision Matrix

<table>
<thead>
<tr>
<th>Specification</th>
<th>System 1</th>
<th></th>
<th>System 2</th>
<th></th>
<th>System 3</th>
<th></th>
<th>System 4</th>
<th></th>
<th>System 5</th>
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<td>Total</td>
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### Pairwise Comparison

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Appendix D: Ideation Models

Wing Extension Ideation Model:
Beak Ideation Model:

Blinking Mechanism Ideation Model
Head and Neck Ideation Model

Rotating base Ideation Model
Appendix E. Decision Matrices (Pugh and Weighted) for Ideation Models

**Pugh Matrix for Head/Neck**

**Ideas**
- 2 DOF Servo
- Linkage Design w/ Electric Actuator
- Strings Connected that Can Be Controlled Like Puppet
- 1 DOF Rotation
- Ball Joints

**Relevant Stakeholder Needs/Wants**
- Low Cost
- Lifelike Movement
- Commercially Available
- Realistic Size
- Scalable
<table>
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<tr>
<th>Concept</th>
<th>2-Way Servo</th>
<th>Linkage Design</th>
<th>Springs</th>
<th>Tilt Rotation</th>
<th>Ball Joint</th>
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<td>A</td>
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<td>U</td>
<td>S</td>
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<td>11</td>
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</table>

**Top Ideas**

1. **Ball Joint**
   
   Connecting a ball joint to the head of the bed would allow for 3 degrees of freedom. However, an encoder and servo motor should be retained to it to make the head move at the start. Additionally, without some kind of electrical actuation, you would need to control the head with your hands, which is not ideal.

2. **2-way Servo Motor**
   
   A 2-way servo motor would allow the head to move in the x-direction and up and down (in the y-z plane). The servo motor needs to be small enough and wired in the proper place to make it move. Alternatively, 2-way motors would need to be used to allow the head.
Wing Extension Pugh Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>String Stiff</th>
<th>Fixed Slope</th>
<th>Large (Curved)</th>
<th>Large (Real Fluid)</th>
<th>Molds (at least)</th>
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<tbody>
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<td>Life Like</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Make Non</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Branding</td>
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<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Weight</td>
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<td>-</td>
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<td>Manufacturability</td>
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<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cost</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
1. String controlled wing has pulleys at each joint that will help the wing compress. Springs will extend the wing since strings can only give force in tension. Concerned with getting caught in costume.

2. Fixed wing is how the original barker bird was designed. This is not lifelike; however, it is similar to the animatronic. Also, would remove a significant amount of designing and manufacturing time.

3. Parallel linkage design was tested with Legos in class. By fixing one pivot point, there will be compression and extension of a pinch point which will cause whole system to compress and extend. Unsure of how to do this.

4. Linkage design two, with pivot points established and smaller linkage bars attached to main structure. Controlled by just rotating main structure point connection to main body. Unsure if this will cause collisions.

5. This is a heavy, expensive option with three motors. This would allow for coding practice of linking up the motions and allows for many different wings flapping routines. Concerned as well with fitting motors in the wings and forces put on 3D structures.

Base Rotation Pugh Matrix

![Pugh Matrix Image]
1) The base rotates about the shaft the bird would sit on while the base stays stationary. The shaft is designed to look similar to the original banker bird stand with a cross shaped design. The difficulty with this design would be running wires from the base to the bird without them getting tangled as it moves.

2) This design is similar to the first except that the motor rotates the bird by moving the base. This would allow the components in the base to rotate with the bird, eliminating most of the tangling problem. The only part that would be tangled now would be the wire to the motor itself.

3) This next design is similar to the second but the motor is attached upside down. This would mean the motor would rotate along with the components located in the base. This would eliminate the wire tangling problem.

4) This next design is similar to the hanging swing design, found in the enchanted tiki room. This design would rotate at the top above the bird. The design while aesthetically pleasing would come with numerous design challenges not present in the other designs.

5) This final design is similar to number three except the motor is attached closer to the perimeter of base. This allows the system to use less energy to rotate the base. This also allows for a different pinning mechanism to hold the base if it becomes to heavy for the motor to support.
Beak Pugh

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Mech 1</th>
<th>Mech 2</th>
<th>Mech 3</th>
<th>Mech 4</th>
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<tbody>
<tr>
<td>Cost</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>+</td>
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<tr>
<td>Student Interest</td>
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<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Simplicity in Use</td>
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<td>5</td>
<td>-</td>
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<tr>
<td>Advantage of Bait</td>
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<td>-</td>
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<td>Direct Position</td>
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<tr>
<td>Amount of Bait Movement</td>
<td>+</td>
<td>5</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Mech 1

Top & Bottom Beak Movement
- From closed mode.
- Beak will open the top & bottom

Mech 2

- Lower Beak Movement
- SIgma Begins After
- Movement, Rotation of the Beak moves back to Belay through Contact

Mech 3

- Linear Alternation starts within Beak of Genu and top beak must be open, but
- very simple, this has the most precise movement, but needs extra piano Bell

Mech 4

- Both fixed

Fixed Bell is the simplest but important
- Most for organs
- Movement, this in the lower orbit since it has no movement
Appendix F: Design Hazard Checklist

<table>
<thead>
<tr>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?</td>
</tr>
<tr>
<td>N</td>
<td>2. Can any part of the design undergo high accelerations/decelerations?</td>
</tr>
<tr>
<td>N</td>
<td>3. Will the system have any large moving masses or large forces?</td>
</tr>
<tr>
<td>N</td>
<td>4. Will the system produce a projectile?</td>
</tr>
<tr>
<td>N</td>
<td>5. Would it be possible for the system to fall under gravity creating injury?</td>
</tr>
<tr>
<td>N</td>
<td>6. Will a user be exposed to overhanging weights as part of the design?</td>
</tr>
<tr>
<td>Y</td>
<td>7. Will the system have any sharp edges?</td>
</tr>
<tr>
<td>Y</td>
<td>8. Will any part of the electrical systems not be grounded?</td>
</tr>
<tr>
<td>N</td>
<td>9. Will there be any large batteries or electrical voltage in the system above 40 V?</td>
</tr>
<tr>
<td>Y</td>
<td>10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?</td>
</tr>
<tr>
<td>N</td>
<td>11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?</td>
</tr>
<tr>
<td>N</td>
<td>12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?</td>
</tr>
<tr>
<td>N</td>
<td>13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?</td>
</tr>
<tr>
<td>N</td>
<td>14. Can the system generate high levels of noise?</td>
</tr>
<tr>
<td>N</td>
<td>15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?</td>
</tr>
<tr>
<td>Y</td>
<td>16. Is it possible for the system to be used in an unsafe manner?</td>
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<tr>
<td>N</td>
<td>17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.</td>
</tr>
</tbody>
</table>

For any “Y” responses, on the reverse side add:

(1) a complete description of the hazard,

(2) the corrective action(s) you plan to take to protect the user, and

(3) a date by which the planned actions will be completed.
| Pinch Points | Since there will be a lot of moving parts, there will be pinch points in the mechanism. We plan to correct this by enclosing all mechanisms that may cause injury inside of the torso of the bird. | Jan 15 | TBD |
| Sharp Edges | The beak of the barker bird will likely have a sharp tip. This is to mimic the real shape of a macaw. We will correct this in the final prototype by trying to round the tip of the beak while keeping the desired beak shape | Nov 29 | TBD |
| Non-Grounded Electrical System | This hazard is not of major concern because we will be working with low voltage and low current electrical systems. | Feb 1 | TBD |
| Electrical Stored Energy | We will have a battery in the system to power all our electrical systems. We will ensure safety here by properly mounting the battery, and the power wires will be properly labeled secured to the inside of the bird, so they are out of the way of any pinch points. | Mid February | TBD |
| Improper Use | As with many things, this model can be dangerous if used incorrectly. We will fix this by thoroughly documenting the proper use of our design. This will include pictures and video to visually demonstrate proper use. | End of April | TBD |

Appendix G. Gantt Chart
<table>
<thead>
<tr>
<th>Task</th>
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<th>05/01</th>
<th>05/02</th>
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Barker Bird Animatronic Project Critical Design Review

February 11, 2021

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CAPED (Cal Poly Amusement Park Engineers and Designers) Club

Peter Schuster, Senior Project Advisor
Abstract
This document describes how our F71 Senior Design Project team developed the design for a 3D printed, electronic bird that will mimic Disneyland’s first animatronic, the Barker Bird. An animatronic is a mechanical puppet that replicates real life movement with robotic parts. Disney’s Barker Bird is a well-known animatronic that replicates a talking macaw with multiple moving systems.

Our final prototype will serve as a teaching tool to CAPED (Cal Poly Amusement Park Engineers and Designers) club members that are interested in the field of animated robots. Additionally, we are designing the bird to have movements that are as realistic as possible. Following PDR, we have made tremendous progress and improvements to the project such as:

- Acquiring the parts we need to have our subsystems function independently
- Designing a custom neck mount to allow for rotation in two different planes
- Implementing speak and beak actuation to mimic a macaw speaking
- Finalizing wing shrugging/flapping mechanism
- Finalizing 3D print of complex bird head
- Complete CAD assembly of integrated subsystems

Staying on track with our progress, a complete prototype will be done by early April and sufficient documentation will be created to allow any member of CAPED to create their own animatronic bird.
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1. Introduction
The objective of this project is to create an autonomous, animatronic bird from 3D printed and easily purchased parts that will interact with people nearby and attract members to the CAPED club. In addition to providing life-like motion in a portable design, this project will be a well-documented teaching tool to assist future students to understand the engineering required to make a functioning animatronic from easily accessible materials.

In this document, we detail the design, manufacturing, and integration steps that have and will take place to produce a robotic bird. This includes updates on production that has taken place, as well as plans for continuing progress. We will start by detailing a high-level design of the bird, including all its subsystems. Significant advancements in code and electrical configuration have been made since PDR, following the advice and recommendations of our sponsors and advisors. This report also justifies each of our design decisions with a functioning CAD model that matches the movement of subsystems we have prototyped. Manufacturability and integration have been considered extensively and the methods of doing each are described in the document. Lastly, a verification plan and its respective tests are detailed to ensure all specifications from the beginning of the project are met.

We have spent several months detailing and justifying our final design decisions that will meet the specifications of Kai Quizon, Dr. Keller, and CAPED. Additionally, manufacturing and design verification plans have been described extensively to ensure the reader has enough knowledge and detail to reproduce the build.
2. System Design and Justification

2.1 System Justification

This section details the final design of the robotic bird and the integration of the major sub-assemblies that will make the robot realistic.

Figure 1 shows the full assembly which verifies that our subsystems presented in PDR fit together and will combine to produce an animatronic bird. We were able to run different interference tests on this model to ensure that when multiple parts move at the same time, the mechanisms do not crash into each other.

In addition to our full assembly CAD model, we 3D printed the head and neck mechanism and assembled it with servo motors. This physical model gave us the platform to show that we can run multiple servo motors at the same time to produce the movement we desire. This physical model demonstrates that we have the capability to move all the servo motors that our full bird assembly will require. This structural prototype shows the electrical system, software, and hardware we chose are able to produce fluid motion.
In addition, we printed and tested several iterations of the wing mechanism, and we learned many important things that we need to consider in future iterations of the design. For example, we planned on using machine screws that thread directly into the 3D printed part. However, we had several instances where threading into the 3D printed parts resulted in the parts cracking and splitting. During our initial CDR presentation with the class, several peers presented the idea of using heat set inserts to thread into the 3D printed parts. This would alleviate the issues we are having regarding the parts cracking when we screwed into them.

Since we believe that this animatronic will not be under any major stresses during regular use, we have not preformed any stress calculations. Due to the rapid manufacturing time of the parts, we plan to test for weak spots in our design by analyzing the parts before, during, and after use. However, one spot that we may perform computer stress analysis on is the shoulder blade. This part will be under the most stress when the wings flap and could be prone to breaking if not properly designed. We will continue to use an iterative design process based on the results we see from rapid prototyping.
2.2 System Design
Drawings for all the following subsystems and their respective parts can be found in Appendix A.

2.2.1 Base
The base is where the Arduino and PCB will be located, and as a result wiring will need to be routed from the base into the bird. Figure 2 below shows a model of the base that incorporates a stepper motor, Lazy Susan, PVC Pipe, and 3D printed custom parts.

![Figure 2: CAD Model of Base](image)

We will use a Lazy Susan and wooden circular piece on the bottom. The perch and stand that the bird sits on will be made of 1” PVC pipe. These two components connect via a T-shaped connector. The inner, hollow circle of the pipe will be helpful in routing the wires to the bird’s subsystems.

The Lazy Susan will be sandwiched between two circular pieces of wood and bolted to the top plate, while the bottom, circular piece will be fixed. A cut-out piece will be made in the top plate for a stepper motor to sit into. The spinning shaft of the stepper motor will be attached to a wheel, causing the wheel to spin. This wheel will be in contact with the bottom, circular piece, which will cause the entire base to rotate with the actuation of the stepper motor.

2.2.2 Wing Extension & Flapping

The wing extension mechanism and flapping are two separate motions that work together to provide dynamic wing motion. Figure 3 below is a view of the wing mechanisms present on both sides of the bird.
Connected to a part labeled as “shoulder blade”, the linkages that make up the wing are actuated by a servo motor that is also connected to the shoulder blade. The shoulder blade component in the wing mechanism serves as the structure to hold a servo motor and to provide support for the wing linkages to rotate. Additionally, the shoulder blade component rotates about its hinge connected to the support spine based on input from the flapping mechanism, as seen in Figure 4.

Figure 3: Wing extension mechanism

Figure 4: Wing flapping mechanism with “Shoulder Blade”

The shoulder blade was designed for optimal linkage geometry of both the wing extension and the flapping mechanism. The flapping mechanism connection is centered with the rotary wheel point of rotation, allowing for symmetric flapping. The wing extension geometry was selected using kinematic calculations relating wingtip position and servo motor angle. The calculations were
iterated with our MATLAB® calculator that can be seen in Appendix K. Flapping mechanism geometry is justified through SolidWorks® animation, however kinetic and kinematic calculations are recommended to verify our design assumption of negligible force being applied to the mechanisms. Failures due to excess stress will be identified and corrected easily with the rapid manufacturing of 3D printed parts.

The structural support “spine” and the linkages connecting the rotary mechanism to the “shoulder blades” are not finalized. We are still determining how parts will fasten to the Lego® u-joints pictured. All other joints shown are joined with the same fasteners used throughout the bird.

Over the current quarter, our team has been working through kinetic and stress calculations for the wing linkage system. We are currently focusing on the stresses observed by the shoulder blade and inner wing linkages caused by forces from gravity and wind. These two forces have been separated as in-plane and out-of-plane forces. These forces will be combined with forces determined from kinetic calculations to justify our current linkage sizing.

2.2.3 Neck/Head Movement
To minimize the assembly time required, we decided to combine as many parts as possible, which led to a head design that is shown in the figures below. We justified our overall design by printing all parts, so we could perform initial testing on them. The overall assembly for the neck and head subsystem is shown below in Figure 6. The figures following show the component parts.
The main part in this assembly is the head, shown below in Figure 7.

The cutouts seen inside the head and on the bottom face are for the servo motors to fit into. They are sized such that the servo motors will be press-fit but still easy to install. This is the main part of the head mechanism that features crucial dimensions, as they require small tolerances to ensure proper servo fit. In addition, the smaller holes seen on the side of the head are slightly smaller than 2mm in diameter, which will allow us to use M2 screws to self-tap into the 3D printed part and into the servo motor to keep it in place. These mounting holes are also paired with a larger
countersink so that regardless of screw choice, the screw head will be recessed into the 3D printed part to avoid clashing while the head is moving. The larger hole on the underside of the upper beak will be used to mount and serve as the center of rotation for the lower beak seen in Figure 8.

![Figure 8: Lower Beak CAD model](image)

The lower beak mechanism features 1/8-inch holes at the top that will allow it to attach and rotate independent of the head mechanism which will allow the beak to “open.” The slot seen in the top view in the second picture is where a custom linkage that will provide the force to open the beak will be located. The beak opening is one of the crucial parts of our design and is justified by the working prototype we have printed and tested. This custom Z-link is shown below in Figure 9.

![Figure 9: Z-Linkage used to open the beak from a servo motor located at the base of the head](image)

With the limited space available in the head, we determined the best way to open the beak was from the base of the head. While modeling in SolidWorks®, we realized that the top section requires a slot to produce the desired beak movement. We were able to verify that this slot was adequate in our CAD assembly as well as in our physical structural prototype. The “Z” shape was necessary because due to the limited space, the servo motor could not be centered in the head, but
we wanted the lower beak to be pulled back from the center, the “Z” shape of this link allows for this movement.

Figure 10 shows the complete beak opening mechanism (lower beak, Z-link, and servo motor).

![Figure 10: Lower Beak assembly](image)

The neck mechanism that allows for two degree-of-freedom movement was integrated into the model of the head above. The part that will allow for the tilting of the neck is shown in Figure 11. This part includes a cut out slot for the injection molded parts to fit securely into. These injection molded parts were supplied with the servo motors. This will allow for the body of the servo motor (attached to the head part) to rotate instead of the motor shaft. Similarly, the part responsible for the rotation of the neck shown in Figure 12 demonstrates the cutout where the servo arm will fit to produce the desired movement.

![Figure 11: Neck mechanism that allows for tilting of the head](image)
2.2.4 Electrical Components

The wiring in the Barker Bird begins in the lower, stationary part of the base. It consists of a barrel type female DC connector that connects to a 12-volt DC power adapter. The 2-volt wire then connects to an on-off switch that will cut off power to the system when in the off position. The 12-volt and ground wire connect to a slip ring that will transition from the bottom stationary part of the base to the top rotating section of the base. The same wires will connect to a 12-volt to 5-volt buck converter and the DC connector on an Arduino Mega.
The 5-volt and ground wires from the buck converter travel to the stepper motor that rotates the base and up through the hollow PVC pipe of the perch and connect to the six servo motors in the bird.

From the Arduino Mega, the control lines of the servos are connected to pins 8 through 13. Pin 8 connects to the wing flapping servo, while pins 9 and 10 connect to the right- and left-wing extensions respectively. Pin 11 controls the movement of the beak, pin 12 controls the neck movement, and pin 13 controls the head tilting. These control lines carry pulse-width modulation (PWM) signals that have an amplitude of 5.0 volts and control the angular position of the servos.

Pins 1 through 4 on the Arduino Mega are connected to the stepper motor that controls the rotation of the base.

The DFPlayer Mini MP3 Player is connected to the Arduino Mega by the Vcc and ground wire of the DFPlayer connected to the 5-volt and ground pins of the Arduino Mega. The RX and TX pins of the DFPlayer are connected to RX1 pin 19 and TX1 pin 18 on the Arduino Mega. These lines are controlled by the hardware Serial1 controller on the Arduino Mega microcontroller. The pin diagram of the Arduino Mega can be seen in Appendix M. The SPK 1 and SPK 2 ports on the DFPlayer are connected to the positive and negative ports on the speaker. The pin diagrams of the Arduino Mega and DFPlayer can be seen in Appendices M and N respectively. The SPK1 port is connected in parallel with the half wave rectifier with gain and averaging circuit. This circuit feeds back into the Arduino Mega to the analog in A0 port. Port A0 utilizes the Analog-to-Digital converter (ADC) that is built into the Arduino Mega. This ADC operates by converting a given analog voltage value of 0 to 5.0 volts to digital values from between 0 and 1023.

![Figure 14: Amplitude to Position feedback sensor](image-url)
The position feedback sensor circuit shown in Figure 14 has three distinct stages. The first stage is a half-wave rectifier, which removes the negative component of a waveform and has a gain of five times the input signal. The second stage utilizes an averaging circuit with a time constant of fifteen milliseconds. The last stage utilizes a noninverting amplifier with a gain of seven. The rectifier is necessary due to the ADC inability to handle negative voltages. The gain brings the voltage in line with the ADCs minimum and maximum voltages. The averaging circuit keeps the feedback from changing too quickly. This circuit is an inline sound detector, so it does not have ambient noise interference. A sample waveform can be seen in Figure 15.

![Figure 14: Waveform with feedback (green) and speech (blue)](image)

Servos 400mA (Stall) x 6 = 2.4 Amps
Stepper Motor = 240mA
That’s A max of 2.64 amps
Arduino Mega provides a current of up to 50 mA

![Figure 16: Current Requirements](image)

Figure 16 demonstrates that the current requirements of the motors are much higher than the Arduino Mega can handle. To resolve this, a power electronic circuit called a buck converter will be used (Figure 17). This circuit will take a voltage of between 7.0 and 40 volts and convert the voltage to 5.0 volts, increasing the max current to 3.0 amps. This is larger than the 2.63 amps necessary to run the motor allowing for possible expansion in the future.
Figure 16: Buck Converter
2.2.5 Software

In software, the actions the Barker Bird can perform are spread across three classes. These classes control the servo motors, an MP3 player, and a stepper motor. These classes are all considered “children” to an action as shown in Figure 18. This allows all these classes to be put into the same array and guarantees that each of these actions will have a `doAction()` function.

```
struct Animation
{
    unsigned long ActionTime;  // Number of milliseconds after last animation or starts to do this action
    Action* ActionToAct;       // Which Action is it?
    int PositionTrack;         // Position form 0-100 or track number
    int SpeedVolume;           // Speed or Volume 0-100
};
```

The Animation structure shown in Figure 19 contains the time to perform the action since the last action in milliseconds. It also contains an action element with a pointer to the Action class that will preforms its `doAction()` function. It also contains to integer values that control the position/track selection and speed/volume.
Figure 19: Animation loop

Figure 20 shows the animation loop that is responsible for each animation in an array individually. Each iteration of the loop checks if it is time to begin the action. Once the doAction() function is called, the two integers are used as arguments and the array index is increased by one. Once there are no more actions to perform, the animations are repeated. Because this is an $O(1)$ action in milliseconds and the Arduino Mega has a clock rated in megahertz, actions can appear simultaneously.

Animation Actions[] = {

    {100,  SPEAK,  3,  30},
    {150,  NECK_VERTIC,  100,  100},
    {100,  NECK_HORIZONTAL,  80,  100},
    {300,  R_WING_EXTEND,  100,  50},
    {0,  L_WING_EXTEND,  50,  100},
    {500,  SPEAK,  2,  30},
    {500,  FLAP,  100,  50},
    {1000,  FLAP,  0,  50},

};

Figure 20: Animation Array

The animation array in Figure 21 is an array of the animation structs. This will serve as the animation interface for the users.

The software will use three sets of open-source drivers: VarSpeedServo.h, DFRobotDFPlayerMini.h, and stepper.h. VarSpeedServo.h allows for variable speed control of the servo motors, DFRobotDFPlayerMini.h drives the MP3 Player, and stepper.h drives the stepper motors.
2.2.6 Cost
Most of our parts are custom, and printed using our personal 3D printer, so the cost to manufacture our parts is relatively low. The table below details the parts we ordered online for each subsystem and the cost of each subsystem/part. Fasteners are neglected from the proposed budget in Table 1, since they will be used in abundance and are relatively cheap. We are currently in the process of ordering fasteners and have waited to do so since our designs are evolving as we are rapid prototyping. A full project budget can be found in Appendix B.

Table 1: Purchased component prices

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<td>Head/Neck Assembly</td>
<td>3 Servo Motors</td>
<td>$10.50</td>
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<tr>
<td>Wing/Shoulder Assembly</td>
<td>3 Servo Motors</td>
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<td>4 U-Joints</td>
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<td>Base</td>
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<td>PVC Pipe</td>
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<td>Lazy Susan</td>
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<td>Stepper Motor</td>
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3. Manufacturing Plan
The goal of the project is to implement parts that can be 3D printed or readily available off the shelf or online. As a result, we used CAD to design various parts specific to our geometry of the bird that can be 3D printed. Additionally, parts can be found easily from websites like Adafruit and Amazon. We will make purchases ourselves with a $500 budget given by CAPED.

3.1 Procurement
All our 3D printed parts are made from Hatchbox PLA material with a 1.75 millimeter filament diameter. We are fortunate enough to have a private 3D printer to use, but any 3D printer that uses PLA material can be used to print parts for this project. Additionally, fasteners, wood, and PVC pipe used in the integration of our systems can be readily found in any hardware store. We used Home Depot to purchase some of these materials for our project. Micro servo motors, the Arduino microcontroller, speaker, MP3 player, and audio level indicator were all purchased through Amazon.
3.2 Manufacturing

3.2.1. 3D Printed Parts
3D printed parts were designed initially before electronic parts were purchased. Each 3D printed part followed a similar process in manufacturing. First, the 3D printed part was designed in SolidWorks using various features dependent on the shape and function of the part. The SolidWorks part file was then converted into an STL file to prepare it for 3D printing. Using CURA as a slicer program, we were able to determine the ideal part orientation to maximize layer strength for crucial areas and minimize print time. We decided to use two walls, 0.2mm layer height, support settings (35% infill density, 50% interface density), and necessary infill density (35%). These settings provide us adequate strength while minimizing printing time.

3.2.2 Base
We will gather plywood to make the circular base part. We will initially cut the plywood down to a twelve-inch square, before using a scroll saw to cut a circle from it. To finish the part, a drum sander will be used to finalize a size for the circular base.

A PVC pipe will need to be acquired to create a perch for the bird to sit on. Two pieces of PVC pipe will be needed, one to create the height in the base and another to act as a perch. A PVC pipe cutter or miter saw from the Cal Poly Machine shops will be used to cut an adequate size of pipe for both pieces needed.

3.3 Assembly

3.3.1 Base
The PVC stand piece is mounted to the wooden base using epoxy or adhesive. The PVC perch attaches to the stand using epoxy as well. Attaching the bird to the PVC perch will be done by putting a 3D printed plugs that fit through holes in the PVC pipe. These plugs will press fit onto holes that are created in the feet of the bird. The microcontroller will reside inside the base and the wires connecting to the various electrical components will be routed through the PVC pipe and torso of the bird, as explained in Section 2 of the report.

3.3.2 Neck/Head
We designed the head and neck mount to allow for two-axis motion of the head. One servo motor is implemented to allow for rotation of the neck, which rotates about the “z” axis. Another servo motor is connected to the head to allow for tilting of the head up and down. Each servo motor has ledges on each of its sides with holes through it. We designed the neck mount to include holes that match the holes on the servo motor, so that the base of the motor can be screwed into the piece, and the shaft for the “neck movement” can spin freely. We took a different approach for the tilting of the head. Each of the servo motor came with injection molded parts that could be fit over the threads of the motor’s shaft. We designed the head movement so that this injection molded part is press fit into the custom neck mount. As a result, the servo motor housing will be spinning instead of the shaft.
3.3.3 Beak Mechanism
Sitting on top of the mount connecting the servo motor to the head will be another servo motor to control the beak opening. The shaft of the servo motor is not connected directly to the lower beak of the head but instead is linked by a custom 3D printed S-shaped linkage. One end of the linkage is attached to the shaft of the servo motor while the other side is attached to holes in the lower beak with a pin. The rotation of the beak is limited by code controlling the degree of rotation to ensure the lower beak doesn’t collide with the head. Additionally, the opening and closing of the beak is moderated by the actuation level that comes from the speaker when talking. The two are correlated so that the beak movement seems to be aligned with the voice of the bird.

3.3.4 Wing Extension Mechanism
These linkages are joined with the same fasteners used throughout the rest of the bird and are in a connected both in series and parallel to create a linkage that move continuously together and maintains congruent internal angles. We designed the linkages with holes for the fasteners to fit through, ensuring easy assembly. The inner linkages are connected to the “shoulder blade” via the same type of fastener. The servo motor is connected via the same fasteners that lock the motor into the given pocket.

3.3.5 Flapping Mechanism
The flapping mechanism is driven by a servo motor which is connected directly to the structural spine of the bird. The servo arm is then connected the rotary mechanism by locating the arm within a cut-out section and adding two small servo screws to joining the two pieces. The rotary mechanism rotates about the servo motor which allows it to actuate two linkages which connect the shoulder blade components to the rotary mechanism. The linkages are connected to the rotary through a bolt and connected the shoulder blade via a connection using the Lego® brand U-joints.

3.3.6 Fasteners
Holes in our custom designed 3D printed parts are sized to fit standard 6/32 screws. We will need various lengths of these screws since parts vary by thickness and fit to each other. Additionally, we will fit the screws into electrical-insulating sleeve washers throughout the wings and other moving parts to ensure parts can seamlessly work together. Additionally, these washers will prevent the threads of the screws from stripping the 3D printed material.

3.4 Outsourcing
Electrical components such as motors, microcontrollers, and wiring are all outsourced and purchased from websites such as Amazon and Adafruit. As mentioned, a goal of our project is to have parts that are readily available and easily integrated with multiple devices. Outsourcing these parts will help us reach this goal. Additionally, the wood, PVC pipe, and fasteners are all are parts that can be found at hardware stores and will be used to manufacture the base and perch the bird will sit on.

4. Safety and Repair
Although our project and design are inherently safe, there are precautions that must be taken to ensure the safety of our design. Maintenance is less of a concern, since our design allows for most parts to be easily reproduced in case one breaks or needs to be modified. Additionally, fasteners and other components can be easily found and replaced.

4.1 Pinch Points
Moving servo motors attached to 3D printed parts results in pinch points for anyone that sticks their fingers in these parts. These pinch points will be mainly enclosed by the 3D printed parts, limiting the gaps where pinching can occur. Additionally, a costume will be attached to the bird by members of CAPED, further minimizing the number of pinch points.

4.2 Sharp Edges
All our 3D printed parts have fillets to minimize any sharp edges. However, the design of our upper and lower beaks has sharp edges in order to mimic the shape of a real macaw. This piece was further rounded at the edge in order to minimize any hazards.

4.3 Electrical Hazards
Our system works with low voltage and low current electrical systems so electrical overflow is not a major concern.

There is a risk of wiring being improperly handled or pinched due to various moving parts and all parts being wired to the base of the bird. As a result, we will fasten wires to the torso of the bird and out of the way of the pinch points. Additionally, we will optimize the location of the battery to minimize this risk of puncturing the battery.

4.4 Improper Use
This design can be dangerous if not used properly. Our documentation of design and hazard warnings will ensure that people are aware of the risks of our design and ensure it will be reproduced safely.

As with many things, this model can be dangerous if used incorrectly. We will fix this by thoroughly documenting the proper use of our design. This will include pictures and video to visually demonstrate proper use.

5. Design Verification Plan
5.1 Specification Evaluation
We have focused on creating a custom design of our animatronic bird so that it will have movements like that of a real-life macaw. Another goal of this project is to produce a replicable bird that can be reproduced by a student in the CAPED club with an interest in animatronics and
without prior engineering experience needed. Once the design is complete and sufficient documentation is produced to allow someone else to build the bird from scratch, we will be surveying our intended audience to determine how easy to follow the process is. All of our tests don’t require special facilities and use measuring tools that can easily be found on the Internet or on campus. Each of the following tests can be found in Appendix F: DVP.

Table 2: Updated Engineering Specifications

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<tr>
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<td>Entire design cost under $500</td>
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<td>3</td>
<td>Garners student interest</td>
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<td>4</td>
<td>Ability for students to follow Design Process</td>
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<td>5</td>
<td>Loud enough to attract attention</td>
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<td>6</td>
<td>Ease to reproduce/recreate</td>
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5.2 Planned Tests for Movements of the Bird
To ensure that our bird’s movements are realistic, restrictions on movements need to be implemented. We are writing code that restricts the movement of the neck/head mechanism to only tilt 45 degrees up and down when the head tilts. Additionally, the head is only able to rotate 90 degrees to the left and right. Lastly, the base of the bird can rotate 180 degrees in each direction, to ensure it reaches all audiences. Testing will require a protractor and will be completed in a day to ensure that the servo motor rotation aligns with the specifications we listed.

The wings and shoulder are complex mechanisms that were extensively designed to allow shrugging of the “shoulder blades” and full extension of the wings. Both mechanisms will be tested independently to ensure neither of the movements cause interferences with other parts or subsystems. The component geometry for the wing extension was validated both through SolidWorks® animation and through kinetics calculation done through MATLAB®. The produced plot and animation show that the wing goes through nearly full extension and compression throughout a servo arm oscillation of 30 degrees. The optimal geometry is subjective, so the exact values were chosen out of preference of wing characteristics. This testing occurred over several weeks and is now complete and ready to be implemented.

5.3 Planned Tests for Replicability of Design
To determine the replicability of our design, we will be selecting three participants from the CAPED club with an interest to create an animatronic. We will supply them with a kit of parts, CAD models, code, and anything else they may need to create a fully functioning animatronic. Throughout the design process we plan to ask the users how easy it is to follow directions and if there are any problems that arise. These specific processes that will be surveyed are 3D printing of parts, accessibility of CAD models, usability of code, and assembly of the bird. We will use a scale of 1-5 for each of these processes to rank how easy/satisfied users were with each process.
If the average score of each of these processes is equal to or above a 3.75, we will consider our documentation successful. We hope that if two members can complete the project, it will demonstrate that our documentation is sufficient to allow any person to create their own animatronic. This test will occur over two weeks and may vary depending on the schedules and skill levels of our participants.

Another test we plan to conduct is surveying our ME 429 section during one class session about how realistic our robot’s movements are and if people would be interested in recreating their own animatronic bird. We plan to survey as many of our peers as possible to get adequate feedback. The minimum number of participants we want to survey is twenty. We will be showing a video of a real macaw in a tree and ask participants to rate how similar our bird’s movements are to that of a real macaw’s. Additionally, we will ask the same participants if they would be willing and interested in creating their own animatronic. We will consider our goal complete if 70% or more of the participants in the survey believe our robot replicates a real macaw’s movements. We will also consider the bird to garner student interest if 60% would want to create their own using our documentation and resources.

5.4 Planned Tests for Showcasing of the Bird

The animatronic bird will potentially be shown at two showcases at Cal Poly, Club Showcase and Open House, to attract potential club members and students. The robot’s voice needs to be loud enough to attract the attention of people at these loud and busy showcases. We ran a test to determine the loudness of the speakers by using an iPhone app that reads how loud a speaker is. Using this app, the robot was outputting about 77 decibels. Our goal is to have the speaker be about 80 decibels, which is equivalent to a busy downtown street. As a result, we plan to implement a second speaker, which will add about three decibels of noise to the reading. This test will occur in one day but may need to happen multiple times until the goal of 80 decibels or more is reached.

5.5 Planed Tests for Software

To ensure that the software is functioning correctly, a test program will be created. This test program will test each function of the bird to ensure that the output is mapped to the correct input. Additionally, each motion will be tested using a potentiometer to map for position. As the potentiometer resistors increase or decrease, the desired motion will occur. Using an analog input will show as the function behaves as expected with all valid and invalid inputs.
Conclusion

We have made significant progress in the past few months on the development of our animatronic bird and have determined the feasibility of our design. We have been able to demonstrate that we are able to 3D print the shape of a bird’s head, implement a moving beak into it, and have our bird speak. Additionally, we have been able to assemble and entire working model of the robot within SolidWorks to demonstrate we have met packaging and price constraints. We hope to continue the progress we have made to further develop the various subsystems of the bird.

Our future goals include manufacturing all custom components, writing code to interface with hardware, and integrating them into a complete functioning bird. After manufacturing and testing of the device is done, we will be producing written and video documentation to aid in helping anyone else produce their own animatronic bird. Lastly, we will run several tests on our intended audience to determine if the specifications determined in the beginning of the year are met.

We are in the process of assembling an autonomous animatronic device that meets your expectations. We request your specific feedback on this document, and any detailed comments on our design directive that we can use to improve our performance on this project.
References


Appendices
Appendix A. Drawing and Spec Package
Appendix B. Product Budget/Completed Purchase Orders/Bill of Materials
Appendix C. Manufacturing Plan (DFMA)
Appendix D: Failure Modes & Effects Analysis (FMEA)
Appendix E. Design Hazard Checklist
Appendix F. Design Verification Plan (DVP)
Appendix G. Gantt Chart
Appendix H. Program Flowcharts
Appendix I. Pseudocode
Appendix J. Wiring Diagrams
Appendix K. Wing Kinetics MatLab® Calculations
Appendix L. Wing Kinetics Hand Calculations
Appendix M. Arduino Mega Pin diagram
Appendix N. DFPlayer Mini pin out
## Appendix A: Drawing and Spec Package with iBOM

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ALL PARTS WILL BE 3D PRINTED. GEOMETRY NOT INCLUDED IN DRAWING PACKAGE, IS CONTAINED IN THE CAD FILES. MANY PARTS CONTAIN SPLINES TO CREATE THE DESIRED COSMETIC SHAPE OF THE PARTS. THESE MANUFACTURING METHODS REQUIRED TO PRODUCE THESE PARTS DO NOT REQUIRE DIMENSIONED DRAWINGS. HOWEVER, NOTABLE DIMENSIONS LIKE HOLE SIZE AND LOCATION ARE NOTED IN THE DRAWING PACKAGE WHERE APPLICABLE.
NOTES
MATERIAL: PLA
UNLESS OTHERWISE SPECIFIED:
TO BE USED FOR DIMENSIONING:
TOP SERVO CONNECTOR
BOTTOM SERVO CONNECTOR
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ±.05
X.XX = ±.01
X.XXX = ±.005
BREAK SHARP EDGES .01 MAX

SERVO MOTOR MOUNTING AREAS, 0.025"
CLEARANCE ON ALL SIDES TO ENSURE FIT
AFTER 3D PRINT. DEPTH OF CUTOUT IS 0.50 IN

THE MAJORITY OF CURVES ARE NOT "SMOOTH"
AND CANNOT BE DIMENSIONED. THEIR GEOMETRY
IS DERIVED IN THE CAD MODEL, AND SINCE THE PART
WILL BE 3D PRINTED, IT IS NOT NECESSARY FOR
ADDITIONAL GEOMETRY TO BE DERIVED ON THIS DRAWING.

Cal Poly Mechanical Engineering
SENIOR PROJECT F71

SECTION 07  CDR  Title: HEAD OF BARKER BIRD  Drawn By: NOLAN CLAPP
Design 1110  Nat Actv. Date: 2/23/2022 Scale: 1:1  Child By: F71
NOTES
MATERIAL: PLA
UNLESS OTHERWISE SPECIFIED:
TO BE USED FOR DIMENSIONING:
TOP SERVO CONNECTOR
BOTTOM SERVO CONNECTOR
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .08
X.XX = ± .01
X.XXX = ± .005
BREAK SHARP EDGES .01 MAX

THE MAJORITY OF CURVES ARE NOT "SMOOTH"
AND CANNOT BE DIMENSIONED, THEIR GEOMETRY
R IS DEFINED IN THE CAD MODEL AND SINCE THE PART
WILL BE 3D PRINTED, IT IS NOT NECESSARY FOR
ADDITIONAL GEOMETRY TO BE DEFINED ON THIS DRAWING

Cal Poly Mechanical Engineering
SENIOR PROJECT F71

SECTION 07 CDR
Title: LOWER BREAK
Dwg. #: 1111
Not Asb.: Date: 2/2/2022
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Chkd: By: F71
Appendix B: Project Budget/Completed Purchase Orders

Materials Budget for Senior Project

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Total expenses: $106.80

Budget: $500.00
Actual expenses: $200.00
Remaining balance: $393.20
**PURCHASE REQUEST**

*Click here for instructions on how to submit this form.*

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<td>Gikfun 2'' 40mm 3W Full Range Audio Speaker Stereo Woofer Loudspeaker for Arduino (Pack of 2pcs) EK1725</td>
<td>LYSB01CHYIU26-ELECTRNCS</td>
<td>Link</td>
<td>1</td>
<td>$9.99</td>
<td>$9.99</td>
</tr>
<tr>
<td>Amazon (ELEGOO Store)</td>
<td>ELEGOO MEGA R3 Board Atmega 2560 – USB Cable Compatible with Arduino IDE Projects R3IS Compatible</td>
<td>EL-CB-003</td>
<td>Link</td>
<td>1</td>
<td>$17.49</td>
<td>$17.49</td>
</tr>
<tr>
<td>Amazon</td>
<td>Mini MP3 Player Audio Module MP3 Voice Board DFPlayer with TF Card Slot, can be Controlled Through Serial Port or I/O Port for Arduino, Raspberry PI, AVR, MSP430, and Other MCUs. (1PCS=2 Speaker)</td>
<td>DFFLAYER</td>
<td>Link</td>
<td>1</td>
<td>$7.99</td>
<td>$7.99</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Amazon</td>
<td>Jili Online 5 LED Meter Audio Level Indicator/Power Meter Level Indicating 3.5V-12V B072L8X15P</td>
<td>B072L8X15P</td>
<td>Link</td>
<td>1</td>
<td>$4.99</td>
<td>$4.99</td>
</tr>
<tr>
<td>Amazon</td>
<td>Gikfun 1.5V-6V Type 130 Miniature DC Motors for Arduino Hobby Projects DIY (Case pack of 6) EKX450</td>
<td>NA</td>
<td>Link</td>
<td>1</td>
<td>$9.58</td>
<td>$9.58</td>
</tr>
</tbody>
</table>

**TOTAL** $105.02

Please note that senior project teams are responsible for all shipping and taxes associated with the above purchases. It is recommended:

**Deliver to:** (Full name, shipping address, phone)

Nolen Clepp, ncleepp@calpoly.edu, (714) 345-1348
1 Grand Avenue
Cal Poly Mustang’60 Machine Shop
San Luis Obispo, CA, 93407

**Special Instructions:** (e.g. Store Pickup, special discounts) Click "Apply Coupon" if still available on the linear actuator

**For Internal Use Only Below**

**Fund Account**
### Appendix C: Manufacturing Plan (DFMA)

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Component</th>
<th>Purchase (P)</th>
<th>Modify (M)</th>
<th>Build (B)</th>
<th>Raw Materials Needed to make/make the part (only M &amp; B)</th>
<th>Wherehow procured?</th>
<th>Equipment and Operations anticipate using to make the component</th>
<th>Key Limitations of this operation place on any parts made from it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Opening</td>
<td>Upper Beak</td>
<td>B</td>
<td></td>
<td></td>
<td>1.7mm White PLA Blancket</td>
<td>-</td>
<td>3D Printing from CAD model</td>
<td>Part to be procured with custom head</td>
</tr>
<tr>
<td></td>
<td>Lower Beak</td>
<td>B</td>
<td></td>
<td></td>
<td>1.7mm White PLA Blancket</td>
<td>-</td>
<td>3D Printing from CAD model</td>
<td>Part to be procured with custom head</td>
</tr>
<tr>
<td></td>
<td>Pivots</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>Amazon P.O.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Front Body</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>Mckinstry (Turkey)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Base Rotation</td>
<td>Physical Base</td>
<td>N</td>
<td></td>
<td></td>
<td>3/4” Phenolic Sheet (Alady Preceded)</td>
<td>1) Cut Phenolic down to 1/2” Square</td>
<td>2) Use 3/8” drill to cut out round shape</td>
<td>3) Bend edges down to the exact size with sharp corner</td>
</tr>
<tr>
<td></td>
<td>LowerSeller</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>Amazon P.O.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>orifice (DC bracket)</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>Amazon P.O.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Perfs</td>
<td>M</td>
<td></td>
<td></td>
<td>3/4” or 1” PVC Pipe (2)</td>
<td>1) Use PVC cutter to cut PVC pipe to correct length</td>
<td>2) Use PVC cutter to cut PVC pipe to correct length</td>
<td>3) Mention parts to base</td>
</tr>
<tr>
<td></td>
<td>Front Body</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>Mckinstry (Turkey)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hand/Work Rotation</td>
<td>2 Stack Motors</td>
<td>T</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3D Printed Mounts</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>Amazon P.O.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Castors: 3D Printed Neck</td>
<td></td>
<td></td>
<td></td>
<td>1.7mm White PLA Blancket</td>
<td>1) SolidWorks Modeling</td>
<td>2) Optimization for 3D printing</td>
<td>3) 3D Print</td>
</tr>
<tr>
<td></td>
<td>Castors: 3D Printed Head</td>
<td></td>
<td></td>
<td></td>
<td>1.7mm White PLA Blancket</td>
<td>1) SolidWorks Modeling</td>
<td>2) Optimization for 3D printing</td>
<td>3) 3D Print</td>
</tr>
<tr>
<td></td>
<td>Wing Extensions</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>1) Design with SolidWorks</td>
<td>2) Optimization for 3D printing</td>
<td>3) 3D Print</td>
</tr>
<tr>
<td></td>
<td>2 Stack Motors</td>
<td>T</td>
<td></td>
<td></td>
<td>-</td>
<td>Amazon P.O.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Castors: 3D Printed Neck</td>
<td></td>
<td></td>
<td></td>
<td>1.7mm White PLA Blancket</td>
<td>1) SolidWorks Modeling</td>
<td>2) Optimization for 3D printing</td>
<td>3) 3D Print</td>
</tr>
</tbody>
</table>
### Appendix E. Design Hazard Checklist

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and shear points?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>2. Can any part of the design undergo high accelerations/decelerations?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>3. Will the system have any large moving masses or large forces?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>4. Will the system produce a projectile?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>5. Would it be possible for the system to fall under gravity creating injury?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>6. Will a user be exposed to overhanging weights as part of the design?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>7. Will the system have any sharp edges?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>8. Will any part of the electrical systems not be grounded?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>9. Will there be any large batteries or electrical voltage in the system above 40 V?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>14. Can the system generate high levels of noise?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>16. Is it possible for the system to be used in an unsafe manner?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Description of Hazard</td>
<td>Planned Corrective Action</td>
<td>Planned Date</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Pinch Points</td>
<td>Since there will be a lot of moving parts, there will be pinch points in the mechanism. We plan to correct this by enclosing all mechanisms that may cause injury inside of the torso of the bird.</td>
<td>Jan 15</td>
</tr>
<tr>
<td>Sharp Edges</td>
<td>The beak of the barker bird will likely have a sharp tip. This is to mimic the real shape of a macaw. We will correct this in the final prototype by trying to round the tip of the beak while keeping the desired beak shape</td>
<td>Nov 29</td>
</tr>
<tr>
<td>Non-Grounded Electrical System</td>
<td>This hazard is not of major concern because we will be working with low voltage and low current electrical systems.</td>
<td>Feb 1</td>
</tr>
<tr>
<td>Electrical Stored Energy</td>
<td>We will have a battery in the system to power all our electrical systems. We will ensure safety here by properly mounting the battery, and the power wires will be properly labeled secured to the inside of the bird, so they are out of the way of any pinch points.</td>
<td>Mid February</td>
</tr>
<tr>
<td>Improper Use</td>
<td>As with many things, this model can be dangerous if used incorrectly. We will fix this by thoroughly documenting the proper use of our design. This will include pictures and video to visually demonstrate proper use.</td>
<td>End of April</td>
</tr>
</tbody>
</table>
Appendix F. Design Verification Plan (DVP)

<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Test Description</th>
<th>Measurement</th>
<th>Acceptance</th>
<th>Required Facilities/Conditions</th>
<th>Test Needed</th>
<th>Repeated</th>
<th>Responsible</th>
<th>Notes on Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Test mode motion allows wings to extend fully and close fully</td>
<td>Actuation</td>
<td>No</td>
<td>Full opening and closing without failure</td>
<td>YES</td>
<td>3D Printed Linkage and Swivel Points</td>
<td>Mark Strome</td>
<td>3/12/2012</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Test mode motion allows wings to swing</td>
<td>Visual Inspection</td>
<td>No</td>
<td>Visual swinging of winglet design</td>
<td>YES</td>
<td>3D Printed Linkage, Mounts, and Swivel Points</td>
<td>Mark Strome</td>
<td>3/10/2002</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Test main Motor can rotate heading response to the name</td>
<td>Resistance Measurement</td>
<td>No</td>
<td>10 degrees minimum to the name</td>
<td>D</td>
<td>3D Printed Mount, Head, and Sensor Mounts</td>
<td>Urban Varanes</td>
<td>1/21/2022</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Servo Motor can maintain head when swinging up and down</td>
<td>Resistance Measurement</td>
<td>No</td>
<td>15 degrees minimum in both directions</td>
<td>NA</td>
<td>3D Printed Mount, Head, and Sensor Mounts</td>
<td>Ellen Chapp</td>
<td>1/21/2022</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Torque on operation-based basis can spin allocates the end points</td>
<td>Resistance Measurement</td>
<td>No</td>
<td>Full rotation about the axis and 100 degrees in each direction</td>
<td>NA</td>
<td>Manufactured Sensor and Mount Points</td>
<td>Urban Varanes</td>
<td>1/21/2022</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Test away motors can maintain balance up and down due to the inherent design features</td>
<td>Audio/Visual Indication</td>
<td>No</td>
<td>Higher audio levels correlate with lower balance and lower levels</td>
<td>NA</td>
<td>3D Printed Head, Lower Body Balancing Indicators</td>
<td>Jonathan Ogden</td>
<td>1/21/2022</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Test that speaks produce audible phrases</td>
<td>Quality Control</td>
<td>No</td>
<td>Audible, consistent with desired output</td>
<td>NA</td>
<td>Voice Decoder reading app</td>
<td>Jonathan Ogden</td>
<td>1/21/2022</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Students are able to operate the vehicle with user-friendly control software and documentation</td>
<td>Documentation</td>
<td>No</td>
<td>Device utilizes and functions with Bluetooth technology</td>
<td>NA</td>
<td>Device-specific documentation and 3D printed code</td>
<td>Ellen Chapp</td>
<td>1/21/2022</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Subassembly on the balloon unit is constructed in real-time</td>
<td>Functioning</td>
<td>No</td>
<td>Fully functional with independent movement and control</td>
<td>NA</td>
<td>All parts accepted and code implemented</td>
<td>Ellen Chapp</td>
<td>1/21/2022</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>sensor design ensures that all sensors have reliable movement and actual values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mark Strome</td>
</tr>
</tbody>
</table>
Appendix G. Gantt Chart

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Definition</td>
<td>09/26/21</td>
<td>10/26/21</td>
</tr>
<tr>
<td>Choose Project</td>
<td>09/29/21</td>
<td>09/30</td>
</tr>
<tr>
<td>Meet Team</td>
<td>09/29/21</td>
<td>09/30</td>
</tr>
<tr>
<td>Customer/Need Research</td>
<td>09/29/21</td>
<td>10/12/21</td>
</tr>
<tr>
<td>Interview Spokespon (PR)</td>
<td>09/30/21</td>
<td>10/05</td>
</tr>
<tr>
<td>Research technical issues</td>
<td>09/30/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Identify technical challenges</td>
<td>09/30/21</td>
<td>09/30</td>
</tr>
<tr>
<td>Find Journal articles</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Find Challenge 1 articles</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Find Challenge 2 articles</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Find Challenge 3 articles</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Product Research</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Ask sponsors about current product</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Search online for current products</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Search patents for similar products</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Find product reviews</td>
<td>10/01/21</td>
<td>10/07/21</td>
</tr>
<tr>
<td>Interview stakeholders</td>
<td>10/08/21</td>
<td>10/31/21</td>
</tr>
<tr>
<td>Interview End Users</td>
<td>10/08/21</td>
<td>10/12</td>
</tr>
<tr>
<td>Interview Purchasers</td>
<td>10/08/21</td>
<td>10/12</td>
</tr>
<tr>
<td>Interview Work/Shakelers</td>
<td>10/08/21</td>
<td>10/12</td>
</tr>
<tr>
<td>Capture Customer Need/Weight</td>
<td>10/08/21</td>
<td>10/12</td>
</tr>
<tr>
<td>Write Problem Statement</td>
<td>10/13/21</td>
<td>10/14</td>
</tr>
<tr>
<td>Create Initial Plan</td>
<td>10/13/21</td>
<td>10/24</td>
</tr>
<tr>
<td>Perform GFD</td>
<td>10/16/21</td>
<td>10/20</td>
</tr>
<tr>
<td>Create Specification Table</td>
<td>10/16/21</td>
<td>10/20</td>
</tr>
<tr>
<td>Write Specification Descriptions</td>
<td>10/16/21</td>
<td>10/22</td>
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<tr>
<td>Write Scope of Work</td>
<td>10/06/21</td>
<td>11/18/21</td>
</tr>
<tr>
<td>Write Background</td>
<td>10/07/21</td>
<td>10/07</td>
</tr>
<tr>
<td>Write Scope</td>
<td>10/08/21</td>
<td>10/09</td>
</tr>
<tr>
<td>Write Objectives</td>
<td>10/12/21</td>
<td>10/22</td>
</tr>
<tr>
<td>Write Prig Plan</td>
<td>10/12/21</td>
<td>10/22</td>
</tr>
<tr>
<td>Review Scope of Work</td>
<td>10/12/21</td>
<td>11/09</td>
</tr>
<tr>
<td>Write Inter/Concl</td>
<td>10/07/21</td>
<td>10/07</td>
</tr>
<tr>
<td>Scope of Work (SW)</td>
<td>10/08/21</td>
<td>10/20</td>
</tr>
<tr>
<td>Concept Generation &amp; Selection</td>
<td>10/26/21</td>
<td>11/21/21</td>
</tr>
<tr>
<td>Layout PR presentation order</td>
<td>10/28/21</td>
<td>11/04</td>
</tr>
<tr>
<td>Write background</td>
<td>10/28/21</td>
<td>11/04</td>
</tr>
<tr>
<td>Analyze current progress</td>
<td>10/26/21</td>
<td>11/04</td>
</tr>
<tr>
<td>Write instruction/solution</td>
<td>10/30/21</td>
<td>11/03</td>
</tr>
<tr>
<td>Finish Rough Draft final edits</td>
<td>11/11/21</td>
<td>11/14</td>
</tr>
<tr>
<td>Finish Final Draft</td>
<td>11/13/21</td>
<td>11/27</td>
</tr>
<tr>
<td>Submit to Stakeholders</td>
<td>11/13/21</td>
<td>11/18</td>
</tr>
<tr>
<td>Preliminary Design Review (PDR)</td>
<td>11/13/21</td>
<td>11/16</td>
</tr>
<tr>
<td>Detailed Design &amp; Analysis</td>
<td>10/03/22</td>
<td>12/08/22</td>
</tr>
<tr>
<td>Internal Design Review (IDR)</td>
<td>10/04/22</td>
<td>10/04</td>
</tr>
<tr>
<td>Complete CDR</td>
<td>02/06/22</td>
<td>02/13</td>
</tr>
<tr>
<td>Write and Finish CDR</td>
<td>05/07/22</td>
<td>06/07</td>
</tr>
<tr>
<td>Critical Design Review (CDR)</td>
<td>06/12/22</td>
<td>06/12</td>
</tr>
</tbody>
</table>
Appendix H. Program Flowcharts
Appendix I. Pseudocode

```c
struct Animation
{
    unsigned long ActionTime; // Number of milliseconds after sequence starts to do this action
    Action* ActionToAct; // Which Action is it?
    int Position/Track; // Position form 0-100 or track number
    int Speed/Value; //Speed or Value 0-100
};

void loop()
{
    if(millis() - StartTime > Actions[index].ActionTime){
        Actions[index].ActionToAct->DoAction(Actions[index].Position/Track, Actions[index].Speed/Value);
    }
    if (++index >= numberOfActions){ // if the animation is complete start over
        index = 0;
        StartTime = millis();
    }
}

ServoAction Actions[] = {
    {500, NECK_HORIZONTAL, 2500, 255},
    {500, NECK_VERTICAL, 600, 255},
    {2000, NECK_VERTICAL, 2500, 30},
    {2000, NECK_HORIZONTAL, 600, 255},
    {2300, NECK_HORIZONTAL, 2500, 255},
    {2500, BEAK, 2500, 100},
    {2500, FLAP, 2500, 100},
    {2500, R_WING_EXTEND, 2500, 255},
    {2800, BEAK, 550, 100},
    {2800, FLAP, 2000, 200},
    {2800, FLAP, 700, 200},
};
```
Appendix J. Wiring Diagrams

Barker Bird Wiring Diagram
Appendix K. Wing Kinetics MatLab® Calculations

Wing Kinetics- Barker Bird Senior Project

Author: Marcus Monroe
Editors: Nolan Clapp, Ishan Jandaur
Code Inspiration: Charlie Refvem
California Polytechnic State University, San Luis Obispo, California

Date Created: 1/26/2022
Date Modified: 2/2/2022

Description
The purpose of this exercise is to model the position of the wing tip and the forces acting on linkages.

Problem Statement
Consider a multi-bar mechanism with rotating parts. This code solves given mechanism lengths and angles, along with finding the velocity and accelerations of different points on the figure.

Wingtip Position, Velocity, and Acceleration Calculator

Purpose:
To relate servo angle position, velocity, and acceleration to the position, velocity, and acceleration of the wingtip. Additional function plots wingtip position over a range of servo motor angles that can be used to validate location of servo motor.

Establishing Variables
Analysis for Given equations can be found through hand calculations shown in the appendix

Setting symbolic variables

```
clear all
% Lengths of linkages:
syms l_a2 l_c l_d1 l_f l_a0 l_b0 l_sa
% Servo values
syms lever theta_s(t) B_x B_y
% Point Locations
syms P0_x P0_y
% Theta values for servo
syms theta theta_dot theta_ddot
```

Simple Position Calculation from Servo Angle:

System's Independent Variable:

```
servo_angle = deg2rad(100); % Input your degrees into the function
```
servo_speed = deg2rad(10); % Input degrees/sec to function
servo_accel = deg2rad(1); % Input degrees/s^2 to function

Finding position of servo connection point, S0 (s-knot)

\[
\begin{align*}
S_0.x &= B.x + \text{lever} \cdot \cos(\theta_s) + P_0.x; \\
S_0.y &= B.y + \text{lever} \cdot \sin(\theta_s) + P_0.y; \\
P_5 &= \sqrt{(S_0.x - P_0.x)^2 + (S_0.y - P_0.y)^2}; \text{ Distance of } S_0 \text{ from } P_0
\end{align*}
\]

Finding angles from S0 location

\[
\begin{align*}
\theta_{s-p} &= \text{atan2}((P_0.y - S_0.y), (P_0.x - S_0.x)); \text{ atan2 accounts for 4 quadrants} \\
\phi &= 2 \cdot \text{acos} \left( \frac{(1_{a0} + P_5)}{2 \cdot (P_0 + P_5)} \right); \text{ law of cosines} \\
\alpha &= \pi - \phi; \\
\theta_A &= \theta_{s-p} + \phi/2; \\
\theta_B &= \theta_{s-p} - \phi/2;
\end{align*}
\]

Wingtip Position (Symbolic):

\[
\begin{align*}
P_7.x &= (1_{a2+l_1} + l_1) \cdot \cos(\theta_A) + (1_{c+l_1}) \cdot \cos(\theta_B) + P_0.x; \\
P_7.y &= (1_{a2+l_1} + l_1) \cdot \sin(\theta_A) + (1_{c+l_1}) \cdot \sin(\theta_B) + P_0.y;
\end{align*}
\]

Wingtip Velocity (Symbolic):

\[
\begin{align*}
P_7.x\_dot &= \text{diff}(P_7.x, t); \\
P_7.y\_dot &= \text{diff}(P_7.y, t);
\end{align*}
\]

Wingtip Acceleration (Symbolic):

\[
\begin{align*}
P_7.x\_ddot &= \text{diff}(P_7.x\_dot, t); \\
P_7.y\_ddot &= \text{diff}(P_7.y\_dot, t);
\end{align*}
\]

Trading Symbolic Variables:

\[
\begin{align*}
P_7.x &= \text{subs}(P_7.x, \theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)); \ldots \\
P_7.y &= \text{subs}(P_7.y, \theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)); \ldots \\
P_7.x\_dot &= \text{subs}(P_7.x\_dot, \theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)); \ldots \\
P_7.y\_dot &= \text{subs}(P_7.y\_dot, \theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)); \ldots \\
P_7.x\_ddot &= \text{subs}(P_7.x\_ddot, \theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)); \ldots \\
P_7.y\_ddot &= \text{subs}(P_7.y\_ddot, \theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)); \ldots
\end{align*}
\]

Wingtip Position (Numeric):

% Replacing symbolic variables with numeric values. Value in num_param % corresponds with variable in sym_param at same index
sym_param = [l_a2, l_c, l_d1, l_f, l_a0, l_sa, P0_x, P0_y, B_x, ... 
B_y, lever, theta, theta_dot, theta_ddot]; % inches and radians
num_param = [0.75, 6, 6, 6, 0.75, 0.5, 0.8, 0, 0, 0, 0, 0, ... 
  -0.8, 0.85, servo_angle, servo_speed, servo_accel];

P7_x_num = double(subs(P7_x, sym_param, num_param)); % inches
P7_y_num = double(subs(P7_y, sym_param, num_param)); % inches
P7_x_dot_num = double(subs(P7_x_dot, sym_param, num_param)); % inches/sec
P7_y_dot_num = double(subs(P7_y_dot, sym_param, num_param)); % inches/sec
P7_x_ddot_num = double(subs(P7_x_ddot, sym_param, num_param)); % inches/sec^2
P7_y_ddot_num = double(subs(P7_y_ddot, sym_param, num_param)); % inches/sec^2

Total Wing Length Characteristics

wing_length = sqrt(P7_x_num^2 + P7_y_num^2)
wing_length = 10.4973

wing_extension_speed = sqrt((P7_x_dot_num)^2 + (P7_y_dot_num)^2)
wing_extension_speed = 4.4911

wing_extension_accel = sqrt(P7_x_ddot_num^2 + P7_y_ddot_num^2)
wing_extension_accel = 0.0919

Parametric Table to Determine Shoulder Blade Configuration
This code will run through various servo angles and plot the wingtip position. Re-running this code various
time with different positions of the servo box will allow the user to compare which graphs produce desirable
characteristics.

% Selecting servo box location to test
B_x_num = -0.75; % in relative to P0
B_y_num = -0.8; % in relative to P0

% Establishing blanks lists to be filled
P7_x_list = zeros(1,19);
P7_y_list = zeros(1,19);
wing_length_list = zeros(1,19);
theta_min = 90;
theta_max = 120;
theta_list = linspace(90,120,19);

for k = 1:19

% Set up new theta values
servo_angle = deg2rad(theta_list(k));

% Sub in values and solve
sym_param = [l_a2, l_c, l_d1, l_f, l_a0, l_sa, P0_x, P0_y, ... 
  B_x, B_y, lever, theta]; % inches and radians
Figure 1: Wingtip position vs. Servo angle

fprintf('Figure 1 plotted with servo box location (%1.2f,%1.2f) inches relative to P0', Bx_num, By_num);

Figure 1 plotted with servo box location (-0.75,-0.80) inches relative to P0
Appendix L. Wing Kinetics Hand Calculations
**GEOMETRIC VARIABLES**

<table>
<thead>
<tr>
<th>Lengths:</th>
<th>Angles (relative to xon)</th>
<th>Angles (between parts)</th>
<th>Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l_a - l_{a0} )</td>
<td>( \theta_a )</td>
<td>( \alpha_1 )</td>
<td>( P_0 )</td>
</tr>
<tr>
<td>( -l_{a2} )</td>
<td></td>
<td>( \phi_1 )</td>
<td>( P_1 )</td>
</tr>
<tr>
<td>( l_b - l_{b2} )</td>
<td>( \theta_b )</td>
<td>( \phi_2 )</td>
<td>( P_2 )</td>
</tr>
<tr>
<td>( -l_{b2} )</td>
<td></td>
<td>( \beta )</td>
<td>( P_3 )</td>
</tr>
<tr>
<td>( -l_{b0} )</td>
<td></td>
<td></td>
<td>( P_4 )</td>
</tr>
<tr>
<td>( l_c )</td>
<td>( \theta_c )</td>
<td></td>
<td>( P_5 )</td>
</tr>
<tr>
<td>( l_d - l_{d2} )</td>
<td>( \theta_d )</td>
<td></td>
<td>( P_6 )</td>
</tr>
<tr>
<td>( -l_{d2} )</td>
<td></td>
<td></td>
<td>( s_0 )</td>
</tr>
<tr>
<td>( l_e )</td>
<td>( \theta_e )</td>
<td></td>
<td>( s_1 )</td>
</tr>
<tr>
<td>( l_f - l_{f1} )</td>
<td>( \theta_f )</td>
<td></td>
<td>( s_2 )</td>
</tr>
<tr>
<td>( -l_{f1} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( l_{sa} )</td>
<td>( \theta_{sp} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Simple Geometric Relations**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Reasoning</th>
<th>Assumption:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_1 = \alpha_2 )</td>
<td>Alternate Interior Angles</td>
<td>Part B &amp; C are II</td>
</tr>
<tr>
<td>( \alpha_2 = \alpha_3 )</td>
<td>Corresponding Angles</td>
<td>Part D &amp; E are II</td>
</tr>
</tbody>
</table>

Only changing values: \( \alpha, \phi, \beta, \theta_{sp} \)

Also...

\( l_{a2} = l_{d2} = l_{f2} \) & \( l_{a0} = l_{b0} \)
KINEMATICS

\* \( c_1 = \cos(\theta_2), \ s_1 = \sin(\theta_1) \)

\( P_0 \) is fixed: \((\text{call it origin})\)

\[ P_1 = (la \cdot Cc) \hat{e} + (la \cdot Sc) \hat{s} \]

\[ P_2 = (lb_1 \cdot Cc) \hat{e} + (lb_1 \cdot Sc) \hat{s} \]

\[ P_3 = ((lb_1 + lb_2) \cdot Cc) \hat{e} + ((lb_1 + lb_2) \cdot Sc) \hat{s} \]

\[ P_4 = P_1 + (lc \cdot Cc) \hat{e} + (lc \cdot Sc) \hat{s} \]

\[ P_5 = P_2 + (ld_1 \cdot Cc) \hat{e} + (ld_1 \cdot Sc) \hat{s} \]

\[ P_6 = P_3 + (le \cdot Cc) \hat{e} + (le \cdot Sc) \hat{s} \]

\[ P_7 = P_4 + (lf \cdot Cc) \hat{e} + (lf \cdot Sc) \hat{s} \]

OR...

\[ P_7 = (la \cdot Ca + lc \cdot Cc + ld_1 \cdot Cc + lf \cdot Cc) \hat{e} + (la \cdot Sc + lc \cdot Sc + ld_1 \cdot Sc + lf \cdot Sc) \hat{s} \]

Since \( O_A = O_B = O_E \) & \( O_B = O_C = O_F \)

\[ P_7 = ((la_2 + lb) \cdot Ca + (le + lf) \cdot Cc) \hat{e} + ((la_2 + lb) \cdot Sc + (le + lf) \cdot Sc) \hat{s} \]
EQUATING ANGLES

\[ \phi, \theta_{sp}, \alpha = \pi - \phi \]

Let's say \( \phi \) and \( \theta_{sp} \) are known.

\[ \theta_A = \frac{\phi}{2} + \theta_{sp} \]
\[ \theta_B = -\frac{\phi}{2} + \theta_{sp} \]
\[ \theta_C = \theta_B \]
\[ \theta_D = \theta_A \]
\[ \theta_E = \theta_A \]
\[ \theta_F = \theta_B \]

Finding \( \phi \) and \( \theta_{sp} \)

\[ P_0 = (0, 0) \]

Length \( S_0 - P_0 = l_{na} \cos\left(\frac{\beta}{2}\right) + l_{a_0} \cos\left(\frac{\theta}{2}\right) \)

\[ \phi + \beta + 2m = 2\pi \text{ RAD} \]

\[ \sin\left(\frac{\phi}{2}\right) = l_{sp}/l_{a_0} = \sin\left(\frac{\beta}{2}\right) l_{sp}/l_{a_0} \]

Shared angle identity

\[ \frac{1 - \cos \phi}{1 - \cos \beta} = \left(\frac{l_{sp}}{l_{a_0}}\right)^2 \]

\[ S_0 = \text{box} + (\text{lever} \cos(\phi))^2 \]
\[ \quad + (\text{lever} \sin(\phi))^2 \]
\[
\frac{PB}{P_0 R_{ox}} + \frac{P_5}{P_0 S_0} = \frac{P_5}{P_0 S_0}
\]
\[
(P_{Bx}, P_{By}) = (\text{known, } C_S^2, \text{known } S_S) = P_{5x}, P_{5y}
\]
\[
|P_{5}^1| = \sqrt{\left(P_{Bx} + \text{known } C_S^2\right)^2 + \left(P_{By} + \text{known } S_S\right)^2}
\]
\[
\theta_{SP} = -\tan^{-1}\left(\frac{P_{5y}}{P_{5x}}\right) + 180 \quad (\text{since } P_{5y} \text{ not } S_{5y})
\]

Also: Finding $\phi$

- Law of Cosines: $c = \sqrt{a^2 + b^2 - 2ab \cos \gamma}
- \cos \gamma = \frac{a^2 + b^2 - c^2}{2ab}
- \gamma = \cos^{-1} \left( \frac{a^2 + b^2 - c^2}{2ab} \right)
- \text{where } \gamma = \frac{\phi}{2} \text{ and } c = l_{5a} \text{ and } a = l_{a_0} \text{ and } b = |P_{51}|

then
\[
\frac{\phi}{2} = \cos^{-1} \left( \frac{l_{a_0}^2 + |P_{51}|^2 - l_{5a}^2}{2(l_{a_0} \cdot |P_{51}|)} \right)
\]
Appendix M. Arduino Mega Pin diagram
Appendix N. DFPlayer Mini pin out
Appendix O: Updated House of Quality

![Updated House of Quality Diagram](image-url)
Appendix P: Decision Matrices and Pairwise Comparison Charts

### Pairwise Comparison

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Similarity</th>
<th>Replicable</th>
<th>Cost</th>
<th>Student Interest</th>
<th>Weight</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similarity</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
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<td>0</td>
</tr>
<tr>
<td>Replicable</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cost</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Student Interest</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Complexity</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Sum</td>
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<td>3.5</td>
<td>4.5</td>
<td>0.5</td>
<td>1.5</td>
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<tr>
<td>Calculated Weight</td>
<td>0.277777778</td>
<td>0.16666667</td>
<td>0.1944</td>
<td>0.25</td>
<td>0.0278</td>
<td>0.083333333</td>
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<tr>
<td>Adjusted Weight</td>
<td>25</td>
<td>22.5</td>
<td>15</td>
<td>22.5</td>
<td>5</td>
<td>10</td>
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</table>

### Specification

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>Similarity to Real Birds</td>
<td>We want the bird’s movement to be more life-like than the Barker Bird. The movement of the wings and neck should allow enough degrees of freedom to simulate a bird.</td>
</tr>
<tr>
<td>Replicable</td>
<td>Our design should be replicable and made of parts that are easy to find off the shelf. This will enable other students to follow our design process to create their own animatronic</td>
</tr>
<tr>
<td>Cost</td>
<td>We want our bird to be as low-cost as possible yet still fulfill the other specifications.</td>
</tr>
<tr>
<td>Student Interest</td>
<td>The design of the bird should gather interest from other students and prospectors. Additionally, the design should be accessible and easy enough to keep students’ interests when they are following it.</td>
</tr>
<tr>
<td>Weight</td>
<td>The design should be the lowest weight possible while still fulfilling the specifications outlined by sponsors and customers.</td>
</tr>
<tr>
<td>Complexity of Design</td>
<td>The design should be the least complex as possible to ensure students can build it and understand what they are building. Additionally, complexity tends to bring problems into the design.</td>
</tr>
<tr>
<td>Specification</td>
<td>Weight</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Similarity to Real Birds</td>
<td>25</td>
</tr>
<tr>
<td>Replicable</td>
<td>22.5</td>
</tr>
<tr>
<td>Cost</td>
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<tr>
<td>Weight</td>
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<tr>
<td>Complexity of Design</td>
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<tr>
<td>Total:</td>
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</tbody>
</table>
Barker Bird Animatronic Project Final Design Review

June 2, 2021

Presented By Team F71:

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CAPED (Cal Poly Amusement Park Engineers and Designers) Club

Peter Schuster, Senior Project Advisor
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1. Design Updates

After completing CDR, we realized that our design needed several updates. Some of the main things we changed were overall height of the bird, increased clearance for inserting servo motors, and updating the PCB for required changes. The changes we made are found below and are separated into mechanical design updates, software development updates, and electrical system updates.

1.1 Mechanical Design Updates

We made mechanical updates to the majority of our subsystems after CDR. The use of rapid prototyping allowed us to design, print, test, redesign, and reprint (often several times). One of the biggest areas of redesign was in system integration. We changed our mind several times on how each of the subsystems would come together and how to best achieve a proper fit between subsystems.

1.1.1 Overall Bird Height

After CDR, we determined that the overall height of the bird was around two feet tall. The full CAD assembly allowed us to see that our height to wingspan ratio was way off, and it would have been very difficult to increase our wingspan to match the height of the bird. Instead, we decided to reduce the overall height of the bird. This included minimizing “wasted space” in the areas where subsystems came together. We were able to reduce the height of the bird to around 16 inches, which gives it much more reasonable proportions. Another factor in changing the overall height of the bird was to angle the bird so that the head comes forward and is not longer over the center of the bird. This change made the bird look more realistic, and also reduced how tall the bird appeared when looking at it. This change is depicted in Figure 1 below.

Figure 1: Change in Overall Bird Height. CAD Model at CDR (Left) and Most Recent CAD Model (Right)
1.1.2 Head and Neck Changes
After CDR, we determined that our prototype presented at CDR, while functional, needed some updates. The first update was increasing the clearance for the neck motor in the bottom of part H1. This included updating the axis of rotation to utilize a heat set insert. The addition of this insert reduces the overall “bounce” we experience during our CDR demo while moving the head up and down. This updated area is shown below in Figure 2.

![Figure 2: Updated Head to Neck Joint]

In addition, we increased the clearance for the beak servo motor. Prior to the update, the beak motor took significant force to push into place, but with the new design, the motor should be easily inserted into place. This part was not tested in our final prototype however, no mounting holes were moved, the biggest change was removal of material in areas that were not important to the functionality of the head. This update will improve the ability of future assembly and disassembly.

Lastly, we added a thrust bearing to the neck rotation. During CDR, we received feedback and many people, us included, were worried about the weight of the head and neck working axially through the motor shaft. Now, the weight of the head and neck is distributed through the thrust bearing and into the motor housing to relieve the axial load on the servo motor.

1.1.3 Motor Update
After completing our initial prototype, we realized that the MG90s servo motors that we intended on using to actuate all of our movement were not strong enough to overcome the friction and weight of flapping or extending the wings. In order to produce a fully functional prototype, we ordered new motors with around 5x more torque, the MG995 servo motor. We updated the shoulder blades of the bird (Part W7R/L) and the spine (Part T1) to properly mount these new motors and were able to produce the desired movement.
1.1.4 Torso Changes
We updated the torso from a round cross section to a square cross section after CDR. This improved quality and time required to 3D print the part, as well as improved the joints between other parts because the square cross section removed any possible rotation where the parts came together. In addition, we made small changes to the spine (Part T1) to house the new servo motors. In addition, we created a more robust joint where the shoulder blades (Part W7R/L) attach. These changes are shown in Figure 3 below.

![Figure 3: Old (Left) and New (Right) Spine](image)

1.1.5 Wing Changes
The main update that came after CDR was a change in the cross section of the wings. We initially had an I-Beam shaped cross section, but we moved to a rectangular cross section. Although the I-Beam design has a higher strength and stiffness to material ratio, since the parts are all 3D printed, the overhangs on the I-Beam shape would require supports to print, so it made more sense to move to a rectangular cross section because they required the same amount of material to print and require less post-processing to remove supports.

1.1.6 Lower Body Changes
For CDR, we did not have much complete in terms of the lower body of the bird. For our final prototype, we added legs and feet for purely aesthetic reasons. These attach into the coupler (Part L1) and provide no structural support to the bird because we wanted all of the bird to be supported through the PVC perch and down into the base.
1.1.7 Base Changes
The design changes that we made to the base were significant. We had initially planned to have a friction wheel driven by a small DC motor. We updated the design to use a stepper motor attached to a pinion that rotated on an internal gear. The internal gear and other slots in the bottom wooden piece were laser cut in Mustang 60. The design change is shown below in Figure 4.

![Figure 4: Friction wheel design (Left) and updated geared design (Right)](image)

1.2 Software Development Updates
No significant software changes were made after CDR. The only change was adding a section of the code to make sure that all the animations have been completed and restarts the animation loop after they have all been completed.
1.3 Electrical System Updates
Several modifications needed to be made to the CAPED BarkerBird PCB. First, the pinouts for the LM2576TV-5G were incorrect. The incorrect pinouts can be seen in Figure 5 and the updated can be seen in Figure 6. Next, the power and ground connections to the Arduino Mega were originally incorrect and have also been updated. Additionally, some of the connections to the stepper motor were crossed, making it more difficult to connect to the PCB, we have also updated this. A connection was added from the busy signal of the DFPlayer mini MP3 to the Arduino Mega. We did this to inform the software when the Barker Bird has finished talking. Finally, some of the tolerances and trace widths have been changed to comply with manufacturability standards.

In addition to the changes above, we found that the original audio level to position sensor was designed with an inaccurate assumption. We assumed that the audio coming from the DFPlayer mini-MP3 players audio was centered at 0 volts. However, our testing revealed that the DFPlayer mini-MP3 players audio has a 2.5-volt DC offset. This made the audio level to position sensor not well-suited for this purpose. After simulating the output with the 2.5-volt offset, we
determined that a high pass filter could be added to remove the offset. With the DC offset removed the circuit should work as intended, however we have not validated this new design. Simulations of the new design can be seen in Figures 7 and 8. We added this new circuit to the PCB and saved it in a different file, this can be seen in Figure 9.

![Figure 7: High-Pass filter added to Audio to Position sensor](image)

![Figure 8: V(n0002) input V(vout) output](image)

![Figure 9: Changes Plus Lowpass Filter](image)
2. Manufacturing

The goal of this project was to develop a replicable animatronic. For this reason, all of our parts were either readily available from Amazon, local hardware stores, or 3D-printed. This allowed for our design to be easily reproduced and manufactured.

2.1 Part Procurement

One of our main design considerations was design for replicability. We wanted to make sure that our final design could be easily reproduced by CAPED club members. For this reason, all of our custom parts were designed to be 3D printed, or easily manufactured using readily available materials like plywood and PVC pipe. In addition, we chose to use consumer level servo motors available from Amazon or similar websites. If the club wanted to use other servo motors in the future, the parts that were designed to interface with the motors can be easily updated and reprinted.

In addition, we decided to use a standard size fastener for all of our attachment points. We decided to order our fasteners through Fastenal in San Luis Obispo. Fastenal provided us a discount because we are part of the Mechanical Engineering Department.

We had a budget of around $300 for this project. A full itemized list of our orders and project budget is shown in Appendix A: Final Project Budget. A summary of our budget is shown below in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Budget</td>
<td>$300.00</td>
</tr>
<tr>
<td>Ordered Parts</td>
<td>$252.81</td>
</tr>
<tr>
<td>Fasteners</td>
<td>$17.00</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>$22.99</td>
</tr>
</tbody>
</table>

2.2 Manufacturing Methods

We used several different manufacturing methods throughout the process of this project such as 3D printing, soldering, laser cutting, and use of basic hand tools.

2.2.1 Printed Circuit Board (PCB)

Order the CAPED Barker Bird Printed Circuit Board (PCB) from the manufacturer of your choosing using the provided files. Solder the electronic components of the Barker Bird onto the CAPED Barker Bird PCB as detailed in Appendix B. Then place the CAPED Barker Bird PCB board onto the Arduino Mega microcontroller so that all the downward facing pins are interfaced into the microcontroller. The PCB can be manufactured, and components can be soldered on anywhere that is well ventilated, has access to a soldering iron, and has access to flush cutters. The full manufacturing guide is in Appendix B PCB Manufacturing. This procedure has been updated to reflect correct PCB manufacturing because of several issues we had that are discussed in the assembly section.

2.2.2 Base Manufacturing

We manufactured this base with the tools available in the Mustang 60 machine shop according to the procedure listed in the User Manual in Appendix H. We did not experience any issues using this procedure.
2.2.3 3D Printed Parts
The majority of our custom parts were 3D printed. We had several different print settings depending on how much stress was going to be on our parts. However, all parts were printed with PLA using 0.2mm layer height with a nozzle temperature of 200°C and a bed temperature of 60°C. The general settings based on structure (load bearing, structural, cosmetic) are listed below in Table 2.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Infill</th>
<th>Walls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Bearing</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>Structural</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td>Cosmetic</td>
<td>25</td>
<td>3</td>
</tr>
</tbody>
</table>

We chose these settings to maximize strength where important and minimize material usage and print time. The individual part settings as well as part orientation is shown in Appendix D. 3D Print Settings and Orientation. As a general rule of thumb, the embossed part name should be pointed up on the print bed (the face opposite the embossed name should be touching the print bed).

2.2.1 PVC Manufacturing
We bought three feet worth of 1 inch nominal pipe and a foot worth of ½ inch pipe. Both of these pipes need to be cut to length. The ½ inch pipe was cut to any length the designer wants in order to mimic a tail that can have feathers attached to it. The 1-inch nominal pipe served as the perch of the bird and was in a T-shape. As a result, two pieces were to be cut to two 6-inch-long pieces that were be the tees of the bird. The remaining piece was cut to a 14-inch-long piece of PVC pipe that will serve as the “base”. A ruler and marker were used to measure out and mark the distances that need to be cut. The PVC pipe was cut on a miter saw, with the piece properly fixtured to the worktable with appropriate clamps. All necessary tools can be found in the Mustang 60 Machine Shop on Cal Poly campus. Reference Appendix for a step-by-step procedure for cutting the PVC pipe along with pictures.

2.3 Full Assembly
The only tools required to assemble our bird after manufacturing is a hand-held screwdriver and a container of PVC cement, both of which can be found in Mustang 60’. A full step-by-step procedure can be found in the user guide’s manufacturing and assembly sections in the Appendix H.

2.3.1 Base Assembly
The parts assembled for the base subsection of the bird were the bottom disk, top disk, “Lazy Susan” bearing, stepper motor, and 3D-printed pinion for the stepper motor. These are assembled together with #6-32 wood screws and should be connected in a specific order. First, we attached the “Lazy Susan” bearing and the stepper motor to the top disk by screwing them into their respective positions. Before securing the bottom disk, we pressed the drive pinion onto the stepper motor. The “Lazy Susan” bearing was then screwed into the bottom disk through the clearance holes on the top disk.
2.3.2 Wiring the base
We wired the base by using wire cutters, wire strippers, a crimping tool, crimps, and twist-on wire connectors. We attached the slip ring to the top part of the rotating base with the wires on the swiveling end pulled all the way through to the other side of the base. With the slip ring connected, we cut the rubber insulation off one female and two male DC power connectors. We then cut both the red and black wires for each DC power connector to a manageable size, about 6 inches. Once that was complete, we connected the red end to one side of a power switch using the included crimp. Next, we connected the other end of the power switch to the red wire on the swiveling end of the slip ring using the included crimp. Finally, we connected the black wire of the swiveling end of the slip ring to the black wire of the female DC power connector using male and female 22-16 crimps. Lastly, we connected the non-swiveling side of the slip ring to the matching-colored wires from the two male DC connectors using twist-on wire connectors.

2.3.3 Assemble 3D Printed Parts
Servo motors were placed in their respective places before we assembled and were connected to the 3D printed parts with #6-32 screws. A full assembly guide is in the User Manual.

2.3.4 Assemble PVC Perch
Using the 3D printed holder for the PVC pipe, we lined up the holder with the center of the top piece of the wooden base, piece B4. We marked holes for the holder with a pencil to prepare for drilling. Using #6-32 wood screws, we fastened the 3D printed holder to the top piece of the wooden base using a cordless hand drill with a Phillips head screw bit. We applied PVC pipe primer to the 15-inch long, 1-inch nominal pipe. It was important for us to glue before the primer dries and to slide the pipe into the 3D printed holder that fastened to the wooden base. We connected the cross connector from Home Depot to the pipe. Then we applied primer and glue to the smaller two pieces of PVC pipe before we fit the pieces into the left and right sides of the cross connector.

2.3.5 Assembling the PCB
Assembling the PCB can be done anywhere with access to a soldering iron, flush cutters, and that is well ventilated. The CAPED Barker Bird PCB was assembled using the guide found in Appendix H. When assembling it, we found that the part LM2576TV-5G did not match the EAGLE library used. We addressed this by manipulating the part and to fitting it to the board as ordered. Additionally, there was a mistake with the power and ground pins from the Arduino to the CAPED Barker Bird PCB. We have since updated the CAPED Barker Bird PCB so that in the future, Appendix H will be the correct procedure and will avoid the problems we faced.

2.3.6 Assembling Electronics
We attached the Arduino Mega microcontroller to the top part B1 with the screw holes on the microcontroller and #4-40 screws. We oriented it so that the back side of the Arduino was flush with the outer diameter of the base. Next, we attached the CAPED Barker Bird PCB to the Arduino Mega microcontroller by lining up the bottom facing pins of the CAPED Barker Bird PCB with the pins on the Arduino microcontroller. The PCB was located right on top, and we then connected each servo to the “Servo Extension Cables” as needed so that the cables reached the PCB. Then, we connected the cables to the CAPED Barker Bird PCB so that each servo was connected to the appropriately labeled pins. Finally, the wires were connected from the stepper motor to the CAPED Barker Bird PCB’s screw-in terminals so that each coil was attached to their respective labels on the board. Similarly, we connected the wires from the two potentiometers and the speaker to the appropriately labeled screw in connectors. Finally, we plugged the two DC male power connectors into the CAPED Barker Bird PCB and Arduino Mega microcontroller.
2.4 Challenges
During the manufacturing process, we faced several challenges. Some of the main challenges were dealing with print orientation and supports, laser cutting issues, and tight spaces for assembly.

2.4.1 Print Orientation and Supports
When 3D printing multiple parts with unique and complex properties, it was important to consider the orientation of the part in the slicer program. We decided that our prints would come out best if it started on a flat face with the greatest surface area as possible. This set a good foundation for the rest of the print and allowed the part to have supports. Furthermore, we tried to minimize any overhangs or parts of the print that were “hanging” in the air.
Whenever we could not avoid overhangs, we implemented the use of supports in our print. Supports supplied a material that started from the baseplate of the printer to provide structure to overhangs while the printer was working. Whenever supports were used, we carefully used various tools such as blades and needle nose pliers to rid the support material from the part. It was essential to remember how the supports were modeled in the slicer program to make sure we were removing support material and not material from the actual part.

2.4.2 Laser Cutting
In our first iteration of the laser cut wooden base, we used 3/4” plywood, since this is the overall thickness of the part we desired. We transitioned to using the on-campus laser cutters for making our base, due its simplicity and educational benefits for young students. Additionally, laser cutting adds another rapid prototyping process for students to familiarize themselves with. Using the material available, we attempted to cut out our 3/4” plywood sheet on the laser cutter. This promptly resulted in a charred, burned-out piece of wood that lost all the gear teeth and strong smokey smell. Because the laser cutters available at Mustang 60’ are not equipped to slice through plywood that thick, we transitioned to using 1/4” plywood sheet that were then glued together to the desired 3/4” thick structure.

2.4.3 Tight spaces for Assembly
One issue we had during assembly was fitting the parts into tight spaces. For example, the servo motor that controls the beak fits in a very small gap in the head, and it is difficult get the motor into place. This issue was fixed in the CAD model, but we did not have the time to reprint the head model.
3. Design Verification

Overall, we feel that our prototype provided us with useful information and is a very promising first version of the animatronic. In addition to having a functional prototype, the use of rapid prototyping methods allowed us to make many design changes during the testing phase of the project. During this last quarter, we tested the key deliverables of the project and fixed problems as they arose as documented in this chapter.

3.1 Specification Evaluation

Our prototype was designed to meet the specifications listed below in Table 3. To ensure these specifications were met, we designed and conducted several tests throughout the design process.

Table 3: Updated Engineering Specifications

<table>
<thead>
<tr>
<th>Spec #</th>
<th>Specification Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Similarity to real Macaw</td>
</tr>
<tr>
<td>2</td>
<td>Entire design cost under $500</td>
</tr>
<tr>
<td>3</td>
<td>Garners student interest</td>
</tr>
<tr>
<td>4</td>
<td>Ability for students to follow Design Process</td>
</tr>
<tr>
<td>5</td>
<td>Loud enough to attract attention</td>
</tr>
<tr>
<td>6</td>
<td>Ease to reproduce/recreate</td>
</tr>
</tbody>
</table>

3.2 Tests for Movements of the Bird

All functions of the animatronic were tested to make sure that our software, mechanical designs, and electrical wiring worked without interruption. Table 4 below details the requirements for the movement of each part.

Table 4: Mechanical Mechanism Testing Results

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Test Requirement</th>
<th>Results (Pass/Fail/Inconclusive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wings</td>
<td>Full extension to 20% extension</td>
<td>Pass</td>
</tr>
<tr>
<td>Flap</td>
<td>80 degrees to 30 degrees</td>
<td>Pass</td>
</tr>
<tr>
<td>Neck Rotation</td>
<td>90 degrees clockwise and counterclockwise relative to start position</td>
<td>Pass</td>
</tr>
<tr>
<td>Head Tilt</td>
<td>45 degrees up and down from start position</td>
<td>Pass</td>
</tr>
<tr>
<td>Base Rotation</td>
<td>135 degrees of rotation clockwise and counterclockwise</td>
<td>Pass (270 degrees)</td>
</tr>
<tr>
<td>Beak Actuation</td>
<td>Beak moves with speech of animatronic.</td>
<td>Pass (with separate microcontroller)</td>
</tr>
</tbody>
</table>
Although our tests are working now, preliminary testing of the wings and flapping mechanism proved that our servo motors for these mechanisms were not powerful enough. We initially used the same servo motors for the neck rotation, head tilt, and beak actuation on the wing flapping and extending mechanisms, which is rated for 2 N-cm. However, these servo motors did not work for the flapping and extending mechanism since these designs have a lot of moving parts and are heavier. As a result, we redesigned these mechanisms for more powerful servo motors, rated at 10 N-cm.

The wing extension, wing flapping, and head tilt were fully functioning to our standards. Although the stepper motor was fully implemented into our base, it moves slowly and creates a lot of noise. We recommend that a more efficient and powerful stepper motor is used to spin the base. Additionally, the internal gear that is laser cut into the wood should be fastened to the base with screws.

The beak actuation test did not pass as we originally intended since our designed printed circuit board did not properly actuate the beak. As a result, we used a separate microcontroller and created a separate circuit on a microcontroller to accomplish beak actuation. Currently, we need two power supplies due to this configuration, which isn’t ideal. We updated the PCB design to fix the beak actuation circuit so that future students can avoid this issue and run their animatronic with a single power supply, computer and microcontroller. Furthermore, part H3 that is responsible for connecting the servo motor to H2, the lower beak, slipped out when the motor rotated past the range it was designed for. This was both a mechanical and software issue since part H3 only slipped when the beak no longer had space to move. As a result, it is essential that students and future designers of the bird set software limits for the beak rotation so that the linkage doesn’t strip out. As a precaution, we have redesigned part H3 to have a smaller hole so that the press fit is tighter and there is less clearance. This solution solves the problem mechanically, but the issue will still be present if the servo motor tries to rotate outside of the ideal range.

3.4 Tests for Showcasing of the Bird
The bird will be used at club showcases and open houses to generate interest in the CAPED club. And therefore, we preformed several tests to determine the suitability of showcasing the bird.

3.4.1 Audio Level
The bird will be used at club showcases and open houses to generate interest in the CAPED club. Our audio test verified that our speaker was able to generate a maximum 82 dB of sound. While this number did reach the desired value of 80dB, we feel that the speaker needs to be louder. At senior expo, we learned that 80 dB was not nearly enough to hear audio files and recommend that a louder speaker and amplified audio file is used.
3.4.2 Cyclic Loading of Wings
During a showcase, the bird may be run for long periods of time, so we decided to run a cyclic loading test on the wings. The wings were an area of concern for our sponsors, and they asked us to provide them with an estimate of how long they will last to determine how often to replace high-wear parts. The results of this test are shown below in Table 5. Cyclic Loading Results.

Table 5: Cyclic Loading Results. Failure was from Part W10 stripping on the motor shaft at the 2:30 mark.

<table>
<thead>
<tr>
<th>Hour</th>
<th>Noticeable Wear (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Y</td>
</tr>
</tbody>
</table>

The cyclic loading test matches our FEA shown below. This FEA calculated in plane stress, with a torque of 10 N-cm applied to the bottom hole of part W10. The torque applied here simulates the servo motor attached to the part that causes the wing movement. The end tip of the wing system is also held fixed. The bottom hole of part W10 sees the highest stress and aligns with the fact that shear forces caused stripping at this hole.

3.5 Power Consumption Test
One test that we found necessary was to determine the power consumption for all of our motors. We preformed this test by measuring the current draw from each of the motors while they are under their intended torque. We then calculated the power from each motor. The results for this test are shown below in Table 6 Electronic Test Results.
Table 6: Electronic Test Results

<table>
<thead>
<tr>
<th>Motor</th>
<th>Idle Current (mA)</th>
<th>Max Current (mA)</th>
<th>Voltage (V)</th>
<th>Max Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beak</td>
<td>47.051</td>
<td>107.43</td>
<td>5.0001</td>
<td>0.537</td>
</tr>
<tr>
<td>Neck UD</td>
<td>62.492</td>
<td>230.38</td>
<td>5.0413</td>
<td>1.16</td>
</tr>
<tr>
<td>Neck LR</td>
<td>21.224</td>
<td>104.78</td>
<td>5.0408</td>
<td>0.528</td>
</tr>
<tr>
<td>Flap</td>
<td>10.467</td>
<td>297.82</td>
<td>5.0362</td>
<td>1.50</td>
</tr>
<tr>
<td>L Wing</td>
<td>10.261</td>
<td>336.69</td>
<td>5.0382</td>
<td>1.70</td>
</tr>
<tr>
<td>R Wing</td>
<td>12.899</td>
<td>108.82</td>
<td>5.0401</td>
<td>0.548</td>
</tr>
<tr>
<td>Total</td>
<td>164.394</td>
<td>1185.92</td>
<td>5.97</td>
<td></td>
</tr>
</tbody>
</table>

We also performed uncertainty calculations for our power readings to find the relative accuracy of our measured findings. Our calculated results show that there is a minimal amount of uncertainty, 0.33 W, so we determined this past our test.

Table 7: Electronic Uncertainty Calculations

<table>
<thead>
<tr>
<th>Motor</th>
<th>Uncertainty of Current (%)</th>
<th>Uncertainty of Voltage (%)</th>
<th>Uncertainty of Power (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beak</td>
<td>0.0093</td>
<td>0.0020</td>
<td>9.52</td>
</tr>
<tr>
<td>Neck UD</td>
<td>0.0043</td>
<td>0.0020</td>
<td>4.77</td>
</tr>
<tr>
<td>Neck LR</td>
<td>0.0095</td>
<td>0.0020</td>
<td>9.75</td>
</tr>
<tr>
<td>Flap</td>
<td>0.0033</td>
<td>0.0020</td>
<td>3.90</td>
</tr>
<tr>
<td>L Wing</td>
<td>0.0029</td>
<td>0.0020</td>
<td>3.57</td>
</tr>
<tr>
<td>R Wing</td>
<td>0.0091</td>
<td>0.0020</td>
<td>9.40</td>
</tr>
<tr>
<td>Total</td>
<td>% 0.039</td>
<td>% 0.012</td>
<td>% 5.5</td>
</tr>
</tbody>
</table>

The maximum power that can be managed by the PCB is 15 Watts. Our power consumption test determined that we are well below this value. Our power consumption test also indicated the servo motor that moves the left wing was taking too much current and thus made the other servo motors work less efficiently. We think this is due to a faulty motor, so we replaced it to fix the current issue. Furthermore, we learned that the servo motor that handles the head tilt up and down takes a lot more current than we expected. This makes sense since the servo motor holds the weight of part H1 at various positions and prevents it from drooping down. As a result, the servo motor draws current even when part H1 is not in the active movement of tilting up and down.
3.6 Uncompleted Tests/Specifications

Because of the technical difficulties we encountered during the last section of this project, we did not complete every test and specification we had hoped to. The specifications we did not complete and verify as planned are the beak movement and replicability of the bird.

In our original research, we had planned to coordinate the movement of the beak with the audio through using available circuits that map audio levels. With the addition of our custom printed PCB board, we integrated this in with the other functions of the board. In the last couple weeks of assembling and testing the bird, this circuit had not worked consistently, and the team was unable to find a solution with the materials we had available.

One of the main specifications of this project is that it is replicable and can be used as a kit for future students to replicate on their own. Although we designed the project to meet this specification, we were unable to properly test the specification because of technical difficulties. We combatted software and electronic errors up to expo, however after discussion with our sponsor at CAPED, we chose not to complete this test in favor of focusing on other pressing matters. CAPED will have the resources they need to conduct these tests and troubleshoot new errors as they implement this project for younger students.
4. Discussion and Recommendations

Throughout the design, manufacturing, and verification phases of our work on the project we have had the opportunity to learn valuable lessons about designing linkages with 3D printed components and integrating electronics. Although we are unable to start this senior design process again from the beginning, future members of CAPED who use this bird can and should continue the learning process by making future iterations of the bird. In this section we share some of the key lessons we learned while making our iterations, and our recommendations for the next iterations of the bird.

4.1 Challenges and Lessons Learned

This project provided numerous lessons about 3D printing, linkage design, electrical engineering, and software development. The lessons we learned about 3D printing focused on the orientation of prints and the infill density used in the prints. Refer to the manufacturing section of the Appendix H for the printing and design specifications for manufacturing with a 3D printer.

Lessons we learned through the linkage design include the difficulty to estimate friction forces. During the first iterations of design, we assumed all friction forces at joints would be negligible compared to the torque produced by the servos. Specifically for the wing extension, motors cannot operate if the assembly is fastened with too much torque at the joints. If the linkages are too loose, the wings will rattle as they extend, so users are required to fasten the assembly to a specific torque. Future designs could include a way to either clearly specify what torque is acceptable, or to design joints where further torquing does not cause large increases in friction.

Furthermore, we learned that there are inevitable setbacks when assembling any design that we did not foreshadow or design for. For example, our animatronic stopped working the next day after testing for some unknown reason. After testing the electronic components with a multimeter, we learned that the buck converter controller shorted out since one of its leads touched another of its leads. As a result, we had to buy a new part, remove the shorted part from the PCB, resolder the new part, and wrap electrical tape around the leads. Although we spent an extensive amount of time designing this entire project, there are problems that become apparent only during assembly that were hard to predict.

4.2 Recommendations for Design Continuation

Two functions of the bird we originally planned to include was a bowing motion and eye blinking. Designing the bird to bow would be of medium difficulty and would only require redesign of one part (T3). Additionally, we had hoped to integrate motion sensors into the bird allowing it to orient itself to face whomever it was dancing for. A LIDAR sensor could be installed somewhere on the perch and used to coordinate the rotation of the base towards motion.

Two functions of the bird that are included in our final design but are not working to our standards is the base rotation and the audio. Specifically, we designed the base rotation with an inexpensive stepper motor and stepper motor driver, causing it to operate with excessive vibrations and noise. Replacing these components would only require small changes to the custom parts and would greatly improve the function of the base.
4.3 Recommendations for Future Use
Our team designed this project for the final deliverable to be a kit that will be built by new students with limited assistance from experienced club members. Although this document is extensive in explaining how to reproduce and use the bird, we have a couple specific recommendations to have a smooth experience with the project.

4.3.1 Purchasing Supplies
Luckily for the club, many of the components can be purchased from online retailers such as Amazon. Materials not purchased from Amazon include the custom printed PCB board, circuit components, fasteners, plywood, and PVC pipe. We recommend that the fasteners, PCB boards, circuit components, and motors are purchased in bulk to limit the cost per bird. Another reason to buy in bulk is because we experienced a couple faulty motors and circuit components which had to be replaced with rushed shipping.

4.3.2 Spare parts
With the entire project designed around low-cost components and 3D printed linkages, durability should not be considered a strong point for the project. If the club makes multiple birds each year, it would be convenient to keep spares of all 3D printed parts. Additionally, keeping spare electrical components is imperative in case the inexpensive parts either fail or arrive faulty as ordered.

4.3.3 Dance Routine Development
The PCB board is not rated to run all motors simultaneously, and it is not designed to run multiple motors non-stop for long periods of time. Further testing is required to find the upper limits of this board’s capabilities, however an easy recommendation for future programmers is to stagger the movements of the joints. A safe rule of thumb is that 3 motors can be running at the same time, and there should be pauses throughout the routine to prevent overheating the motors or circuit.

5. Conclusion
All of us learned about many fields of engineering through this project such as electrical wiring, software development, linkage design, and rapid prototyping. Additionally, we learned a lot about management and documentation. We were able to develop a fully functioning prototype that met all the engineering specifications we established in the beginning of the school year. We hope that this project will be showcased at Cal Poly Open House and Club Showcase for years to come. Additionally, we hope to see this design iterated on to implement various new improvements and functions.
Appendices

Appendix A. Final Project Budget
Appendix B. DVP&R
Appendix C. Test Procedures
Appendix D. Software
Appendix E. Calculations (New since CDR)
Appendix F. Kinematic Calculations
Appendix G. Risk Assessment
Appendix H. Owner’s Manual
## Appendix A: Final Project Budget

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<th>Description of items purchased</th>
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**Total Expenses:** $384.15  
**Total for 1 bird:** $147.94
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**Appendix B: DVP&R**
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**Test Plan - Design Verification Plan (G Report)**

- Test Plan
- Design Verification Plan
- G Report
Appendix C: Test Procedures

**Power Draw Test Procedure:**

**Scope:** Power consumption of each major electrical component, including the servos, stepper motor, and speakers.

**Equipment:**
- Multimeter
- Breadboard
- Measured electrical components

**Hazards:** Electrical components should be treated as live at all times. Avoid touching bare wires. All electrical currents and voltages are small, so major safety risk is not present.

**PPE Requirements:** Wear safety glasses when operating moving parts.

**Facility:** This test can occur on any tabletop that is clear of obstacles. The tabletop should be made of a non-conductive material.

**Procedure:**
1. Connect a servo to the bread board in addition to your power device.
2. Connect the multi-meter leads to breadboard allowing you to read power across the servo.
3. Repeat steps 1-2 for the speaker and stepper motor devices.
4. Multiply the power consumption of each part by the number occurring in bird (6 servos, 2 speakers, 1 stepper), and take the summation to find total power use.

**Results:** Repeat measurements of power at least three times for each component, taking the average for each component in the total power summation. If total power consumption is 90% or less than the total power available through the buck convertor, the test passes.
**Joint Movement Procedure:**

**Scope:** Use a computer and potentiometer to test the max rotation of the servo-controlled joints of the Barker Bird.

**Equipment:**
- Potentiometer
- Computer
- Protractor

**Hazards:** Electrical components should be treated as live at all times. Avoid touching bare wires. All electrical currents and voltages are small, so major safety risk is not present.

**PPE Requirements:** Wear safety glasses when operating moving parts.

**Facility:** This test can occur on any tabletop that is clear of obstacles. The tabletop should be made of a non-conductive material. We will be using 192-130

**Procedure:**
1. Connect a potentiometer to the A0 analog pin on the Arduino.
2. Download the PotentiometerTest.cpp code to the Arduino.
3. While Test code is running turn the potentiometer as far as it can go.
4. Read the angles from the serial monitor on the Arduino IED.
5. Visually inspect that there are no crashing components.
6. Repeat turning the potentiometer the other direction.

**Results:** Check the measured results to make sure they don’t exceed maximum angle of each respective joint as specified in owner’s manual.
Test Procedure for Beak and Audio Synchronization

Purpose:
Ensure beak opening is synchronized to audio file

Equipment/Parts:
1. PCB board
2. 3D printed head and beak

Location:
Any Space

Safety:
1. Ensure electrical connections are secure
2. Safety glasses

Data Collection:
NA this is a test that is qualitative, not quantitative

Procedure:
1. Download mp3 file that you want to test to the microcontroller
2. Run the program that synchronizes beak movement to mp3 audio levels
3. Verify the beak opening and closing matches the peaks and valleys of the audio file
4. If adjustment is desired, the knobs on the PCB can be rotated
   a. Knob 1 adjusts the lag time between when the audio plays and when the beak opens. Turn this clockwise to increase the lag time and counterclockwise to decrease the lag time to the desired level.
   b. Knob 2 adjusts the maximum that the beak will open. If you desire the beak to open a greater amount, turn knob 2 clockwise. If you want to reduce the opening, turn the knob counterclockwise.
Test Procedure for Ensuring Parts Fit Together

Purpose:
Ensure no crashing when multiple movements are attempted at the same time

Equipment/Parts:
Fully assembled Bird

Location:
Any Space

Safety:
1. Ensure electrical connections are secure and you stand clear of the bird while it is preforming its movements.
2. Safety glasses

Data Collection:
NA this is a test that is qualitative, not quantitative

Procedure:
1. Ensure all parts are assembled correctly
2. Connect all wires according to the provided wiring diagram
3. Run CrashTestCPBB file on the microcontroller
   a. This program goes through a range of movements that ensure all components are working correctly, and interface correctly together.
4. If no parts crash during the test, test is successful
5. If parts do crash, check assembly instructions, and check for potential damage to parts
Cyclical fatigue test on the wing mechanism

Purpose:
Test the wing durability when operating for an extended period of time

Equipment/Parts:
1. Fully assembled wing mechanism
2. Electrical board

Location:
Any open and undisturbed place where the bird could open and close its wings many times.

Safety:
1. Make sure no people around who could accidently get withing range of the wings.
2. Ensure that motors will survive this prolonged use and have a failsafe in place if the motor was to fail before the wings.
3. Safety glasses

Data Collection:
Wear on wing joints. We will measure the diameter of the wing joints before, during, and after this test to see how the joints fail over time. This will allow us to estimate the overall lifespan of the wings. Use table on following page to record data.

Procedure:
1. Assemble wing mechanism
2. Attach to testing fixture (likely plywood of some kind)
3. Actuate the wings to ensure everything is working properly
4. Set up a loop to open and close the wings completely over and over
5. Measure the diameter of the wing joint holes at consistent time intervals (1 hr or 2 hrs)
6. If no major deformation after 12 hours of testing, the joints are suitable for our application and have a reasonable life

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Base Rotation Functionality Test

**Purpose:** Ensure that rotation of 270 degrees for the base is possible

**Scope:** This animatronic will need to be able to spin in order to “bark” at people around it. 270 degrees is the limit because a full 360 degrees would potentially cause wire tangling.

**Location:** Bonderson 104 Classroom

**Equipment:**
- Functioning servo motor
- Manufactured Base
- Assembled Bird

**Hazards:** Snagging of Wires, Moving Parts (Perch may hit someone standing by while spinning)

**PPE Requirements:** None required

**Facility:** Empty classroom

**Procedure:** (List number steps of how to run the test, can include sketches and/or pictures):
1) Set up assembled bird and base in classroom
2) Use user interface code to actuate base and cause it to rotate 180 degrees in each direction
3) Observe if the 180 degrees in both direction is achieved (use a protractor or visual observation)
4) Determine if any wires got any tangled, also check other functions of the bird to ensure it is still functioning properly

**Results:**
The test passes and the base is able to rotate the amount that we indicated.

**Test Date(s):** 5/9/22

**Test Results:**
Pass if able to rotate 180 degrees around

**Performed By:**
Jonathan Ogden
Audio Level Requirement

**Purpose:** Ensure the speaker reaches at least a volume of 75 decibels

**Scope:** This animatronic will be showcased at Open House and Club Showcase, both of which are loud events with a lot of people. The bird’s speaker must reach a volume of 75 decibels since this level is equivalent to the noise of heavy traffic or a busy restaurant.

**Location:** TECHE Lab 192-130 and Orange Parking Lots

**Equipment:**
- Functioning speaker
- Smartphone
- IPhone App Decibel X (or any phone app that measures audio levels)

**Hazards:** Loud sounds

**PPE Requirements:** None required

**Facility:** Empty classroom and Outside Area (preferably a parking lot)

**Procedure:** (List number steps of how to run the test, can include sketches and/or pictures):

1) Set up bird in empty classroom so that it can speak and run the corresponding code.

2) Open the Decibel X app on your smartphone and start measuring the audio levels.

3) Measure the sound level at three different occasions and average them. If the average is higher than 75 decibels, the test is passed.

4) Repeat Steps 1-3 outside to simulate an event like Club Showcase

**Results:**

**Classroom Test**

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**Test Date(s): 2/25/22**

**Test Results:**
Pass if average is above 75 decibels

**Performed By: Ishan Jandaur**

**Discussion:**
The average for the outdoor test is higher than the average for indoor test due to other noise coming from students and general commotion. However, both tests pass.
Appendix D: Software

#ifndef ANIMATION_H
#define ANIMATION_H

#include "Actions.h"

//This initializes all the actions the Barker bird can take

SeroAction* BEAK = new SeroAction(); //this is the action that allows the BarkerBird to open and close its mouth
SeroAction* FLAP = new SeroAction(); //this one will makes the BarkerBird flap its wings
SeroAction* NECK_L_R = new SeroAction(); //this one rotats the neck left and right
SeroAction* NECK_U_D = new SeroAction(); //this on rotates the neck up and down
SeroAction* WING_R = new SeroAction(); //this one extend the right wing
SeroAction* WING_L = new SeroAction(); //this one will extend the left wing
AudioAction* SPEAK = new AudioAction(); //this one will make the BarkerBird play a pre recorded voice live
StepperAction* BASE = new StepperAction(); //this one will move the base the BarkerBird sits on left and right

//to use any of the actions above you will call the by the all uppercase letters for example FLAP
//This Animation struct is the format in with each animation will be called

struct Animation
{
    unsigned long ActionTime; // Number of milliseconds after last animation or starts to do this action
    Action* ActionToAct; // Which Action is it?
    int PositionTrack; // Position form 0-100 or track number
    // for the base - numbers are CCW and + are clockwise
    int SpeedValume; // Speed or Valume 0-100
};

//the animations will be created hellow by fallowing the animation format above
//for example if I wanted the BarkerBird to flap its wing to 50% 100 milliseconds after the last action at 20% speed
//I would right {100, FLAP, 50, 20}
// {time, thing preforming the action, move to, howFast },

Animation Actions[] = {
    {100,   NECK_L_R, 50, 20},
    {0,     NECK_U_D, 50, 20},
    {1000,  SPEAK, 1, 30},
    {1000,  BASE, -80, 100},
    {1000,  NECK_U_D, 25, 25},
    {1000,  FLAP, 100, 25},
    {1000,  WING_L, 100, 25},
    {1000,  WING_R, 100, 25},
    {1000,  BASE, 100, 100},
    {0,     NECK_U_D, 90, 25},
    {100,   NECK_L_R, 50, 30},
    {1000,  NECK_L_R, 10, 40},
    {1000,  WING_L, 0, 25},
    {1000,  WING_R, 0, 25},
    {1000,  FLAP, 0, 25},
    {0,     NECK_U_D, 25, 30},
    {1500,  NECK_L_R, 50, 40},
    {0,     NECK_U_D, 50, 30},
    {1000,  BASE, 0, 100}
};

#endif
```c
#ifndef ACTIONS_H
#define ACTIONS_H

#include <VarSpeedServo.h>
#include "DFRobotDFPlayerMini.h"
#include "AccelStepper.h"

const int BEAK_PIN = 13;
const int NECK_U_D_PIN = 10;
const int NECK_L_R_PIN = 9;
const int FLAP_PIN = 8;
const int BAS_DIRECTION_PIN = 5;
const int BAS_STEP_PIN = 4;
const int WING_R_PIN = 11;
const int WING_L_PIN = 12;

const int STEPPER_CONST = 3;

const int BEAK_INTERCEPT = 1029;
const int FLAP_INTERCEPT = 1500;
const int NECK_U_D_INTERCEPT = 613;
const int NECK_L_R_INTERCEPT = 1094;
const int WING_R_INTERCEPT = 1500;
const int WING_L_INTERCEPT = 1500;

const double BEAK_SLOP = -1.97;
const double FLAP_SLOP = 5;
const double NECK_U_D_SLOP = 15.87;
const double NECK_L_R_SLOP = 13.25;
const double WING_R_SLOP = -4;
const double WING_L_SLOP = 4;

const int BEAKdefault = 1500;
const int FLAPdefault = 1500;
const int NECK_L_Rdefault = 1500;
const int NECK_U_Ddefault = 1500;
const int WING_Rdefault = 1500;
const int BASEdefault = 675;
const int WING_R_DEFAULT = 1500;
const int WING_L_DEFAULT = 1500;

class Action {
public:
    virtual void doAction(int pos, int Speed){
    }
    virtual int isDone(){
        return 0;
    }
};
```
class SeroAction : public Action{

private:
    VarSpeedServo MyServo;
    double Slop;
    int intercept;
    int pin;
    int initalPosition;
    int finalPosition;

public:
    void doAction(int pos, int Speed){
        if(pos > 100){ pos = 100; }
        if (pos < 0) { pos = 0; }
        this->finalPosition = Slop*pos + intercept;
        MyServo.slowmove(finalPosition ,Speed);
    }
    int isDone(){
        /* retnurs 0 if done and nonzer if not */
        return this->MyServo.readMicroseconds() - this->finalPosition;
    }
    int getFinalPosition(){
        return this->finalPosition;
    }
    void setPin(int pin){
        this->pin = pin;
    }
    int getPin(){
        return pin;
    }
    void setSlop(double slop){
        this->Slop = slop;
    }
    double getSlop(){
        return Slop;
    }
    void setIntersept(int intersept){
        this->intersept = intersept;
    }
    int getIntersept(){
        return intercept;
    }
    void setInitalPosition(int intersept){
        this->initalPositon = initalPositon;
    }
    int getInitalPositon(){
        return initalPositon;
    }
}
void setMyServo(VarSpeedServo myServo){
    this->MyServo = myServo;
}
VarSpeedServo getMyServo(){
    return MyServo;
}

void init(int Pin, double Slop, int Intersept, int InitalPositon){
    this->setPin(Pin);
    this->setIntersept(Intersept);
    this->setSlop(Slop);
    this->setInitalPositon(InitalPositon);
    getMyServo().attach(Pin);
    getMyServo().slowmove(InitalPositon, 25);
}

};
class AudioAction : public Action{

    private:
    DFRobotDFPlayerMini myPlayer;

    public:
    void init(HardwareSerial *stream, int baudrate){
        stream->begin(baudrate);
        myPlayer.begin(*stream);
    }
    void doAction(int track, int volume){
        myPlayer.volume(volume);  //Set volume value. From 0 to 30
        myPlayer.playMp3Folder(track);  //Play the mp3
    }
    int isDone(){
        return (myPlayer.read() == Sleeping) ? 0 : -1;
    }
};
class StepperAction : public Action{

    private:
    AccelStepper myStepper;
public:

    void doAction(int Steps, int Speed){

        if(Steps > 100){ Steps = 100; }
        if(Steps < -100) { Steps = -100; }

        Steps = Steps*(STEPPER_CONST)*STEPPER_CONST;

        myStepper.setMaxSpeed(Speed);
        // myStepper.setAcceleration(Speed/2);
        Serial.println(Steps);
        myStepper.moveTo(Steps);

    }

    void init(int dirpin, int steppin, int stepstosenter){

        myStepper = AccelStepper(steppin, dirpin);
        myStepper.setAcceleration(100.0);
        myStepper.runToNewPosition(STEPPER_CONST*stepstosenter);
        myStepper.setCurrentPosition(0);

    }

    int isDone(){
        return myStepper.distanceToGo();
    }

    void run(){
        myStepper.run();
    }

};

#endif
Appendix E: Calculations (New since CDR)
The FEA above shows the out of plane stress seen when 4lbf distributed across all the wing linkages. The part is fixed at the part at the far right, W10, and at the middle hole of part W1. The largest stress and largest displacement are shown below.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largest Stress</td>
<td>5.12E7</td>
</tr>
<tr>
<td>Largest Displacement (mm)</td>
<td>117</td>
</tr>
</tbody>
</table>
The FEA shown above is done to observe the in-plane stress of the wing system. A torque of 10 N-cm is applied to the bottom hole of part W10 and the end tip all the way on the left is fixed. The highest stress and displacement is shown below.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largest Stress</td>
<td>1.024E7</td>
</tr>
<tr>
<td>Largest Displacement (mm)</td>
<td>4.079E-2</td>
</tr>
</tbody>
</table>
Bolt tearout calculations were done for the wings that are using M2 screws. The equation comes from pg. 446 *Shigley’s Mechanical Design 10th Edition*:

\[
\tau = \frac{F}{at} = \frac{0.577(S_y)}{n_d}
\]

\(N_d = \text{safety/design factor}\)

\(S_y = \text{yield strength of material}\)

Using a safety factor of 1.5, the highest force that can be applied in shear to the bolts is 77 lbf, which is a lot higher than any force we anticipate the bolts to encounter.
Description
The purpose of this exercise is to model the position of the wing tip and the forces acting on linkages.

Problem Statement
Consider a multi-bar mechanism with rotating parts. This code solves given mechanism lengths and angles, along with finding the velocity and accelerations of different points on the figure.

Geometric Calculations for Wingtip
Purpose:
To relate servo angle position, velocity, and acceleration to the position, velocity, and acceleration of the wingtip. Additional function plots wingtip position over a range of servo motor angles that can be used to validate location of servo motor.

Establishing Variables
Analysis for given equations can be found through hand calculations shown in the appendix.
Setting symbolic variables and setting system lengths

This is good practice on all complex programs, as it prevents variable of the same name used in previous programs conflicting with the operation of our code

```matlab
clear;
```

Lengths of linkages, including total lengths and joint to joint:

This information can be verified from solidworks parts that all have their respective naming scheme

This code was generated in the second quarter of the senior project, before all parts where adopted to a naming scheme. As seen in the PDR and CDR documents, the wing linkages are refered to as Part A, Part B, ..., Part F. Those parts are currently called W1, W2, ..., W6 in the solidworks part files. to keep uniform with the hand calculations made, the A-F naming scheme is kept in this document, and in the lengths below you can find the current names of the linkages referenced.

```matlab
% Part A, labeled as Part W1:
syms l_a l_a0 l_a2
L_a0 = 0.50; % in
L_a2 = 0.75; % in
L_a = L_a0+L_a2; % in

% Part B, labeled as Part W2:
syms l_b l_b0 l_b1 l_b2
L_b0 = 0.50; % in
L_b1 = 6.0; % in
L_b2 = 0.75; % in
L_b = L_b0+L_b1+L_b2; % in

% Part C, labeled as Part W3:
syms l_c
L_c = 6.0; % in

% Part D, labeled as Part W4:
```
Servo motor values

These values describe the geometric lengths of the servo motor parts and establishes symbolic variables for the angles, angular velocities, and angular accelerations.

Simple Position Calculation from Servo Angle:

System's Independent Variable:

Finding position of servo connection point, S0 (s-knot)

Finding angles from S0 location
Wingtip Calculation at Point 7, the farthest point of the outer linkage, Part F (W6)

Wingtip Position (Symbolic):

\[
P_7_x = (l_{a2} + l_{d1}) \cos(\theta_A) + (l_c + l_f) \cos(\theta_B) + P_0_x;
\]
\[
P_7_y = (l_{a2} + l_{d1}) \sin(\theta_A) + (l_c + l_f) \sin(\theta_B) + P_0_y;
\]

Wingtip Velocity (Symbolic):

\[
P_{7_x\_dot} = \text{diff}(P_7_x, t);
\]
\[
P_{7_y\_dot} = \text{diff}(P_7_y, t);
\]

Wingtip Acceleration (Symbolic):

\[
P_{7_x\_ddot} = \text{diff}(P_{7_x\_dot}, t);
\]
\[
P_{7_y\_ddot} = \text{diff}(P_{7_y\_dot}, t);
\]

Trading Symbolic Variables:

\[
P_{7_x} = \text{subs}(P_7_x, \{\theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)\}, \{\theta, \theta_{dot}, \theta_{ddot}\});
\]
\[
P_{7_y} = \text{subs}(P_7_y, \{\theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)\}, \{\theta, \theta_{dot}, \theta_{ddot}\});
\]
\[
P_{7_x\_dot} = \text{subs}(P_{7_x\_dot}, \{\theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)\}, \{\theta, \theta_{dot}, \theta_{ddot}\});
\]
\[
P_{7_y\_dot} = \text{subs}(P_{7_y\_dot}, \{\theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)\}, \{\theta, \theta_{dot}, \theta_{ddot}\});
\]
\[
P_{7_x\_ddot} = \text{subs}(P_{7_x\_ddot}, \{\theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)\}, \{\theta, \theta_{dot}, \theta_{ddot}\});
\]
\[
P_{7_y\_ddot} = \text{subs}(P_{7_y\_ddot}, \{\theta_s, \text{diff}(\theta_s, t), \text{diff}(\theta_s, t, t)\}, \{\theta, \theta_{dot}, \theta_{ddot}\});
\]

Wingtip Position (Numeric):

% Replacing symbolic variables with numeric values. Value in num_param
% corresponds with variable in sym_param at same index
sym_param = [l_{a2}, l_c, l_{d1}, l_f, l_a0, l_sa, P_0_x, P_0_y, B_x, ...  
             B_y, lever, \theta, \theta_{dot}, \theta_{ddot}]; % inches and radians

num_param = [L_{a2}, L_c, L_{d1}, L_f, L_a0, L_sa, \theta, \theta_{dot}, \theta_{ddot}, -.8, lever_num, servo_angle, servo_speed, servo_accel];

\[
P_{7_x\_num} = \text{double}(\text{subs}(P_{7_x}, \text{sym_param}, \text{num_param})); \quad \text{\% inches}
\]
\[
P_{7_y\_num} = \text{double}(\text{subs}(P_{7_y}, \text{sym_param}, \text{num_param})); \quad \text{\% inches}
\]
\[
P_{7_x\_dot\_num} = \text{double}(\text{subs}(P_{7_x\_dot}, \text{sym_param}, \text{num_param})); \quad \text{\% inches/sec}
\]
\[
P_{7_y\_dot\_num} = \text{double}(\text{subs}(P_{7_y\_dot}, \text{sym_param}, \text{num_param})); \quad \text{\% inches/sec}
\]
\[
P_{7_x\_ddot\_num} = \text{double}(\text{subs}(P_{7_x\_ddot}, \text{sym_param}, \text{num_param})); \quad \text{\% inches/s^2}
\]
\[
P_{7_y\_ddot\_num} = \text{double}(\text{subs}(P_{7_y\_ddot}, \text{sym_param}, \text{num_param})); \quad \text{\% inches/s^2}
\]

Total Wing Length Characteristics

\[
\text{wing\_length} = \sqrt{P_{7_x\_num}^2 + P_{7_y\_num}^2}
\]
Parametric Table to Determine Shoulder Blade Configuration

This code will run through various servo angles and plot the wingtip position. Re-running this code various time with different positions of the servo box will allow the user to compare which graphs produce desirable characteristics.

% Selecting servo box location to test
Bx_num = -0.75; % in relative to P0
By_num = -0.8; % in relative to P0

% Establishing blanks lists to be filled
P7_x_list = zeros(1,19);
P7_y_list = zeros(1,19);
wing_length_list = zeros(1,19);
theta_min = 90;
theta_max = 120;
theta_list = linspace(90,120,19);

for k = 1:19
    % Set up new theta values
    servo_angle = deg2rad(theta_list(k));

    % Sub in values and solve
    sym_param = [l_a2,l_c,l_d1, L_f,l_a0,l_sa, P0_x,P0_y,
                 B_x,   B_y,lever, theta]; % inches and radians

    num_param = [l_a2,l_c,l_d1, L_f,l_a0,l_sa, 0, 0,
                 Bx_num,By_num,lever_num, servo_angle];

    P7_x_list(k) = double(subs(P7_x, sym_param, num_param)); % inches
    P7_y_list(k) = double(subs(P7_y, sym_param, num_param)); % inches
    wing_length_list(k) = sqrt((P7_x_list(k))^2 + (P7_y_list(k))^2); % inches
end

Plotting Results

scatter(theta_list, P7_x_list,'blue','+');
hold on
scatter(theta_list, P7_y_list,"green","square");
scatter(theta_list, wing_length_list,"black","filled","o");
hold off
legend('Horizontal Position','Vertical Position','Wing Length','Location','best');
axis([theta_min, theta_max, -10, 20]);
ylabel('Position [in]');
xlabel({'Servo Angle [degrees] ' '' ' '' '
' ''' '' '' '
' \bfFigure 1: \rm Wingtip position vs. Servo angle'});

fprintf('Figure 1 plotted with servo box location (%1.2f,%1.2f) inches relative to P0', ... 
Bx_num, By_num);

Figure 1 plotted with servo box location (-0.75,-0.80) inches relative to P0

Static Force Analysis on Wings

Analyzing forces over whole system:
Selecting Design Variables:

Wind drag is determined by designer, centroid values comes from Solidworks® evaluation of parts

We make the assumptions:

- Wind drag is applied at centroid of each linkage (realistic for distributed weight and simplifies calcs)
- Zero moment at outer joints (not realistic but necessary to prevent indeterminate system)

% Force of the wind drag (D) and wing weight (W)
syms D W
D_num = 1.5; % lbf
W_num = 1; % lbf

% Centroid locations of parts (compared to left side of each part)
syms 1_a_cen_x l_b_cen_x l_c_cen_x l_d_cen_x l_e_cen_x l_f_cen_x
cen_A_num = 0.62; % in centroid of Part A (W1) in local x direction
cen_B_num = 3.13; % in centroid of Part B (W2) in local x direction
cen_C_num = 3.0 ; % in centroid of Part C (W3) in local x direction
cen_D_num = 3.41; % in centroid of Part D (W4) in local x direction
cen_E_num = 3.38; % in centroid of Part E (W5) in local x direction
cen_F_num = 3.41; % in centroid of Part F (W6) in local x direction

Solving for moment arm lengths:

Remember: \( \theta_B = \theta_C = \theta_F \), and \( \theta_A = \theta_D = \theta_E \)

\[
\begin{align*}
L_b_x &= l_b_cen_x \cos(\theta_B); \\
L_b_y &= l_b_cen_x \sin(\theta_B); \\
L_c_x &= l_c_cen_x \cos(\theta_B) + l_a2 \cos(\theta_A); \\
L_c_y &= l_c_cen_x \sin(\theta_B) + l_a2 \sin(\theta_A);
\end{align*}
\]
\[
\begin{align*}
L_d_x &= l_d_{cen}x \cdot \cos(\theta_A) + l_c \cdot \cos(\theta_B) + l_a2 \cdot \cos(\theta_A); \\
L_d_y &= l_d_{cen}x \cdot \sin(\theta_A) + l_c \cdot \sin(\theta_B) + l_a2 \cdot \sin(\theta_A); \\
L_e_x &= l_e_{cen}x \cdot \cos(\theta_A) + (l_b1 + l_b2) \cdot \cos(\theta_B); \\
L_e_y &= l_e_{cen}x \cdot \sin(\theta_A) + (l_b1 + l_b2) \cdot \sin(\theta_B); \\
L_f_x &= l_f_{cen}x \cdot \cos(\theta_B) + l_d1 \cdot \cos(\theta_A) + ... \\
&\quad l_c \cdot \cos(\theta_B) + l_a2 \cdot \cos(\theta_A); \\
L_f_y &= l_f_{cen}x \cdot \sin(\theta_B) + l_d1 \cdot \sin(\theta_A) + ... \\
&\quad l_c \cdot \sin(\theta_B) + l_a2 \cdot \sin(\theta_A); \\

\text{Summing forces in the y and z direction:} & \\
R_y &= D; \quad R_z = W; \\

\text{Summing moment about shoulder blade joint:} & \\
M_z &= -1 \times \left( \frac{D}{6} \times L_b_x + \frac{D}{6} \times L_c_x + \frac{D}{6} \times L_d_x + ... \right) \\
&\quad \left( \frac{D}{6} \times L_e_x + \frac{D}{3} \times L_f_x \right) \\
M_z(t) &= \frac{D}{6} \left( l_{b1} + l_{b2} \right) + l_{e,cen,x} \sigma_2 \right) - \frac{D}{6} \left( l_{c} \sigma_1 + l_{a2} \sigma_2 \right) - \frac{D}{6} \left( l_{c,cen,x} \sigma_1 + l_{a2} \sigma_2 \right) - \frac{D}{3} \left( l_{e} \sigma_1 + l_{f,cen,x} \sigma_1 \right)
}\right]
\left. - \frac{D}{6} \left( l_{c} \sigma_1 + l_{a2} \sigma_2 \right) - \frac{D}{3} \left( l_{e} \sigma_1 + l_{f,cen,x} \sigma_1 \right)
\right]
\text{where}

\sigma_1 &= \cos \left( \frac{B_x + \text{lever cos(}\theta_s(t)\text{)})^2 + (B_y + \text{lever sin(}\theta_s(t)\text{)})^2}{2 l_{a0} \sqrt{\text{(B_x + lever cos(}\theta_s(t)\text{)})^2 + (B_y + \text{lever sin(}\theta_s(t)\text{)})^2}} - \sigma_3 \right) \\
\sigma_2 &= \cos \left( \frac{B_x + \text{lever cos(}\theta_s(t)\text{)})^2 + (B_y + \text{lever sin(}\theta_s(t)\text{)})^2}{2 l_{a0} \sqrt{\text{(B_x + lever cos(}\theta_s(t)\text{)})^2 + (B_y + \text{lever sin(}\theta_s(t)\text{)})^2}} + \sigma_3 \right) \\
\sigma_3 &= \text{atan2}(-B_y - \text{lever sin(}\theta_s(t)), -B_x - \text{lever cos(}\theta_s(t)))
\]

R_{sz} = \frac{(W/3) \times L_c_x + (W/3) \times L_d_x + (W/3) \times L_f_x}{(l_{a0} \times \cos(\theta_A))} \\
R_{sz}(t) = \frac{\sigma_2}{\sigma_1}
\[
W \frac{(l_c \sigma_2 + l_{a2} \sigma_1 + l_{d, cen, x} \sigma_1)}{3} + W \frac{(l_c, cen, x) \sigma_2 + l_{a2} \sigma_1)}{3} + W \frac{(l_c \sigma_2 + l_{f, cen, x} \sigma_2 + l_{a2} \sigma_1 + l_{d1} \sigma_1)}{3}
\]

where

\[
\sigma_1 = \cos \left( \frac{\left( B_x + \text{lever} \cos(\theta_s(t)) \right)^2 + \left( B_x + \text{lever} \sin(\theta_s(t)) \right)^2 + l_{a0}^2 - l_{sa}^2}{2 l_{a0} \sqrt{\left( B_x + \text{lever} \cos(\theta_s(t)) \right)^2 + \left( B_x + \text{lever} \sin(\theta_s(t)) \right)^2}} \right) + \sigma_3
\]

\[
\sigma_2 = \cos \left( \frac{\left( B_x + \text{lever} \cos(\theta_s(t)) \right)^2 + \left( B_x + \text{lever} \sin(\theta_s(t)) \right)^2 + l_{a0}^2 - l_{sa}^2}{2 l_{a0} \sqrt{\left( B_x + \text{lever} \cos(\theta_s(t)) \right)^2 + \left( B_x + \text{lever} \sin(\theta_s(t)) \right)^2}} \right) - \sigma_3
\]

\[
\sigma_3 = \text{atan2}(-B_y - \text{lever} \sin(\theta_s(t)), -B_x - \text{lever} \cos(\theta_s(t)))
\]

Setting numerical values:
These arrays work by...

\[
sym \_param = [l_a, l_a2, l_c, l_d, l_d1, l_d2, l_f, l_f1, l_f2, l_a0, l_sa, B_x, B_y, ...
 l_b, l_b2, l_b1, l_b0, \text{theta}_s(t), \text{lever}, l_b \_cen \_x, ...
 l_c \_cen \_x, l_d \_cen \_x, l_e \_cen \_x, l_f \_cen \_x, D, W]; \text{\% inches and radians}
\]

\[
um \_param = [L_a, L_a2, L_c, L_d, L_d1, L_d2, L_f, L_f1, L_f2, L_a0, L_sa, Bx \_num, By \_num, ...
 L_b, l_b2, l_b1, l_b0, \text{servo} \_angle, \text{lever} \_num, \text{cen} \_B \_num, ...
 \text{cen} \_C \_num, \text{cen} \_D \_num, \text{cen} \_E \_num, ...
 \text{cen} \_F \_num, D \_num, W \_num];
\]

\[
Ry \_num = \text{double}(\text{subs}(Ry, sym \_param, num \_param)) \text{\% -j [ lbf ]}
\]

\[
Ry \_num = 1.5000
\]

\[
Rz \_num = \text{double}(\text{subs}(Rz, sym \_param, num \_param)) \text{\% -j [ lbf ]}
\]

\[
Rz \_num = 1
\]

\[
Mz \_num = \text{double}(\text{subs}(Mz, sym \_param, num \_param)) \text{\% -k [lbf-in]}
\]

\[
Mz \_num = -12.6687
\]

\[
Rsz \_num = \text{double}(\text{subs}(Rsz, sym \_param, num \_param)) \text{\% -j [ lbf ]}
\]

\[
Rsz \_num = 20.9201
\]

**Out of plane forces**

Analyzing forces over whole system:
Assumptions:

- Zero moment joints (except at the shoulder blade)

For these calculations, I will start at the farthest part (Part F), and follow the forces back by means of summing forces and summing moments.

Part F (W6) calculation:

\[
\text{F}_{\text{ef}_y} = \frac{D/3}{l_{f,cen_x}}/l_2 \quad \% \ -j_{\text{hat}}
\]

\[
\text{F}_{\text{df}_y} = \text{F}_{\text{ef}_y} - \frac{D}{3} \quad \% \ j_{\text{hat}} \quad \text{check}
\]

Part E (W5) calculation:

\[
\text{F}_{\text{be}_y} = \frac{D/6 + \text{F}_{\text{ef}_y}}{l_{cen_x}} \quad \% \ -j_{\text{hat}}
\]

Part D (W4) calculation:

\[
\text{F}_{\text{cd}_y} = \left( \frac{\text{F}_{\text{df}_y} l_d - (D/6) l_d_{cen_x}}{1/l_2} \right) \quad \% \ j_{\text{hat}}
\]
\[ F_{cd,y} = \frac{D}{6} l_{d,cen,x} + l_d \left( \frac{D}{3} - \frac{D l_{f,cen,x}}{3 l_{t2}} \right) \]

% Sum of forces in y direction
\[ F_{bd,y} = F_{cd,y} + \frac{D}{6} - F_{df,y} \] % -j_hat

\[ F_{bd,y} = \frac{D}{2} \left( \frac{D}{6} l_{d,cen,x} + l_d \left( \frac{D}{3} - \frac{D l_{f,cen,x}}{3 l_{t2}} \right) \right) - \frac{D l_{f,cen,x}}{3 l_{t2}} \]

Part C (W3) calculation:

% Sum of forces in the y direction
\[ F_{ac,y} = F_{cd,y} + \frac{D}{6} \] % -j_hat

\[ F_{ac,y} = \frac{D}{6} \left( \frac{D}{6} l_{d,cen,x} + l_d \left( \frac{D}{3} - \frac{D l_{f,cen,x}}{3 l_{t2}} \right) \right) \]

Part B (W2) calculation:

% Sum of moments about joint sb
\[ M_{sb} = F_{be,y}*(l_{b1}+l_{b2}) + F_{bd,y}*(l_{b1}) + ... \\
(D/6)*(l_{b_cen_x}-l_{b0}) \] % perpendicular to part

\[ M_{sb} = (l_{b1} + l_{b2}) \left( \frac{D}{6} + \frac{D l_{f,cen,x}}{3 l_{t2}} \right) - D (l_{b0} - l_{b0,cen,x}) - l_{b1} \left( \frac{D l_{d,cen,x}}{6} + l_d \left( \frac{D}{3} - \frac{D l_{f,cen,x}}{3 l_{t2}} \right) \right) - \frac{D}{2} + \frac{D l_{f,cen,x}}{3 l_{t2}} \]

% Sum of forces in y direction
\[ F_{sb,y} = F_{be,y} + F_{bd,y} + \frac{D}{6} \] % -j_hat

\[ F_{sb,y} = \frac{5D}{6} \left( \frac{D}{6} l_{d,cen,x} + l_d \left( \frac{D}{3} - \frac{D l_{f,cen,x}}{3 l_{t2}} \right) \right) \]

Part A (W1) calculation:

% Sum of moments about joint sa
\[ M_{sa} = F_{ac,y} l_{a2} \] % perpendicular to part

\[ M_{sa} = \]
\[
I_{d2} \left( \frac{D}{6} \frac{D_{d,cen,y}}{l_d} + I_{d} \left( \frac{D}{3} - \frac{D_{f,cen,y}}{3 l_{t2}} \right) \right)
\]

% Sum of forces in y direction
F_{sa_y} = F_{ac_y} % -j_hat

\[
F_{sa_y} = \frac{D I_{d,cen,y}}{6} + I_{d} \left( \frac{D}{3} - \frac{D I_{f,cen,y}}{3 l_{t2}} \right)
\]

Finding numerical values:

\[
F_{sa_num} = \text{double}(\text{subs}(F_{sa_y}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f
\]
F_{sa_num} = 15.0733

\[
F_{sb_y_num} = \text{double}(\text{subs}(F_{sb_y}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f
\]
F_{sb_y_num} = 16.0733

\[
F_{ac_y_num} = \text{double}(\text{subs}(F_{ac_y}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f
\]
F_{ac_y_num} = 15.0733

\[
F_{bd_y_num} = \text{double}(\text{subs}(F_{bd_y}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f
\]
F_{bd_y_num} = 13.3000

\[
F_{be_y_num} = \text{double}(\text{subs}(F_{be_y}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f
\]
F_{be_y_num} = 2.5233

\[
F_{cd_y_num} = \text{double}(\text{subs}(F_{cd_y}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f
\]
F_{cd_y_num} = 14.8233

\[
F_{df_y_num} = \text{double}(\text{subs}(F_{df_y}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f
\]
F_{df_y_num} = 1.7733

\[
M_{sa_num} = \text{double}(\text{subs}(M_{sa}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f-\text{in}
\]
M_{sa_num} = 11.3050

\[
M_{sb_num} = \text{double}(\text{subs}(M_{sb}, \text{sym_param}, \text{num_param})) \quad \% \ \text{lb}f-\text{in}
\]
M_{sb_num} = 97.4900

**In Plane forces**
Assumptions:

- Zero moment joints (except at the shoulder blade)
- Negligible deflection

For these calculations, I will start at the farthest part (Part F), and follow the forces back by means of summing forces and summing moments.

Part F (W6) calculations:

% Summing moments about point df
F_{ef,z} = ( (W/3) * l_{f,cen,x} ) / l_{f2} % -k_hat (direction)

F_{ef,z} = \frac{W l_{f,cen,x}}{3 l_{f2}}

% Summing forces in z direction
F_{df,z} = F_{ef,z} - W/3 % k_hat

F_{df,z} = \frac{W l_{f,cen,x}}{3 l_{f2}} - \frac{W}{3}

Part E (W5) calculation:

% Sum of forces in z direction
F_{be,z} = F_{ef,z} % -k_hat

F_{be,z} = \frac{W l_{f,cen,x}}{3 l_{f2}}

Part D (W4) calculation:

% Sum of moments about joint bd
\[ F_{cd_z} = \frac{( F_{df_z} \cdot l_d + (W/3)\cdot l_d_{cen_x} )}{l_d^2} \frac{1}{j\_hat} \]

\[ F_{cd_z} = \frac{W}{3} \left( \frac{W}{3} - \frac{W}{3} \right) - l_d \left( \frac{W}{3} - \frac{W}{3} \right) \]

% Sum of forces in y direction
\[ F_{bd_z} = -F_{cd_z} + W/3 + F_{df_z} \frac{1}{-j\_hat} \]

% Part C (W3) calculation:
\[ F_{ac_z} = F_{cd_z} + W/3 \frac{1}{-j\_hat} \]

% Part B (W2) calculation:
\[ F_{sb_z} = \frac{( F_{be_z} \cdot l_b + F_{bd_z} \cdot (l_b - l_b2) )}{l_b0} \frac{1}{j\_hat} \]

% Sum of forces in y direction
\[ F_{mb_z} = -F_{be_z} + F_{bd_z} + F_{sb_z} \frac{1}{-j\_hat} \]

% Part A (W1) calculation:
\[ F_{sa_z} = \frac{( F_{ac_z} \cdot l_a )}{l_a0} \frac{1}{j\_hat} \]
\[
F_{ma\ z} = F_{ac\ z} - F_{sa\ z} \quad \text{\(-j\_hat\)}
\]

Finding numerical values:

\[
F_{sa\ z\ num} = \text{double}(\text{subs}(F_{sa\ z}, \text{sym\_param}, \text{num\_param})) \quad \text{\% lbf}
\]

\[
F_{sa\ z\ num} = 31.2222
\]

\[
F_{sb\ z\ num} = \text{double}(\text{subs}(F_{sb\ z}, \text{sym\_param}, \text{num\_param})) \quad \text{\% lbf}
\]

\[
F_{sb\ z\ num} = -116.3444
\]

\[
F_{ac\ z\ num} = \text{double}(\text{subs}(F_{ac\ z}, \text{sym\_param}, \text{num\_param})) \quad \text{\% lbf}
\]

\[
F_{ac\ z\ num} = 12.4889
\]

\[
F_{bd\ z\ num} = \text{double}(\text{subs}(F_{bd\ z}, \text{sym\_param}, \text{num\_param})) \quad \text{\% lbf}
\]

\[
F_{bd\ z\ num} = -10.6400
\]

\[
F_{be\ z\ num} = \text{double}(\text{subs}(F_{be\ z}, \text{sym\_param}, \text{num\_param})) \quad \text{\% lbf}
\]

\[
F_{be\ z\ num} = 1.5156
\]

\[
F_{cd\ z\ num} = \text{double}(\text{subs}(F_{cd\ z}, \text{sym\_param}, \text{num\_param})) \quad \text{\% lbf}
\]

\[
F_{cd\ z\ num} = 12.1556
\]

\[
F_{df\ z\ num} = \text{double}(\text{subs}(F_{df\ z}, \text{sym\_param}, \text{num\_param})) \quad \text{\% lbf}
\]

\[
F_{df\ z\ num} = 1.1822
\]

**Wing Equations of Motion**

**Assumptions:**

- Angular velocity is low enough we can ignore centrifugal force
- The force transmitted from the servo arm to linkages A and B are equal. Technically, the ratio between them will change with the angle of rotation, however they should be more or less similar in value.

**Kinetics input:** Torque from servo motor
Torque = -.5; %lb*in
Fma = Torque*lever_num/2;

Setting up the forces along the linkages connecting the servo arm and the linkage system.

\[
Fmb = Fma;
Fma_x = Fma*\cos\left(\frac{\theta_{sp}}{2}\right);
Fma_z = Fma*\sin\left(\frac{\theta_{sp}}{2}\right);
Fmb_x = Fmb*\cos\left(\frac{\theta_{sp}-\phi}{2}\right);
Fmb_z = Fmb*\sin\left(\frac{\theta_{sp}-\phi}{2}\right);
\]

Establishing the unknown variables for the equation. This will be the internal forces and the angular accelerations.

\text{syms } Fsa_x Fsa_z Fac_x Fac_z Fsb_x Fsb_z Fbd_x Fbd_z Fbe_x Fbe_z ... Fcd_x Fcd_z Fdf_x Fdf_z Fef_x Fef_z theta_ddot_A theta_ddot_B

Mass of each Linkage

\begin{align*}
ma &= 1.49/454; \text{ % grams to lbm} \\
mb &= 8.42/454; \text{ % grams to lbm} \\
mc &= 6.39/454; \text{ % grams to lbm} \\
md &= 7.93/454; \text{ % grams to lbm} \\
me &= 8.02/454; \text{ % grams to lbm} \\
mf &= 7.93/454; \text{ % grams to lbm} \\
g &= 32.174*12; \text{ % inches/s}^2
\end{align*}

Mass Moment of Intertia for each linkage

\begin{align*}
Ia &= .27/454; \text{ % (grams to lbm) * in}^2 \\
Ib &= 37.3/454; \text{ % (grams to lbm) * in}^2 \\
Ic &= 20.26/454; \text{ % (grams to lbm) * in}^2 \\
Id &= 30.96/454; \text{ % (grams to lbm) * in}^2 \\
Ie &= 31.62/454; \text{ % (grams to lbm) * in}^2 \\
If &= 31/454; \text{ % (grams to lbm) * in}^2
\end{align*}

Acceleration of the Shoulder Blade

We assume there is no flapping for these calculations, however it can be added with this variable

\begin{align*}
a0_x &= 0; \\
a0_z &= 0;
\end{align*}

Important trigonometry terms, theta_A and theta_B. (Remember, theta_A is the orientation of linkages A, D, and E. theta_B is the orientation of linkages B, C, and F)

Theta A, sin and cosine

\text{Sa} = \text{abs(sin(double(subs(theta_A, sym_param, num_param))))};
Ca = abs(cos(double(subs(theta_A, sym_param, num_param))));

Theta B, sin and cosine

Sb = abs(sin(double(subs(theta_B, sym_param, num_param))));
Cb = abs(cos(double(subs(theta_B, sym_param, num_param))));

Linkage specific Equations

Linkage A (W1)

eqn1 = Ia*theta_ddot_A == (-Fma_z*Ca + Fma_x*Sa)*(cen_A_num)+...  
     (-Fac_z*Ca+Fac_x*Sa)*(L_a-cen_A_num);
eqn2 = Fma_x+Fsa_x-Fac_x == ma*(a0_x + theta_ddot_A*(cen_A_num-L_a0)*Sa);
eqn3 = Fma_z+Fsa_z-ma*g-Fac_z == ma*(a0_z + theta_ddot_A*(cen_A_num-L_a0)*Ca);

Linkage B (W2)

eqn4 = Ib*theta_ddot_B == (-Fmb_z*Cb + Fmb_x*Sb)*(cen_B_num)+...  
     (-Fsb_z*Cb-Fsb_x*Sb)*(cen_B_num-L_b0)+(Fbd_z*Cb-Fbd_x*Sb)*...  
     (L_b1+L_b0-cen_B_num)+(-Fbe_z*Cb+Fbe_x*Sb)*(L_b-cen_B_num);
eqn5 = Fmb_x+Fsb_x-Fbd_x-Fbe_x == mb*(a0_x + theta_ddot_B*(cen_B_num-L_b0)*Sb);
eqn6 = -Fmb_z+Fsb_z-mb*g+Fbd_z-Fbe_z == mb*(a0_z + theta_ddot_B*(cen_B_num-L_b0)*Cb);

Linkage C (W3)

eqn7 = Ic*theta_ddot_B == (-Fac_z*Cb-Fac_x*Sb)*(cen_C_num)+...  
     (-Fcd_z*Cb+Fcd_x*Sb)*(L_c-cen_C_num);
eqn8 = Fac_x-Fcd_x == mc*((a0_x+theta_ddot_A*L_a2*Sa)+theta_ddot_B*cen_C_num*Sb);
eqn9 = Fac_z-Fcd_z-mc*g-W_num/3 == mc*((a0_z-theta_ddot_A*L_a2*Ca)+theta_ddot_B*cen_C_num*Cb);

Linkage D (W4)

eqn10 = -Id*theta_ddot_A == (Fbd_z*Ca+Fbd_x*Sa)*(cen_D_num)+...  
      (-Fcd_z*Ca+Fcd_x*Sa)*(cen_D_num-L_d2)+(-Fdf_z*Ca+Fdf_x*Sa)*(L_d-cen_D_num);
eqn11 = Fbd_x+Fcd_x-Fdf_x == md*(a0_x+(theta_ddot_B)*(L_b-L_b0-L_b2)*Sb+theta_ddot_A*cen_D_num*Sa);
eqn12 = Fbd_z+Fcd_z-md*g-W_num/3-Fdf_z == md*(a0_z+(theta_ddot_B)*(L_b-L_b0-L_b2)*Cb-theta_ddot_A*cen_D_num*Ca);

Linkage E (W5)

eqn13 = -Ie*theta_ddot_A == (-Fbe_z*Ca+Fbe_x*Sa)*(cen_E_num)+(-Fef_z*Ca+Fef_x*Sa)*(L_e-cen_E_num);
eqn14 = Fbe_x-Fef_x == me*(a0_x+(theta_ddot_B)*(L_b-L_b0)*Sb+theta_ddot_A*cen_E_num*Sa);
eqn15 = Fbe_z-Fef_z-me*g == me*(a0_z+(theta_ddot_B)*(L_b-L_b0)*Cb-theta_ddot_A*cen_E_num*Ca);

Linkage F (W6)

eqn16 = If*(theta_ddot_B) == (-Fdf_z*Cb+Fdf_x*Sb)*(cen_F_num)+...  
      (Fef_z*Cb-Fef_x*Sb)*(cen_F_num-L_f2);
eqn17 = Fdf_x+Fef_x == mf*((a0_x+theta_ddot_B)*(L_b-L_b0-L_b2)*Sb+theta_ddot_A*L_d*Sa)+theta_ddot_B*cen_F_num*Sb);
Creating matrices to represent the kinematic properties

This will create a system where $A\times X = B$, where $[X]$ is a matrix of the angular accelerations and internal forces. $[B]$ consists of constants such as gravity and the weight of the costume.

\[
[A, B] = \text{equationsToMatrix}([\text{eqn1, eqn2, eqn3, eqn4, eqn5, eqn6, ...}
\text{ eqn7, eqn8, eqn9, eqn10, eqn11, eqn12, eqn13, eqn14, eqn15, eqn16, eqn17, eqn18], ...]
\text{[theta\_ddot\_A theta\_ddot\_B Fsa\_x Fsa\_z Fac\_x Fac\_z Fsb\_x Fsb\_z ...}
\text{ Fbd\_x Fbd\_z Fbe\_x Fbe\_z Fcd\_x Fcd\_z Fdf\_x Fdf\_z Fef\_x Fef\_z ]};
\]
\[
X = \text{linsolve}(A, B);
\]

Determined angular accelerations from the matrix.

\[
\text{theta\_ddot\_A\_num} = \text{double}(X(1))
\]
\[
\text{theta\_ddot\_A\_num} = 81.7127
\]

\[
\text{theta\_ddot\_B\_num} = \text{double}(X(1))
\]
\[
\text{theta\_ddot\_B\_num} = 81.7127
\]

Finding values of force at joints

\[
\text{Fsa\_x\_num} = \text{double}(X(3))
\]
\[
\text{Fsa\_x\_num} = 3.3056
\]

\[
\text{Fsa\_z\_num} = \text{double}(X(4))
\]
\[
\text{Fsa\_z\_num} = 3.0680
\]

\[
\text{Fac\_x\_num} = \text{double}(X(5))
\]
\[
\text{Fac\_x\_num} = 3.1014
\]

\[
\text{Fac\_z\_num} = \text{double}(X(6))
\]
\[
\text{Fac\_z\_num} = 1.8782
\]

\[
\text{Fsb\_x\_num} = \text{double}(X(7))
\]
\[
\text{Fsb\_x\_num} = 22.8079
\]

\[
\text{Fsb\_z\_num} = \text{double}(X(8))
\]
\[
\text{Fsb\_z\_num} = 12.5069
\]

\[
\text{Fbd\_x\_num} = \text{double}(X(9))
\]
\[
\text{Fbd\_x\_num} = -12.8176
\]

\[
\text{Fbd\_z\_num} = \text{double}(X(10))
\]
\[
\text{Fbd\_z\_num} = 24.5993
\]
\begin{verbatim}
Fbe_x_num = double(X(11))
Fbe_x_num = 34.0271
Fbe_z_num = double(X(12))
Fbe_z_num = 27.5169
Fcd_x_num = double(X(13))
Fcd_x_num = 1.3679
Fcd_z_num = double(X(14))
Fcd_z_num = -5.3953
Fdf_x_num = double(X(15))
Fdf_x_num = -17.3318
Fdf_z_num = double(X(16))
Fdf_z_num = 10.6107
Fef_x_num = double(X(17))
Fef_x_num = 27.7162
Fef_z_num = double(X(18))
Fef_z_num = 18.4347
\end{verbatim}

**Stress Calculations**

Part B is both the longest part and the innermost (along with the short Part A), making Part B the part seeing the highest stresses. Since Part B should break before any other linkage, stress calculations are only necessary for this part.

**Part B**

The out-of-plane forces are unaffected by dynamics (since we are ignoring the flapping forces). The in-plane forces calculated are to be replaced by the values found in Kinetic analysis. Therefore this FBD consists of values found in both the out-of-plane and kinetic calculations.
In addition to an FBD, having a cross section to analyze the moment forces is often useful.

Sum of shear forces at cut:

\[ \text{Sum of shear forces at cut} \]
% In the x'z' plane
Shear_xz = -mb*g*Cb-Fbd_z_num*Cb-Fbe_z_num*Cb-Fbe_x_num*Sb-Fbe_x_num*Sb;
% In the x'y' plane
Shear_xy = D_num/6 + F_bd_y_num + F_be_y_num;

Sum of axial forces:

% In the x' direction
Axial_x = mb*g*Sb+Fbd_z_num*Sb-Fbd_x_num*Cb+Fbe_z_num*Sb-Fbe_x_num*Cb;

Sum of the moment forces:

% Moments in the y' direction
Moment_y = -(mb*g)*(cen_B_num-L_b0)*Cb +(-Fbd_z_num*Cb-Fbd_x_num*Sb)*... 
(L_b1)*Cb +(-Fbe_z_num*Cb-Fbe_x_num*Sb)*(L_b1+L_b2)*Cb;
% Moments in the z' direction
Moment_z = (D_num/6)*(cen_B_num-L_b0)*Cb +(F_bd_y_num)*(L_b1)*Cb +... 
(F_be_y_num)*(L_b1+L_b2)*Cb;

Torsion is not a signifigant factor

Geometry:

A   = 0.25*.2;  % in^2
c_y = 0.1;      % in
I_y = (1/12)*0.25*0.2^3; % in^4
c_z = 0.125;    % in
I_z = (1/12)*0.2*0.25^3; % in^4

Stresses:

Stresses from bending: sigma_b = M*c / I

sigma_b_y = abs(Moment_y*c_z/I_y)
sigma_b_y = 2.5167e+05

sigma_b_z = abs(Moment_z*c_y/I_z)
sigma_b_z = 3.2684e+04

Stresses from axial forces: sigma_a = P/A

sigma_a_x = Axial_x/A

sigma_a_x = 207.7230

Stresses from shear forces: tau = V/A

tau_xz = Shear_xz/A;
tau_xy = Shear_xy/A;

Axial and bending stress combined

sigma_x_z = sigma_b_z + sigma_a_x;
\[ \sigma_{x\ y} = \sigma_{b\ y} + \sigma_{a\ x}; \]

Total primary stress

\[ \sigma_{1\ xz} = \frac{\sigma_{x\ z}}{2} + \sqrt{\left(\frac{\sigma_{x\ z}}{2}\right)^2 + \tau_{xz}^2} \]

\[ \sigma_{1\ xz} = 3.2939 \times 10^4 \]

\[ \sigma_{1\ xy} = \frac{\sigma_{x\ y}}{2} + \sqrt{\left(\frac{\sigma_{x\ y}}{2}\right)^2 + \tau_{xy}^2} \]

\[ \sigma_{1\ xy} = 2.5188 \times 10^5 \]

Total shear stress

\[ \tau_{1\ xz} = \sqrt{\left(\frac{\sigma_{x\ z}}{2}\right)^2 + \tau_{xz}^2} \]

\[ \tau_{1\ xz} = 1.6493 \times 10^4 \]

\[ \tau_{1\ xy} = \sqrt{\left(\frac{\sigma_{x\ y}}{2}\right)^2 + \tau_{xy}^2} \]

\[ \tau_{1\ xy} = 1.2594 \times 10^5 \]

\[ \sigma_{\text{of concern}} = \max(\{|\sigma_{1\ xy}|, \sigma_{1\ xz}, 2\tau_{1\ xy}, 2\tau_{1\ xz}|) \]

\[ \sigma_{\text{of concern}} = 2.5188 \times 10^5 \]

Online research found the yield strength of printed PLA to be 8399 Pa. If either the primary stress or double the largest shear stress doubled is larger than the yield strength, the wing is expected to fail.

```matlab
sigma_x_y = sigma_b_y + sigma_a_x;

Total primary stress

sigma_1_xz = (sigma_x_z/2)+sqrt((sigma_x_z/2)^2 +tau_xz^2)

sigma_1_xz = 3.2939e+04

sigma_1_xy = (sigma_x_y/2)+sqrt((sigma_x_y/2)^2 +tau_xy^2)

sigma_1_xy = 2.5188e+05

Total shear stress

tau_1_xz = sqrt((sigma_x_z/2)^2 +tau_xz^2)

tau_1_xz = 1.6493e+04

tau_1_xy = sqrt((sigma_x_y/2)^2 +tau_xy^2)

tau_1_xy = 1.2594e+05

sigma_of_concern = max([abs(sigma_1_xy), sigma_1_xz, 2*tau_1_xy, 2*tau_1_xz])

sigma_of_concern = 2.5188e+05

Online research found the yeild strength of printed PLA to be 8399 Pa. If either the primary stress or double the largest shear stress doubled is larger than the yeild strength, the wing is expected to fail.

safety_factor = 8399/\sigma_{\text{of concern}}

safety_factor = 0.0333

if safety_factor <= 1
    disp('The wing will FAIL')
else
    disp('The wing will PASS')
end
```

The wing will FAIL
### Appendix G Risk Assessment

**designsafe Report**

**Application:** CAPED Barker Bird  
**Analyst Name(s):**  
**Description:**  
**Company:**  
**Product Identifier:**  
**Facility Location:**  
**Assessment Type:** Detailed  
**Limits:**  
**Sources:**  
**Risk Scoring System:** ANSI B11.0 (TR3) Two Factor  

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

<table>
<thead>
<tr>
<th>Item Id</th>
<th>User / Task</th>
<th>Hazard / Failure Mode</th>
<th>Initial Assessment Severity</th>
<th>Initial Assessment Probability</th>
<th>Risk Level</th>
<th>Risk Reduction Methods /Control System</th>
<th>Final Assessment Severity</th>
<th>Final Assessment Probability</th>
<th>Risk Level</th>
<th>Status / Responsible /Comments /Reference</th>
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</thead>
<tbody>
<tr>
<td>1-1-1</td>
<td>operator(s) normal operation</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points</td>
<td>Not Applicable</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-1-2</td>
<td>operator(s) normal operation</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>1-1-3</td>
<td>operator(s) normal operation</td>
<td>mechanical : entanglement / drawing-in / trapping Issues with wings pulling on external cables</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>NA</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>1-1-4</td>
<td>operator(s) normal operation</td>
<td>mechanical : unexpected motion Wings may extend or bird may rotate without warning</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Announce before the bird starts to move for the first time</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>1-1-5</td>
<td>operator(s) normal operation</td>
<td>pinch points : against fencing/walls Wings extending may push against an external wall</td>
<td>Minor</td>
<td>Likely</td>
<td>Low</td>
<td>Make costume bright so the ends of the wings are very visible and people can avoid them when they are extended</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>Item Id</td>
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<td>Risk Level</td>
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<tr>
<td>1-1-6</td>
<td>operator(s) normal operation</td>
<td>electrical / electronic : parts live from fault condition (indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experience in electronics</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/18/2022] Jonathan</td>
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<tr>
<td>1-1-7</td>
<td>operator(s) normal operation</td>
<td>electrical / electronic : water / wet locations Water may cause issues with electronic components that can cause shorts or other issues</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Enclose critical electronics to ensure no contact with water</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>1-1-8</td>
<td>operator(s) normal operation</td>
<td>electrical / electronic : unexpected start up Wings may extend or bird may rotate without warning</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Announce when initial movement will happen</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td></td>
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<tr>
<td>1-1-9</td>
<td>operator(s) normal operation</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Have someone double check the software before it is run on the bird</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/20/2022] Jonathan</td>
</tr>
<tr>
<td>1-1-10</td>
<td>operator(s) normal operation</td>
<td>fire and explosives : hot surfaces Motors may get hot when run for prolonged periods of time</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>NA</td>
<td>Moderate</td>
<td></td>
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<tr>
<td>1-1-11</td>
<td>operator(s) normal operation</td>
<td>noise / vibration : sound levels &gt; 85 dba Excessive exposure to noise may cause hearing damage</td>
<td>Minor</td>
<td>Likely</td>
<td>Low</td>
<td>Warn users about loud noises and implement a volume knob to limit the maximum volume</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>1-1-12</td>
<td>operator(s) normal operation</td>
<td>noise / vibration : fatigue / material strength 3D printed parts may become damaged from vibration</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Design for failure and use stronger materials in high stress locations</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/23/2022] Marcus /No damage detected during testing and semi-regular use</td>
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<tr>
<td>Item Id</td>
<td>User / Task</td>
<td>Hazard / Failure Mode</td>
<td>Initial Assessment</td>
<td>Risk Reduction Methods /Control System</td>
<td>Final Assessment</td>
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<td>1-1-13</td>
<td>operator(s)</td>
<td>noise / vibration : equipment damage Vibration may loosen hardware or damage 3D printed connections</td>
<td>Moderate Likely</td>
<td>Heat set inserts and other mechanical devices to ensure joints are secure and will not fail over time</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/3/2022] Nolan</td>
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<td></td>
<td>normal operation</td>
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<tr>
<td>1-1-14</td>
<td>operator(s)</td>
<td>material handling : instability If the bird is placed on an unbalanced surface, it may fall over when it moves due to shifting center of gravity.</td>
<td>Moderate Unlikely</td>
<td>Place bird on stable and level surface</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<td></td>
<td>normal operation</td>
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<tr>
<td>1-2-1</td>
<td>operator(s)</td>
<td>struck by/impact : robot If the robot falls over, it may cause damage to people around it</td>
<td>Moderate Unlikely</td>
<td>Ensure bird is on a stable surface</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<td></td>
<td>adjust controls</td>
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<td>Low</td>
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<td>1-2-2</td>
<td>operator(s)</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor Unlikely</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td></td>
<td>adjust controls</td>
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<td>Negligible</td>
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<td>1-2-3</td>
<td>operator(s)</td>
<td>electrical / electronic : parts live from fault condition(indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate Unlikely</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experinece in electronics</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/18/2022] Jonathan</td>
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<td>adjust controls</td>
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<td>Low</td>
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<td>1-2-4</td>
<td>operator(s)</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate Likely</td>
<td>Have someone double check the softare before it is run on the bird</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/20/2022] Jonathan</td>
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<td></td>
<td>adjust controls</td>
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<td>Medium</td>
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<tr>
<td>1-3-1</td>
<td>operator(s)</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate Likely</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points Not Applicable</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td></td>
<td>clear jams</td>
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<td>Medium</td>
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<tr>
<td>1-3-2</td>
<td>operator(s) clear jams</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>1-3-3</td>
<td>operator(s) clear jams</td>
<td>pinch points : between robot/turntable Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>Enclose base to make sure rotating parts are out of the way</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
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<tr>
<td>1-3-4</td>
<td>operator(s) clear jams</td>
<td>pinch points : against fencing/walls Wings extending may push against an external wall</td>
<td>Minor</td>
<td>Likely</td>
<td>Low</td>
<td>Make costume bright so the ends of the wings are very visible and people can avoid them when they are extended</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>1-3-5</td>
<td>operator(s) clear jams</td>
<td>electrical / electronic : parts live from fault condition(indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experience in electronics</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/18/2022] Jonathan</td>
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<tr>
<td>1-4-1</td>
<td>operator(s) shut down</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points /Not Applicable</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>2-1-1</td>
<td>technician(s) teach robot</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points /Not Applicable</td>
<td>Minor</td>
<td>Unlikely</td>
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<td>2-1-2</td>
<td>technician(s) teach robot</td>
<td>mechanical : sharp edges  Beak and wings may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>2-1-3</td>
<td>technician(s) teach robot</td>
<td>pinch points : between robot/turntable Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>Enclose base to make sure rotating parts are out of the way</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
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</tr>
<tr>
<td>2-1-4</td>
<td>technician(s) teach robot</td>
<td>pinch points : against fencing/walls Wings extending may push against an external wall</td>
<td>Minor</td>
<td>Likely</td>
<td>Low</td>
<td>Make costume bright so the ends of the wings are very visible and people can avoid them when they are extended</td>
<td>Minor</td>
<td>Unlikely</td>
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<td>technician(s) teach robot</td>
<td>electrical / electronic : parts live from fault condition(indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
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<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/18/2022] Jonathan</td>
</tr>
<tr>
<td>2-1-6</td>
<td>technician(s) teach robot</td>
<td>noise / vibration : sound levels &gt; 85 dba Excessive exposure to noise may cause hearing damage</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
<td>Warn users about loud noises and implement a volume knob to limit the maximum volume</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
<td></td>
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<tr>
<td>2-1-7</td>
<td>technician(s) teach robot</td>
<td>noise / vibration : fatigue / material strength 3D printed parts may become damaged from vibration</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Design for failure and use stronger materials in high stress locations</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/23/2022] Marcus /No damage detected during testing and semi-regular use</td>
</tr>
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<td>Item Id</td>
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<tr>
<td>2-1-8</td>
<td>technician(s) teach robot</td>
<td>noise / vibration : equipment damage Vibration may loosen hardware or damage 3D printed connections</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Heat set inserts and other mechanical devices to ensure joints are secure and will not fail over time</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Complete [5/3/2022] Nolan</td>
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<tr>
<td>2-2-1</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>struck by/impact : robot If the robot falls over, it may cause damage to people around it</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Ensure bird is on a stable surface</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<tr>
<td>2-2-2</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points / Not Applicable</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<tr>
<td>2-2-3</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td>2-2-4</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>pinch points : between robot/turntable Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Moderate Remote</td>
<td>Negligible</td>
<td>Enclose base to make sure rotating parts are out of the way</td>
<td>Minor Remote</td>
<td>Negligible</td>
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<tr>
<td>2-2-5</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>pinch points : against fencing/walls Wings extending may push against an external wall</td>
<td>Minor Likely</td>
<td>Low</td>
<td>Make costume bright so the ends of the wings are very visible and people can avoid them when they are extended</td>
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<td>Negligible</td>
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<tr>
<td>2-2-6</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : parts live from fault condition (indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate Unlikely</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experience in electronics</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/20/2022] Jonathan</td>
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<tr>
<td>2-2-7</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : water / wet locations Water may cause issues with electronic components that can cause shorts or other issues</td>
<td>Moderate Unlikely</td>
<td>Enclose critical electronics to ensure no contact with water</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<tr>
<td>2-2-8</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : unexpected start up Wings may extend or bird may rotate without warning</td>
<td>Moderate Unlikely</td>
<td>Announce when initial movement will happen</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<tr>
<td>2-2-9</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate Likely</td>
<td>Have someone double check the software before it is run on the bird</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/20/2022] Jonathan</td>
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<tr>
<td>2-2-10</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>noise / vibration : sound levels &gt; 85 dba Excessive exposure to noise may cause hearing damage</td>
<td>Minor Likely</td>
<td>Warn users about loud noises and implement a volume knob Limit the maximum volume</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<tr>
<td>2-2-11</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>noise / vibration : fatigue / material strength 3D printed parts may become damaged from vibration</td>
<td>Moderate Likely</td>
<td>Design for failure and use stronger materials in high stress locations</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/23/2022] Marcus</td>
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<tr>
<td>2-2-12</td>
<td>technician(s) trouble-shooting / problem solving</td>
<td>noise / vibration : equipment damage Vibration may loosen hardware or damage 3D printed connections</td>
<td>Moderate Likely</td>
<td>Heat set inserts and other mechanical devices to ensure joints are secure and will not fail over time</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/3/2022] Nolan</td>
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<tr>
<td>Item Id</td>
<td>User / Task</td>
<td>Hazard / Failure Mode</td>
<td>Initial Assessment Severity</td>
<td>Probability</td>
<td>Risk Level</td>
<td>Risk Reduction Methods / Control System</td>
<td>Final Assessment Severity</td>
<td>Probability</td>
<td>Risk Level</td>
<td>Status / Responsible</td>
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<tr>
<td>2-3-1</td>
<td>technician(s) set-up or changeover</td>
<td>struck by/impact : robot If the robot falls over, it may cause damage to people around it</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td></td>
<td>Ensure bird is on a stable surface</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
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<tr>
<td>2-3-2</td>
<td>technician(s) set-up or changeover</td>
<td>struck by/impact : turntable While working on the robot, the turntable base may rotate, causing the perch to strike the technicians</td>
<td>Minor Likely</td>
<td>Low</td>
<td></td>
<td>Explain to users to lock down the rotation before they work on it</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
<td></td>
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<tr>
<td>2-3-3</td>
<td>technician(s) set-up or changeover</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td></td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>2-3-4</td>
<td>technician(s) set-up or changeover</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
<td></td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>2-3-5</td>
<td>technician(s) set-up or changeover</td>
<td>pinch points : between robot/turntable Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Moderate Remote</td>
<td>Negligible</td>
<td></td>
<td>Enclose base to make sure rotating parts are out of the way</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
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<tr>
<td>2-3-6</td>
<td>technician(s) set-up or changeover</td>
<td>pinch points : against fencing/walls Wings extending may push against an external wall</td>
<td>Minor Likely</td>
<td>Low</td>
<td></td>
<td>Make costume bright so the ends of the wings are very visible and people can avoid them when they are extended</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td></td>
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<tr>
<td>Item Id</td>
<td>User / Task</td>
<td>Hazard / Failure Mode</td>
<td>Initial Assessment Severity Probability</td>
<td>Risk Level</td>
<td>Risk Reduction Methods / Control System</td>
<td>Final Assessment Severity Probability</td>
<td>Risk Level</td>
<td>Status / Responsible / Comments / Reference</td>
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<td>2-3-7</td>
<td>technician(s) set-up or changeover</td>
<td>electrical / electronic : parts live from fault condition (indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experience in electronics</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Complete [5/18/2022] Jonathan</td>
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<tr>
<td>2-3-8</td>
<td>technician(s) set-up or changeover</td>
<td>electrical / electronic : water / wet locations Water may cause issues with electronic components that can cause shorts or other issues</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Enclose critical electronics to ensure no contact with water</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<tr>
<td>2-3-9</td>
<td>technician(s) set-up or changeover</td>
<td>electrical / electronic : unexpected start up Wings may extend or bird may rotate without warning</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Announce when initial movement will happen</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<td>2-3-10</td>
<td>technician(s) set-up or changeover</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Have someone double check the software before it is run on the bird</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Complete [5/20/2022] Jonathan</td>
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<tr>
<td>2-3-11</td>
<td>technician(s) set-up or changeover</td>
<td>noise / vibration : fatigue / material strength 3D printed parts may become damaged from vibration</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Design for failure and use stronger materials in high stress locations</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Complete [5/23/2022] Marcus</td>
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<tr>
<td>2-3-12</td>
<td>technician(s) set-up or changeover</td>
<td>noise / vibration : equipment damage Vibration may loosen hardware or damage 3D printed connections</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Heat set inserts and other mechanical devices to ensure joints are secure and will not fail over time</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Complete [5/3/2022] Nolan</td>
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<tr>
<td>2-4-1</td>
<td>technician(s) adjust controls / switches</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td>Item Id</td>
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<td>Initial Assessment</td>
<td>Risk Reduction Methods</td>
<td>Final Assessment</td>
<td>Status / Responsible</td>
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<tr>
<td>2-4-2</td>
<td>technician(s) adjust controls / switches</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor Unlikely Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor Unlikely Negligible</td>
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<tr>
<td>2-4-3</td>
<td>technician(s) adjust controls / switches</td>
<td>electrical / electronic : unexpected start up Wings may extend or bird may rotate without warning</td>
<td>Moderate Unlikely Low</td>
<td>Announce when initial movement will happen</td>
<td>Moderate Remote Negligible</td>
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<tr>
<td>2-4-4</td>
<td>technician(s) adjust controls / switches</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate Likely Medium</td>
<td>Have someone double check the softare before it is run on the bird</td>
<td>Moderate Unlikely Low Complete [5/20/2022] Jonathan</td>
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<tr>
<td>2-5-1</td>
<td>technician(s) demonstration</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate Likely Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points /Not Applicable</td>
<td>Minor Unlikely Negligible</td>
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<tr>
<td>2-5-2</td>
<td>technician(s) demonstration</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor Unlikely Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor Unlikely Negligible</td>
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<td>2-5-3</td>
<td>technician(s) demonstration</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate Likely Medium</td>
<td>Have someone double check the softare before it is run on the bird</td>
<td>Moderate Unlikely Low Complete [5/20/2022] Jonathan</td>
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<td>2-5-4</td>
<td>technician(s) demonstration</td>
<td>noise / vibration : sound levels &gt; 85 dba Excessive exposure to noise may cause hearing damage</td>
<td>Moderate Likely Medium</td>
<td>Warn users about loud noises and implement a volume knob to limit the maximum volume</td>
<td>Minor Unlikely Negligible</td>
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<td>2-5-5</td>
<td>technician(s) demonstration</td>
<td>noise / vibration : fatigue / material strength 3D printed parts may become damaged from vibration</td>
<td>Moderate Likely Medium</td>
<td>Design for failure and use stronger materials in high stress locations</td>
<td>Moderate Unlikely Low Complete [5/23/2022] Marcus</td>
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<td>Item Id</td>
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<td>Final Assessment</td>
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<td>Severity</td>
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<td>Risk Level</td>
<td>Comments /Reference</td>
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<tr>
<td>2-5-6</td>
<td>technician(s) demonstration</td>
<td>noise / vibration : equipment damage Vibration may loosen hardware or damage 3D printed connections</td>
<td>Moderate</td>
<td>Likely</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/3/2022] Nolan</td>
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<tr>
<td>2-6-1</td>
<td>technician(s) service turntable</td>
<td>pinch points : between robot/turntable Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>Enclose base to make sure rotating parts are out of the way</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
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<tr>
<td>2-7-1</td>
<td>technician(s) shut down</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate</td>
<td>Likely</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>2-7-2</td>
<td>technician(s) shut down</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate</td>
<td>Likely</td>
<td>Have someone double check the software before it is run on the bird</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/20/2022] Jonathan</td>
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<tr>
<td>3-1-1</td>
<td>installer(s) install robot</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>3-1-2</td>
<td>installer(s) install robot</td>
<td>mechanical : unexpected motion Wings may extend or bird may rotate without warning</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<td>Risk Reduction Methods /Control System</td>
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<tr>
<td>3-1-3</td>
<td>installer(s) install robot</td>
<td>electrical / electronic : parts live from fault condition(indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experience in electronics</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/18/2022]</td>
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<tr>
<td>3-1-4</td>
<td>installer(s) install robot</td>
<td>electrical / electronic : water / wet locations Water may cause issues with electronic components that can cause shorts or other issues</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Enclose critical electronics to ensure no contact with water</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td></td>
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<tr>
<td>3-1-5</td>
<td>installer(s) install robot</td>
<td>electrical / electronic : unexpected start up Wings may extend or bird may rotate without warning</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Announce when initial movement will happen</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
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<tr>
<td>3-1-6</td>
<td>installer(s) install robot</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Have someone double check the software before it is run on the bird</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/20/2022]</td>
</tr>
<tr>
<td>3-2-1</td>
<td>installer(s) calibrate robot / system</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points /Not Applicable</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>3-2-2</td>
<td>installer(s) calibrate robot / system</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
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<tr>
<td>3-2-3</td>
<td>installer(s) calibrate robot / system</td>
<td>pinch points : between robot/turntable Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>Enclose base to make sure rotating parts are out of the way</td>
<td>Minor</td>
<td>Remote</td>
<td>Negligible</td>
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<tr>
<td>3-2-4</td>
<td>installer(s) calibrate robot / system</td>
<td>pinch points : against fencing/walls</td>
<td>Minor</td>
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<td></td>
<td></td>
<td>Wings extending may push against an external wall</td>
<td>Likely</td>
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<td>Risk Level: Low</td>
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<td>Risk Reduction Methods: Make costume bright so the ends of the wings are very visible and people can avoid them when they are extended</td>
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<td>3-2-5</td>
<td>installer(s) calibrate robot / system</td>
<td>electrical / electronic : software errors</td>
<td>Moderate</td>
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<td>Software used incorrectly may cause unwanted movement in the bird</td>
<td>Likely</td>
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<td>Risk Reduction Methods: Have someone double check the software before it is run on the bird</td>
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<td>noise / vibration : sound levels &gt; 85 dba</td>
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<td>Excessive exposure to noise may cause hearing damage</td>
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<td>Risk Reduction Methods: Warn users about loud noises and implement a volume knob to limit the maximum volume</td>
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<td>3-3-1</td>
<td>installer(s) run tests</td>
<td>mechanical : crushing / impact</td>
<td>Moderate</td>
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<td></td>
<td>Robot wings closing on fingers</td>
<td>Likely</td>
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<td>Risk Reduction Methods: Costume on outside of bird will provide padding and space to remove fingers from pinch points</td>
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<td>3-3-2</td>
<td>installer(s) run tests</td>
<td>mechanical : sharp edges</td>
<td>Minor</td>
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<td>Beak and wings may be sharp</td>
<td>Unlikely</td>
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<td>Risk Reduction Methods: Warn users in the user manual that these parts may be sharp</td>
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<td>Probability: Unlikely</td>
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<td>3-3-3</td>
<td>installer(s) run tests</td>
<td>pinch points : between robot/turntable</td>
<td>Moderate</td>
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<td>Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Remote</td>
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<td>Risk Reduction Methods: Enclose base to make sure rotating parts are out of the way</td>
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<td>Probability: Remote</td>
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<td>Item Id</td>
<td>User / Task</td>
<td>Hazard / Failure Mode</td>
<td>Initial Assessment</td>
<td>Risk Level</td>
<td>Risk Reduction Methods /Control System</td>
<td>Final Assessment</td>
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<td>Status / Responsible /Comments /Reference</td>
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<td>3-3-4</td>
<td>installer(s) run tests</td>
<td>pinch points : against fencing/walls Wings extending may push against an external wall</td>
<td>Minor Likely</td>
<td>Low</td>
<td>Make costume bright so the ends of the wings are very visible and people can avoid them when they are extended</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td>3-3-5</td>
<td>installer(s) run tests</td>
<td>electrical / electronic : parts live from fault condition(indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experience in electronics</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/18/2022] Jonathan</td>
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<td>3-3-6</td>
<td>installer(s) run tests</td>
<td>electrical / electronic : water / wet locations Water may cause issues with electronic components that can cause shorts or other issues</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Enclose critical electronics to ensure no contact with water</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<td>3-3-7</td>
<td>installer(s) run tests</td>
<td>electrical / electronic : unexpected start up Wings may extend or bird may rotate without warning</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Announce when initial movement will happen</td>
<td>Moderate Remote</td>
<td>Negligible</td>
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<td>3-3-8</td>
<td>installer(s) run tests</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Have someone double check the software before it is run on the bird</td>
<td>Moderate Unlikely</td>
<td>Low Complete [5/20/2022] Jonathan</td>
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<td>3-3-9</td>
<td>installer(s) run tests</td>
<td>fire and explosives : hot surfaces Motors may get hot when run for prolonged periods of time</td>
<td>Moderate Remote</td>
<td>Negligible</td>
<td>NA</td>
<td>Moderate</td>
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<td>3-3-10</td>
<td>installer(s) run tests</td>
<td>noise / vibration : sound levels &gt; 85 dba Excessive exposure to noise may cause hearing damage</td>
<td>Moderate Likely</td>
<td>Medium</td>
<td>Warn users about loud noises Minor and implement a volume knob Unlikely to limit the maximum volume</td>
<td>Negligible</td>
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<td>Item Id</td>
<td>User / Task</td>
<td>Hazard / Failure Mode</td>
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<td>Status / Responsible</td>
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<td>3-3-11</td>
<td>installer(s) run tests</td>
<td>noise / vibration : fatigue / material strength 3D printed parts may become damaged from vibration</td>
<td>Moderate Likely</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Complete [5/23/2022] Marcus</td>
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<td>3-3-12</td>
<td>installer(s) run tests</td>
<td>noise / vibration : equipment damage Vibration may loosen hardware or damage 3D printed connections</td>
<td>Moderate Likely</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Complete [5/3/2022] Nolan</td>
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<td>3-4-1</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate Likely</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td>3-4-2</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor Unlikely</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td>3-4-3</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>pinch points : between robot/turntable Base rotating may cause injury if extremities are in the gap between top and bottom plate</td>
<td>Moderate Remote</td>
<td>Minor Remote</td>
<td>Negligible</td>
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<td>3-4-4</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>pinch points : against fencing/walls Wings extending may push against an external wall</td>
<td>Minor Likely</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
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<td>User / Task</td>
<td>Hazard / Failure Mode</td>
<td>Initial Assessment Severity</td>
<td>Initial Assessment Probability</td>
<td>Risk Level</td>
<td>Risk Reduction Methods /Control System</td>
<td>Final Assessment Severity</td>
<td>Final Assessment Probability</td>
<td>Risk Level</td>
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<td>3-4-5</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : parts live from fault condition(indirect contact) Faulty wiring or wires becoming damaged or unplugged</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Ensure wires are connected correctly and securely to prevent pullout by having wiring reviewed by someone with significant experience in electronics</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/18/2022]</td>
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<td>3-4-6</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : water / wet locations Water may cause issues with electronic components that can cause shorts or other issues</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Enclose critical electronics to ensure no contact with water</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>installer(s) trouble-shooting / problem solving</td>
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<td>3-4-7</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : unexpected start up Wings may extend or bird may rotate without warning</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Announce when initial movement will happen</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>installer(s) trouble-shooting / problem solving</td>
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<tr>
<td>3-4-8</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>electrical / electronic : software errors Software used incorrectly may cause unwanted movement in the bird</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Have someone double check the software before it is run on the bird</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Low</td>
<td>Complete [5/20/2022]</td>
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<td>3-4-9</td>
<td>installer(s) trouble-shooting / problem solving</td>
<td>noise / vibration : sound levels &gt; 85 dba Excessive exposure to noise may cause hearing damage</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Warn users about loud noises and implement a volume knob to limit the maximum volume</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>installer(s) trouble-shooting / problem solving</td>
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<td>3-5-1</td>
<td>installer(s) adjust controls</td>
<td>mechanical : crushing / impact Robot wings closing on fingers</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Costume on outside of bird will provide padding and space to remove fingers from pinch points /Not Applicable</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>installer(s) adjust controls</td>
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<td>3-5-2</td>
<td>installer(s) adjust controls</td>
<td>mechanical : sharp edges Beak and wings may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>Warn users in the user manual that these parts may be sharp</td>
<td>Minor</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>installer(s) adjust controls</td>
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<td>Item Id</td>
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<td>Hazard / Failure Mode</td>
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<td>Low</td>
<td>Enclose critical electronics to ensure no contact with water</td>
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<td>Warn users in the user manual that these parts may be sharp</td>
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Daily Operation Guide

These instructions are for operating a fully assembled bird that has the appropriate dance routine program uploaded to the PCB. For instructions on uploading programs to the PCB, refer to Chapter X for program uploading and customization.

1. Location requirements of Barker Bird
   a. Bird must be on flat, steady table that is protected from significant wind
   b. A power source 120 V AC power source (the common house electricity level)
   c. Bird must be clear of obstacles, with at least a 3-foot radius of clearance

2. Powering on bird
   a. Plug the bird into a common outlet with the appropriate charging cable (barrel type 12V DC connector)
   b. Check to see there are no obstacles within the wing radius of the bird
   c. Rotate the base all the way to counterclockwise position
   d. Turn the power switch to the “ON” position
Manufacturing Guide: Base

Parts B1, B2, B3, B4, B5 Manufacturing

All machining of these parts was done on the laser cutter in Mustang 60 machine shop. The steps for machining these parts are listed below, however, the steps to set up the laser cutter is not included. Mustang 60 has their own documents on how they want the laser set up.

Materials:
- Sheet of ¼” plywood or similar material
- Wood screws ¾” long, preferably #6 or #8 screws
- Wired slip ring

Tools:
- Laser Cutter (Available in Mustang 60 Machine Shop)
- Drill with Philips driving bit

Files:
- PartB1.ai
- PartB2.ai
- PartB3.ai
- PartB4.ai
- PartB5.ai

Parts B2, B3, B4, B5 Machining Process

Material Pre-Processing Steps:
1. Cut sheet of material down into 4, 14” squares or into sheets that will fit the bed of the laser (the laser we used had a bed size of 18”x32”). If the squares are larger than 14”, that is okay, because the laser will cut the material into 14” rounds.

File Processing Steps:
1. Save provided Adobe Illustrator files for Part B2, Part B3, Part B4 and Part B5 onto a flash drive
2. Open these files on the computer for the laser cutter, and copy the contents of the files onto the laser cutter bed template

Laser Cutting Steps:
1. Refer to the manual provided by Mustang 60 to ensure the laser is set up properly
2. Line up the material in the upper right corner of the laser bed
Manufacturing Guide: Base

3. Run “dry passes” with the laser to ensure the material is lined up properly in the bed (dry passes on the laser are performed with the lid of the laser raised, and are used to demonstrate the path the laser will take before actually cutting any material)

4. Have a shop tech verify set up and the material is ready to cut

Post-Processing and Assembly Steps:

1. Layout all of your laser cut parts on a table with B4 on the far left, B3 to the right of that, B2 to the left of that, and lastly B5 on the first right

2. Apply wood glue to the top of piece B3 an B2

3. Stack B4 on top of B3 and then both of those on top of B2

4. Make sure that you carefully align the gear teeth on all three pieces

5. Either clamp the three pieces together, or drive several screws into the large sections of wood while the glue dries

6. Once the glue has fully dried, you can remove the clamps and or screws

7. Jump to section Wiring before continuing to step 8

8. After the slip ring is attached and the wires are run through the slot, line up piece B5 on the bottom of piece B2 (this should “close” the slot, so the wires are not visible from the top or bottom)

9. Screw piece B5 to the stack of the other 3 pieces using wood screws. Use caution to not drill into the geared or wired area

Wiring:

1. Run the female barrel plug and on off switch through the center of the glued pieces

2. The barrel plug goes through one slot, and the power switch goes through the other

3. Secure the slip ring to the top of piece B4 with wood screws
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Manufacturing Guide: Printing

Part B8

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Manufacturing Guide: Printing

Part H1

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### Manufacturing Guide: Printing

**Part H3**

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**Manufacturing Guide: Printing**

**Part L1**

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Manufacturing Guide: Printing

Part L2

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Part L3

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# Manufacturing Guide: Printing

**Part T4**

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![3D model](image-url)
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Manufacturing Guide: Printing

Part W1

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Manufacturing Guide: Printing

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Manufacturing Guide: Printing

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**Part W5**

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Manufacturing Guide: Printing

Part W7R and W7L

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Part W9

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Part W10

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Manufacturing Guide: Perch

A cordless hand drill and Phillips Head screw can be checked out from the Mustang 60 Machine Shop to complete the assembly process.

Materials:

- 5x #6-32x3/4” Wood Screws
- Cut PVC Pipe
- PVC Pipe cross connector
- PVC Pipe Primer
- PVC Pipe glue

Tools:

- Hand Drill
- Phillips Head Screw Bit
- Eye Protection and Other Appropriate PPE

Machining Process

1. Wear proper PPE
2. Find the center of the top piece of the wooden base by drawing two straight lines across the diameters of the circular piece. Mark where the lines intersect.
3. Line up the center hole of the 3D printed holder piece with the center mark of the circular wooden piece. Mark the hole pattern that aligns with the 3D printed holder piece onto the wood with a pencil.
4. Line up the 3D printed holder piece with the hole pattern you marked. Using a cordless hand drill, screw the #6-32 wood screws into the wood to fasten the holder piece to the wood.
5. Apply PVC pipe primer to the 15 inch long 1 inch nominal pipe. Apply glue directly after to the outside edge of the pipe. Slide the pipe into the hole of the 3D printed holder piece for the glue to harden.
6. Apply the primer and glue to the two 8-inch pieces of PVC pipe. Slide the two pieces into the left and right sides of the PVC Pipe cross connector. Allow time for the glue to harden.
## Assembly Guide: Part’s List

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| Fasteners   | #6-32xXX           | 5       |
|             | #6-32xXX           | 12      |
|             | #6-32xXX           | 21      |
|             | #6-32xXX           | 234     |
|             | #6-32xXX           | 32895   |
|             | #6-32 Nuts         | 8       |
|             | #6-32 NyLock Nuts  | 14      |

| Motors       | MG90s Servo        | 3       |
|             | MG90 1-sided arm   | 1       |
|             | MG90 2-sided arm   | 1       |
|             | MG955 Servo        | 3       |
|             | MG955 2-sided arm  | 1       |
|             | Stepper Motor      | 1       |
Assembly Guide: Head and Neck

Step 1. Press fit Part H3 onto one of the smaller MG90s servo motors.
Assembly Guide: Head and Neck

Step 2. Move the servo motor with H3 attached into the position shown below. Secure the servo motor in place using 2X M2x10mm screws.
Step 3. Attach Part H2 to Part H1. Screw one #6-32x ½” screw through the counterbored hole on each side of the head to secure H2 to H1. Then, use a M3x8mm Screw to attach the bottom hole of Part H2 to the slot of Part H3.
Assembly Guide: Head and Neck

Step 4. Attach another MG90s servo motor to the bottom of Part H1 as shown below. Use 2xM2x10mm screws to hold the servo motor in place

Note: This is the best time to install the M4x6mm heat set insert into Part H1. This should be done with a soldering iron with an appropriate tip. The insert goes into the hole with the red dot as shown below. Be sure that the insert is flush with the inside face of the servo motor cutout, so the servo motor still fits in the slot.
Step 5. Place the two-sided servo motor arm into the slot on Part N2 as shown below. Then place a thrust bearing washer, then the needle roller, and then another washer into Part N2 as shown below.
Assembly Guide: Head and Neck

Step 6. Attach a MG90s servo motor into the square slot in Part N1 as shown below. Fix the servo motor in place using 2x M2x10mm screws.

Note: Thread the servo motor wires through the small square slot below the “N1” engraving before you place the motor; lightly pull on the wires as you push the motor into place to prevent wire damage.
Assembly Guide: Head and Neck

Step 7. Attach the servo motor shaft extending out of part N1 through the thrust bearing and into the servo arm connector in part N2. Use a M2.5x10mm screw with one washer and a small dab of Blue Loctite on the end to go through the square slot on the bottom of Part N2 into the servo motor. Hold Part N1 and try to rotate N2 while tightening the screw. Once you feel the rotation get harder, back the screw out a ¼ turn.

Note: The servo motor should sit flush against the thrust bearings, and the rectangular face of the motor should sit just above the top of part N2.
Step 8. Attach the head to the neck by angling the shaft of the motor on the bottom of the Part H1 through the slotted cut of Part N1. Once Part H1 is between Part N1, press on the servo motor arm and attach with an M2.5x5mm screw. In addition, use a M4x5mm screw with one washer on the opposite side, threaded into the heat set insert.
Assembly Guide: Head and Neck

Step 9. The head and neck assembly should look like the image below. Try moving the head up and down as well as left and right while holding Part N2 in place; all movements should be smooth and not take a significant amount of force.
Assembly Guide: Torso and Wings

Step 10. Place the MG955 servo motors in the rectangular slot of Part T1. Fasten the motor to Part T1 with 4 #6-32x1” screws.
Assembly Guide: Torso and Wings

Step 11. Place the two-sided servo arm in part T2, in the slot shaped like the servo arm.
Step 12. Align the holes of parts T4 with part T2’s counterbored holes on the opposite side of where the two-sided servo arm is placed. Fasten the two T4 parts to part T2 by feeding a #6-32x XX screw through the engraved side of part T2 and tightening the other side of the screw with a nut.
Assembly Guide: Torso and Wings

Step 13. Align the holes of part T3 in between the holes of part T4. Fasten parts T3 to T4 by placing a #6-32x XX screw through the three holes and fastening a nut on the other side. Tighten the nut and screw. Repeat the process for the other part.
Assembly Guide: Torso and Wings

Step 14. Fit the servo motor arm on Part T2 onto the shaft of the servo motor that coming out of Part T1 as shown below. Secure T2 to T1 by screwing a #4-40x ½” screw through the center of Part T2 into the servo arm.
Assembly Guide: Torso and Wings

Step 15. Align the center hole of Part W1 with the inside hole of Part W2 (This is the side with the holes closer together). Place a #6-32x 1 ½” screw through Part W2 and then W1 and finger tighten a NyLock nut onto the end of the screw. DO NOT TIGHTEN ANYMORE
Assembly Guide: Torso and Wings

Step 16. Align Part W3 with Part W1 and shown below. Place a #6-32x 1" screw through the aligned holes and tighten a nut on the other side using a socket wrench. Tighten the screw and nut but ensure the parts can still rotate without any binding.
Assembly Guide: Torso and Wings

Step 17. Align the holes of Part W4 with Part W2 and Part W3 as shown below. Place 2x #6-32x 1" screw through each set of holes and fasten a nut on the other side.
Assembly Guide: Torso and Wings

Step 18. Align the holes of part W5 with part W2 as shown below. Place a #6-32x 1” screw through the aligned holes and fasten a nut on the other side.
Assembly Guide: Torso and Wings

Step 19. Align the holes of Part W6 with Part W4 and Part W5 as shown below. Place a #6-32x 1” screw through each set of holes and fasten a nut on the other side.
Assembly Guide: Torso and Wings

Step 20. Align each of the left-side holes of two of Part W9 with Part W2 and Part W3. Place a #6-32x 1” screw through each set of holes and fasten a nut on the other side.

Note: These screw heads should face the opposite direction than the opposite direction as the rest of the screws in the assembly (screw heads go through the parts marked with the red dots first).
Assembly Guide: Torso and Wings

Step 21. Place a MG955 servo motor in part W7L so that the set of holes on the servo motor aligns with the holes of the shoulder blade. Ensure the servo motor shaft fits through the hole in the shoulder blade. Secure the servo motor in place by using 3x #6-32x 1” screws.
Assembly Guide: Torso and Wings

Step 22. On the shoulder blade, press fit Part W10 onto the shaft of the servo motor. Secure Part W10 in place by screwing a #4-40x ½” through W10 and into the servo arm.
Assembly Guide: Torso and Wings

Step 23. Align the holes of the assembly created from Step 20 with the holes of the Part W7 and servo motor as shown below. Use the #6-32x 1 ½” screw through Part W2 and Part W1 to go through Part W7 (marked in red).

Use a #6-32x 1” screw to go through Part W10 and then through both arms of Part W9 (marked in blue). Note: Insert the screw so that the screw head is closest to Part W7; This screw should face op
Assembly Guide: Torso and Wings

Step 24. Align the holes of the wing assembly from Step 23 in between the holes from Part T1. Fasten the parts together by placing a #6-32x 2” screw between the four holes and tightening a nut on the other end.
Assembly Guide: Torso and Wings

Step 25. Complete Steps 15–24 again to create a second set of wings with part W7R instead of W7L. Attach this configuration to Part T1 to complete the full Torso and Wing assembly.
Assembly Guide: Torso and Wings

Step 26. Attach the head assembly to the top of Part T1. The hole on part N2 should line up with the hole on part T1. Put a #6-32x 2 ½ screw through the hole on Part N2 and through the hole on Part T1. Use a Nylock nut on the other side of the screw and tighten into place.
Assembly Guide: Lower Assembly

Step 27. Slide the bottom of Part T1 into the square cutout of Part L1. Align the slots of Part L1 with the holes of part T1. Place a #6-32x 2 ½” inch screw through the slots of Part L1 and the hole of part T1 and tighten a nut on the other side.
Assembly Guide: PVC Pipe Assembly

Step 28. Attach Parts P1, P2, P3, P4, and P5 as shown below.
Assembly Guide: Base Assembly

Step 29. Screw the lazy Susan bearing to the bottom of Part B1. Ensure that the center of the lazy Susan bearing the hole in the center of Part B1 are concentric. This can be done by drawing two perpendicular lines through the center of Part B1. Use 4x #8-32x ¾" wood screws into the larger holes on the side of the lazy Susan that has a large hole with a small one next to it.
Assembly Guide: Base Assembly

Step 30. Screw in the stepper motor to Part B1 using 4x M3x20mm screws. The heads of the screws should be on the same side of the wood as the lazy Susan bearing.
Assembly Guide: Base Assembly

Step 31. Attach the pinion, Part B8 to the stepper motor. Note: the hole on Part B8 is “D” shaped to line up with the motor, be sure the flat faces line up when pushing Part B8 onto the stepper motor. There is a hole on Part B8 for a set screw to be used, but it is not necessary, as the “D” shaped hole does not allow the motor shaft to slip inside the pinion.
Assembly Guide: Base Assembly

Step 32. Slide the slip ring through the counterbored hole on Part B1 so that the flange sits flat against the top surface of the hole. Fasten the slip ring to the wood using 4x #6-32x ½” wood screws.

Note: Thread the two sets of wires through the hole in Part B1 before fastening is completed. Lightly pull the wires as you put the motor in place to prevent wire damage.
Assembly Guide: Base Assembly

Step 33. Attach the laminated bottom base to the lazy Susan bearing. Line up the holes on the lazy Susan bearing with the clearance holes on Part B1. Place the lazy Susan on top of part B4, ensuring that the pinion meshes with the internal gear, and that the lazy Susan bearing is concentric with Parts B2, B3, B4, and B5. Run the wires from the slip ring through the slot in the laminated bottom base. One of the sets of wires will go through the slot and connect to the power switch while the other set will be directed through the other slot. Secure the bottom base to the lazy Susan by using 4x #6-32x ¾” wood screws (put in through the clearance holes on the top base).

Note: The slip ring is not pictured in CAD, however it should already be connected to your top board.
Assembly Guide: Base Assembly

Step 34. Screw in Part B6 to Part B1. Ensure the hole of Part B6 is concentric with the center hole of Part B1. Use 5x #6-32x ¾” wood screws.
Assembly Guide: Base Assembly

Step 35. Attach the Part P1 from the PVC assembly from step 27 into the hole of Part B6. Note: This will be a tight fit, but Part P1 does fit inside of the hole in Part B6. After it is screwed in, use a hand drill with a number 27 drill bit to drill a hole in Part P1. Use the hole of part B6 as a guide. After a hole is drilled, insert a #6-32x2 ½ Screw through one side of Part B6 and use a Nylock nut on the other, and tighten.

Note: Optional to use PVC glue on the inside of Part B6 for a more permanent fastening method. Not recommended if parts are going to be stored in pieces.
Step 36. Slide the larger hole of part L1 into part P5 as shown below. Align the slots in Part L1 with the holes in part P5. Use a #6-32 x 2 ½” screw that goes through the aligned holes and fasten a nut on the other.
Step 37. Align the hole of L2 with the hole of L3. Place a #6-32x 1 ½” through the aligned holes and fasten a nut on the other side. Repeat this step twice so you have two leg assemblies.
Step 38. Using the assembly created from Step 35 (leg assembly), align the hole in Part L2 with the slot on part L1 as shown below. Use a #6-32 x 1 ½” screw through the aligned holes and tighten (Screws will self-tighten into Part P5).
Assembly Guide: Base

Step 39. Slide part L4 into the back side of Part L1. Place a #6-32 x 2 ½” screw through the aligned holes and fasten a nut on the other side of the screw.
Wiring Guide: Soldering Components to PCB

Materials:

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-Pin Connector</td>
<td>1</td>
</tr>
<tr>
<td>12 V-DC Power Female Connector</td>
<td>1</td>
</tr>
<tr>
<td>CP Barker Bird Printed Circuit Board (PCB)</td>
<td>1</td>
</tr>
<tr>
<td>Soldering Iron</td>
<td>1</td>
</tr>
<tr>
<td>Soldering wire</td>
<td>1</td>
</tr>
<tr>
<td>DF Player</td>
<td>1</td>
</tr>
<tr>
<td>A4988 Stepper Motor Controller</td>
<td>1</td>
</tr>
<tr>
<td>Integrated Circuit (IC) TL9721P</td>
<td>1</td>
</tr>
<tr>
<td>Integrated Circuit (IC) LM2576TV-5G</td>
<td>1</td>
</tr>
<tr>
<td>3 Diodes</td>
<td>1</td>
</tr>
<tr>
<td>Coil Inductor</td>
<td>1</td>
</tr>
<tr>
<td>Flush Cutters</td>
<td>1</td>
</tr>
<tr>
<td>1 x 1 µF Capacitor</td>
<td>1</td>
</tr>
<tr>
<td>2 x 100 µF Capacitors</td>
<td>2</td>
</tr>
<tr>
<td>1 x 1000 µF Capacitors</td>
<td>1</td>
</tr>
<tr>
<td>3 x 1 kΩ Capacitors</td>
<td>3</td>
</tr>
<tr>
<td>1 x 5 kΩ Capacitor</td>
<td>1</td>
</tr>
<tr>
<td>1 x 10 kΩ Capacitor</td>
<td>1</td>
</tr>
</tbody>
</table>

Procedure:

1. Cut or break apart your pinhead connector to the right size to match the part list below:
   a. 10-pin connector x 1
   b. 8-pin connectors x 6
   c. 3-pin connectors x 6

2. On the back side of the Printed Circuit Board (PCB), solder the 10-pin connector to the section marked PWM 1. Solder six 8-pin connectors to the sections on the PCB marked PWM2, COMMUNICATION, POWER, ANALOG_IN, and ANALOG_IN_2. It is important to make sure they are soldered in as straight as possible because these pins need to interface with the Arduino Mega microcontroller.

*Use this website to learn how to solder: [https://www.makerspaces.com/how-to-solder/](https://www.makerspaces.com/how-to-solder/)
Wiring Guide: Soldering Components to PCB

3. Solder the six 3-pin connectors to each of the six servo connection points labeled FLAP, NECK_U/D, NECK_L/R, WING_L, WING_R, and BEAK.

4. Solder the 12 V-DC Female power connector to the top right corner of the PCB as shown below.
5. Solder the DFPlayer to the pins shown below so that it covers the designated outline on the left side of the PCB.

6. Solder the red A4988 stepper motor controller by aligning it in the square space labeled “Stepper Motor Controller”. The orientation of this part is not obvious. The potentiometer, which looks like a small screw, is closest to the right side of the PCB and the A4988 on the red board should be facing right side up.
Wiring Guide: Soldering Components to PCB

7. Solder the small 8-pin IC chip labeled TL972IP to the board by aligning it in its designated space. This IC needs to be oriented so the small circle on the chip is on the same side as the dot on the PCB.

8. Solder the 5 pinned IC (integrated circuit) labeled LM2576TV-5G to the space on the board labeled U2. This chip can only go in one orientation due to its pin layout with two leads directly beneath the I.C. itself and three leads extended farther away.

9. Solder the capacitors to the board. Capacitors are oriented so that the long lead is the positive lead, and the gray stripe indicates the negative lead. Each capacitor on the bird will be oriented so that the positive lead is facing towards the top of the board. There will also be a small + on the board as a precaution.
10. Solder the capacitors to the board at the spaces labeled C1, C2, C3, and C4. C1 is for the 1µF compositor, C2 and C4 are for the 100µF capacitors and C3 is for the large 1000µF capacitor. This can also be seen in table below:

<table>
<thead>
<tr>
<th>Capacitor label</th>
<th>Capacitor Value [µF]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
</tr>
<tr>
<td>C2, C4</td>
<td>100</td>
</tr>
<tr>
<td>C3</td>
<td>1000</td>
</tr>
</tbody>
</table>

![](image1.png)

**Figure 10. Attaching capacitors to PCB**

11. Solder the three diodes to the board at the spots labeled D1, D2, and D3. These are oriented so that the gray strip matches the white-filled strip shown on the illustration on the board. D1 and D2 are smaller diodes while the diode that goes in D3 is larger.

![](image2.png)

**Figure 11. Attaching diodes to the PCB**

12. Solder the coil inductor to the spot labeled L1 on the board.
13. Solder the resistors to the board. These values and the labels should match the table below. The leads are non-polarized, so the either lead can be soldered into either pin.

<table>
<thead>
<tr>
<th>Resistor Label</th>
<th>Value [kΩ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1, R2, R3</td>
<td>1</td>
</tr>
<tr>
<td>R4</td>
<td>5</td>
</tr>
<tr>
<td>R5</td>
<td>10</td>
</tr>
</tbody>
</table>

14. Solder the 6-pin and 4-pin Phoenix Contact Connectors so that the open connection points are facing to the right and hang slightly off the edge of the board.

15. With your CAPED Barker Board PCB assembled, use flush cutters to cut the hanging leads off the back of the board.
Wiring Guide: Routing Wires to PCB

Procedure:

1. Make sure each wire coming from the servo motors and speaker are longer than 2 ½ ft. Wires can be extended by linking jumper cables to extend length. Place small labels at bottom of each part for easy identification when connecting to PCB.
2. Group wires and run them through front slot of part L1 and secure into slot with tape.
3. At the bottom of the slot of part L1, run the wires through the top hole in the PVC pipe, and pull the group of wires the group through the lower hole located near the PVC pipe.
4. Connect servo wires to their labeled pins on the printed circuit board with the black wire towards the inside of the PCB and the white wires towards the outside of the PCB.
5. Connect the speaker wire to its respective screw terminals on the PCB (furthest right). Use a small flat head screwdriver to secure the wires in their terminals.
6. Connect the 10 kΩ potentiometer and 100 kΩ potentiometer to their respective screw terminals on the PCB (next to the speaker wire terminals).
7. Connect the stepper motor wires to the four left wire terminals.
Wiring Guide: Connecting Components to Slip Ring

Procedure:

1. Cut the red and black wires for the DC power connectors to 6 inches each.
2. Connect the red end of the DC power connector to one side of the power switch using the included crimp.
3. Connect the other end of the power switch to the red wire on the swiveling end of the slip ring using the included crimp.
4. Connect the black wire of the swiveling end of slip ring to the black wire of the female DC power connector using male and female 22-16 crimps.
5. Connect the non-swiveling side of the slip ring to the matching colored wires from the two male DC connectors using twist on wire-connectors.
6. Run the female barrel plug and on-off switch through the slot created in the laminated bottom wood piece. The barrel plug goes through one slot, and the power switch goes through the other.
7. Secure the slip ring to the top of piece B4 with wood screws.
Software Guide – Creating an Animation Routine

Files Required:

- CAPEDBarkerBird GitHub Repository -
  - BarkerBird
    - Actions.h
    - Animations.h
    - BarkerBird.ino
  - Libraries
    - AccelStepper
    - DFMiniMp3-master
    - DFRobotDFPlayerMini-master
    - VarSpeedServo

Developed programs for the bird can be found on the project’s GitHub® website. Newly purchased PCB boards with the team’s custom design require program upload before successfully operating the bird.

1. Uploading code to the PCB board
   a. To begin the Arduino IDE will need to be obtained. To do this navigate to
      https://www.arduino.cc/en/software. Next download and install the software appropriate
      for the user’s operating system.
   b. Navigate to the CAPED Barker Bird GitHub repository, and clone the repository onto
      the user’s computer.
   c. Using the Arduino IDE open the BarkerBird.ino file.
   d. Connect the USB cable from the computer to the Arduino Mega microcontroller.
   e. In the Arduino IDE, select the upload icon in the top left corner of the screen.
   f. The Barker bird is now programmed with the default animation routine.
Software Guide – Creating an Animation Routine

Procedure:

1. Download the CAPED Barker Bird Github and open the BarkerBird.ino file, the select Animation.h tab. Find the section of code called Animation Actions[].

   Animation Actions[] = {
   {100,   SPEAK, 3, 30},
   {100,   NECK_L_R, 50, 20},
   {1000,  NECK_U_D, 50, 20},
   {600,   NECK_L_R, 50, 20},
   {1100,  NECK_U_D, 50, 20},
   {0,     BASE, -50, 40},
   {0,     WING_L, 0, 25},
   {0,     FLAP, 100, 25},
   {1000,  FLAP, 0, 25},
   };

   Each action in the routine is created in the following structure.

   struct Animation
   {
      unsigned long ActionTime;
      Action* ActionToAct;
      int PositionTrack;
      int SpeedValue;
   };

2. Set the time for each action to take place.
   a. The Animation structure holds all the information needed for Barker Bird to complete tasks. The first part of this structure, called ActionTime, holds the number of milliseconds after the previous action that must pass before starting this new action. For example, in Animation Actions[], the NECK_L_R action starts 100 milliseconds after the first SPEAK action. SPEAK will start one hundred milliseconds after the start of the program because it is the first animation. If you want to have actions start at the same time, set ActionTime to 0.

3. Select the action to perform
   a. The second section, ActionToAct, is where you would select the action you want to perform. There are 8 actions to select from:
      1. BEAK* - allows the Barker Bird to open and close its mouth
      2. FLAP - makes the Barker Bird flap its wings
      3. NECK_L_R - rotates the neck left and right
Software Guide – Creating an Animation Routine

4. NECK_U_D - tilts the head up and down
5. WING_R - extends the right wing
6. WING_L - extends the left wing
7. BASE – rotates the base the Barker Bird clockwise and counterclockwise
8. SPEAK - outputs a prerecorded MP3 file from speaker

*NOTE: the Beak action is controlled automatically and should never be used when animating

4. Set how far each servo motor will move.
   a. PositionTrack varies numbers from 0 to 100. The designated number represents how far each servo motor will move. For example, WING_R of 100 will extend the wing to its max extension and 0 will be all the way closed. If NECK_U_D has PositionTrack= 0, the bird will move its head all the way down while PositionTrack = 100 will be all the way up. If NECK_L_R has PositionTrack = 0, the head will be rotated clockwise 90 degrees and PositionTrack = 100 rotates the head counterclockwise 90 degrees.
   b. When ActiontoAct = Base, PositionTrack = -100 correlates to 90 degree rotation counter-clockwise and Position Track = 100 correlates to 90 degree rotation clockwise. PositionTrack = 0 correlates to center position.

5. Set the speed of the servo motor
   a. Adjusting SpeedValue will set the speed that each servo moves. This value ranges from 0 – 100.

6. Adjust the values for ActiontoAct = 8.
   a. PositionTrack selects a pre-recorded voice line to play. It is selected based on the order the MP3 files appear on the micro SD card.
   b. SpeedValue selects how loud the speaker is by selecting a number in the range of 0 to 100.

The following are two example structure format for customizing an animation routine.

**Goal:** Flap the wing to 50% extension, 100 milliseconds after the last action. Flap at 20% speed

Following the structure format, you would write: {100, FLAP, 50, 20}

**Goal:** Barker Bird speaks track 4 at 20% volume at the same time as the last action

Following the structure format, you would write: {0, SPEAK, 5, 20}

To add these actions to the list of animations, you would first decide what animations you want them to go after. An example of having the neck rotation second, wing flapping fifth, and speaking be last in the order of animation is shown below.
*Note: Add a comma between each animation action except for the last one. Once the animation routine is finished, the Barker Bird will automatically start to repeat the routine. If two animations use the same action before that action is done, the new one will take precedence.*
Troubleshooting Guide

Mechanical Linkage Failures:

It is suggested that any custom part is re-printed if there are any issues. In addition, it is important to inspect areas of concern such as wing joints, shoulder joints, and u-joints in the flapping mechanism.

Consistent 3D Printing failures:

Printed linkages will be weaker and more prone to breaking if not printed with proper infill. Refer to manufacturing instructions and printed at a higher infill if necessary.

Software malfunctions:

Delete and re-upload the program to the microcontroller if it is not working as expected. If problem continues, report program as faulty and use other programs until a knowledgeable programmer can address the issue.

Electrical Failures:

Overheating:

The custom printed PCB board and the control unit for the buck converter both need to be attached to a heat sink. Check proper attachment to heat sink if these parts do not dissipate heat as expected. Additionally, make sure costuming does not prevent adequate airflow for the microcontroller and attached components. If problem persists, consider updating parts as they may have deteriorating efficiency.

Large Current draw:

Larger than expected current draw is typically caused by faulting components. Check each motor and the speaker for their current draw, this can be done with an multimeter. If all components are at expected current draw, check for hot spots along wires and replace the wires if found. If none of these problems have occurred, consider replacing the custom printed PCB board. Please note: This system is not designed to run everything at once. If making a unique dance routine, avoid running too many components at a time. If one of the servo motors is run without adequate power, it will stop and the entire system will require a reboot to start the motor again. This reboot can be done with a simple turning off and on with the switch on the base.

Weak motor strength:

First check that fasteners are not over tightened preventing motors from freely moving. The check that motors are getting enough current and not too many motors are being run at one. If none of these fixes solve the issue, consider replacing the motor.
Maintenance of 3D printed parts:

3D printing is a rapid prototype technology, and the items produced are not designed to protect against fatigue. Printed parts in the bird should be replaced at the first sign of wear, or after 30 hours of use. If you notice cracks in any joints of 3D printed parts, stop use and replace parts.