Drone Tagging

Jialu Yu

Ethan Parham

Henry Meiselman

David Morris

Table of Contents

Table of Contents 1

Abstract 4

Introduction/Background/Information Sources 4

Design Process 8

Design Context 9

Requirements and Engineering Specifications 11

Concept Exploration Processes & Concept Generation 14

Concept Selection Process 16

Selected Concept Description 19

Engineering Analysis 22

Build Design 28

Final Design Description section 35

Verification Plan 37

Validation Plans 43

Problem Analysis and Iteration 43

Problem Domain Analysis and Reflection 45

Discussion 47

Reflection 50

Recommendations 52

Conclusions 53

Acknowledgments 54

References 55

Appendices 58

Manufacturing/Fabrication Plan 62

Bios 63

Executive Summary

Biologging tags are pieces of equipment that collect data to study animals in the wild. Research teams originally applied these tags to whales from a boat but have recently started to use drones instead for increased success rate and safety of the whales. The current drone drop mechanism is moderately successful, but air perturbations cause the tags to become unstable during descent. As a result the tag does not consistently attach to the whale. Our specific objective is to develop a new release mechanism that will make the tag more robust to perturbations and external factors, resulting in an increase to the deployment success rate of the biologging tags.

The requirements for this project have been updated into three distinct categories: physical, performance and usage. The requirements and specifications were developed with aid from our sponsor and from problem analysis concerning the dropping mechanism's intended functions.

We combined each teammate's individual concept generation into a team mind map of subsystems. Then, we created pugh charts to narrow down to a select few concepts that we would be using for our design. We then produced an alpha design using our highest ranked concepts from the pugh charts, as well as several alternative beta designs.

The performance specifications will be verified using a physical model. This will be done by constructing a test rig which will be used to run controlled releases of the tag. We will collect data from these experiments to verify the force generated on impact, orientation of that tag during descent, accuracy of the drop, and minimum height of a successful drop.

The engineering analysis is conducted to determine two major components, downwash velocity estimation and spring stiffness selection. The DJI M210 downwash velocity analysis is conducted based on CFD models with various drone types while the spring stiffness selection process is mainly based on theoretical engineering analysis.

Our current build design iterates on the alpha design, and involves 3D printing modular parts in order to test various combinations of springs and fin shapes. The design uses a spring to generate an initial velocity for the tag so the fins are effective in the downwash. The final design will use the most effective combination of spring and tag.

Our verification plan covers our most important requirements and specifications to ensure we are meeting the requirements and specifications of our sponsor. The validation plan goes over how we will achieve our sponsors design specifications.

We discuss the results from our experiments with our final design using different fin designs and the strengths and weaknesses of our final design and give recommendations based on our results and discussion.

Abstract

Biologging tags have been used to study whales' behaviors and habits. This helps provide insight on how human behavior affects whales in the wild. Drones are capable of dropping these tags onto the whales, but perturbations from the drone rotors can cause instability and inaccuracy of the tags during flight, leading to the tags not attaching to the whales. Designing a new release mechanism that will make the tag more robust to perturbations and external factors, resulting in an increase to the deployment success rate of the biologging tags.

Project Introduction and Background

Biologging tags have been used to study animals for decades [1,2]. They are able to track different types of information about the whale. These tags can help us understand and characterize the health and lifestyle of whales. This will allow the research team to better understand the whales behavioral ecology [1,2,3,4], which is how the whales behavior affects their ability to reproduce and survive in the wild. For example, the tags can track information such as location data, allowing the researchers to see where the whale has gone. This allows for tracking of habits such migration patterns or travel for feeding. They can record when the whale is feeding and caloric intake for the whales. Tags can also track the temperature of the whale or recording sound and camera footage depending on the capabilities of the tags. The information collected from the tags is helpful for estimating the swimming biomechanics of the whales, which could be how much energy is needed for the whale to swim, to how much energy was needed for the whale to jump out of the water. Analysis of the data could possibly lead to better understanding of how human actions affect their environment, resulting in changes to human activities such as shipping lanes and offshore wind farms.

Currently, each tag has suction cups on it that allows it to stick to the whale. When enough force is applied, the cup will stick to the whale. Previously, tags have been placed on the whales by having a person holding a pole with the tag on it approach the whale with a boat and manually attach the tag to the whale's back. This has issues though, as it is time consuming and has a high chance of failure. The whales at times will move away from the boat or go back underwater [5]. This results in the researchers waiting for the whale to reappear to attempt the tagging process again, causing an increase in funds needed and time for each tag to be successfully placed onto the whales. This can also result in the whale losing feeding time if it was disturbed by the boat [6]. Another issue is the safety of the whales. In fact, there have been reports of boats hitting and harming whales or at times even killing them [7].

The drawbacks of boat tagging has the Ocean Alliance research team moving towards drone tagging. Drone tagging involves a drone flying a tag through the air. Then, once the drone is above the whale, the tag is dropped from a height of between 16 to 18 feet. This allows them to stay a safe distance from the whale, usually around 1 km [8,9]. The noise drones make have little effect on the whales [10], so long as the pilot ensures the drone does not fly in the whales face.

Since the noise has little effect on the whales, the whale is less likely to go back underwater, reducing the amount of time it will take to tag the whales, and further reduce investments needed. Additionally, due to the drone being airborne, rough areas of water inaccessible to boats would still be accessible to the drone which could drop the tag onto the whale without any issues. Figure 1 shows the drone tagging system in use.

Figure 1: The current tag dropping system mounted to a drone [2]

Despite the benefits of drone tagging, the research team has been having issues with the deployment success rate of the tags. Part of this is due to the inaccuracy of the drop that comes from the tags needing to be released from a height of up to six meters [4]. This height is currently required so the tag can orientate itself correctly before making contact with the whale. The issue is that this additional height also gives the tag more time to possibly be impacted by external factors like wind or the movement of the whale. Another issue is there are perturbations from drone downwash that interfere with the tag once it is released from the drone. These cause the tag to orientate incorrectly at release and is another reason why the drone needs such a high release height to stabilize. To ensure that the research team has more successful drops, we will be looking into minimizing these issues by developing a new release mechanism for the tags. The project is sponsored by Professor Shorter, a mechanical engineering professor at the University of Michigan. He is the main contact for the project, and works with a research team who is funded by Ocean's Alliance.

Benchmarking

To gain a better understanding of the mechanism that the sponsor wants for the drone, we researched mechanisms others have used on drones and for imparting initial velocity. These were compared to the requirements and specifications from Professor Shorter, as well as the current method being used by the research team. The full list of the requirements and specifications can be found in Table 1. The first mechanism we looked at was the drone payload release mechanism drop device [11], which can be seen in Figure 2.

Figure 2: The drone payload release Mechanism Drop device for Drone Fishing, Bait Release, Payload Delivery, Search & Rescue, Fun Activities skyhook [11]

This device was designed to drop bait for fishing, and search and rescue devices. The device works with a servo that pulls back a pin that will release the object it is carrying. It weighs only 1 kg and has small enough dimensions that would fit the current drone that is being used. Also the release mechanism is triggered by the pilot that is flying the drone. This device does not give the payload an initial velocity, which would mean the perturbations that are affecting the tags release would still persist. Since this device is meant for dropping bait into a body of water, accuracy is not much of a factor which may be an issue when looking for precise drops. The next device we looked at was the aerial remote tag system (ARTS) [12], which can be seen in Figure 3.

Figure 3: The Aerial Remote tag system [12]

The Aerial Remote Tag System is used to tag animals by using pressurized air that fires the tags. This is done by a person holding the device and aiming it manually at the target. These have been used to tag whales with suction cup tags, with a person using it on a boat. Mounting this on a drone would not be feasible as it would be too heavy for the drone to carry plus the pressurized air carries some risk, but it could be possible to employ similar concepts on a smaller scale to adapt it to drone use. Pressurized gas can be explosive, which on a drone is not ideal. If the pressure is too high the animal could be injured but if it is too low there is a chance the tag does not stick to the animal. Another issue is that the tags impact on the animal is creating stress on the electronics. This stress could potentially damage the electronics on the tag resulting in the loss of data or the tag itself. Another device we looked into was the spring-loaded mini projectile launcher [13], which can be seen in Figure 4.

Figure 4: Spring-loaded Mini Projectile Launcher [13]

The Mini Projectile Launcher is a spring-loaded steel ball launcher typically used for educational purposes. This product has three different launch velocity settings and can vary the launch angle [13]. A similar mechanism could be used to impart varying initial velocities onto a whale tag as it is released from a drone. This initial velocity could allow the tag to overcome initial perturbations caused by external factors.

Design Process

So far our group has followed a problem-oriented, stage-based, abstract design approach. We kept our process problem-oriented and abstract so as to not constrict our range of possible solutions. By focusing on analyzing the problem, rather than potential solutions, we can help eliminate design bias from our previous experiences and knowledge [14]. We are utilizing a Stages Serial design model which is depicted in Figure 5 below. In the context of our project, the stages are problem definition, concept exploration, and solution development and verification. Our design model does allow for movement back and forth between stages so that each stage can be revisited as more knowledge regarding the project is gained.

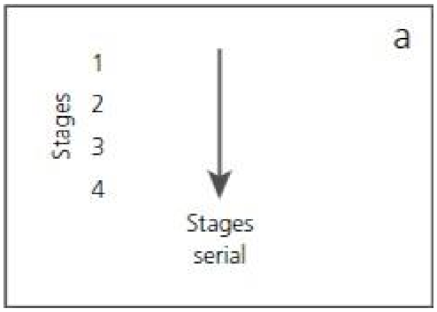


Figure 5: Stages Serial design model [15]

These stages are the same as the ones laid out in the standard design process introduced in ME450. This process is depicted in Figure 6 below.

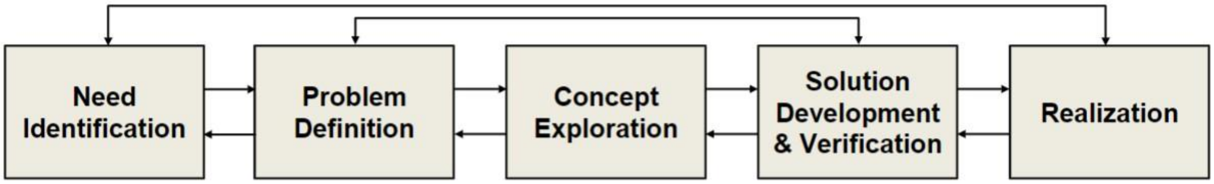


Figure 6: Standard design process model from ME450

We considered a prescriptive, procedural approach where we would use a model to find the optimal tag release conditions and then create a mechanism that releases the tag at these optimal conditions [16]. However, after further consideration this approach was deemed unfeasible because the model and mechanism need to be developed in tandem so they each can be used to validate the results of the other. Having a problem-oriented, abstract approach has been very useful thus far in the context of our project. This approach led us to define our deliverables very broadly while still having the necessary requirements and specifications.This gives us the freedom to fully explore a range of possible solutions. For example, our model could be a CFD/FEA computer-based model or a physical test rig, and either could fulfill our requirements and specifications.

Design Context

In the map, ten stakeholders are sorted by three priorities, four design contexts, and six types of stakeholders.This can be seen in Figure 7, which identifies and organizes the stakeholders.

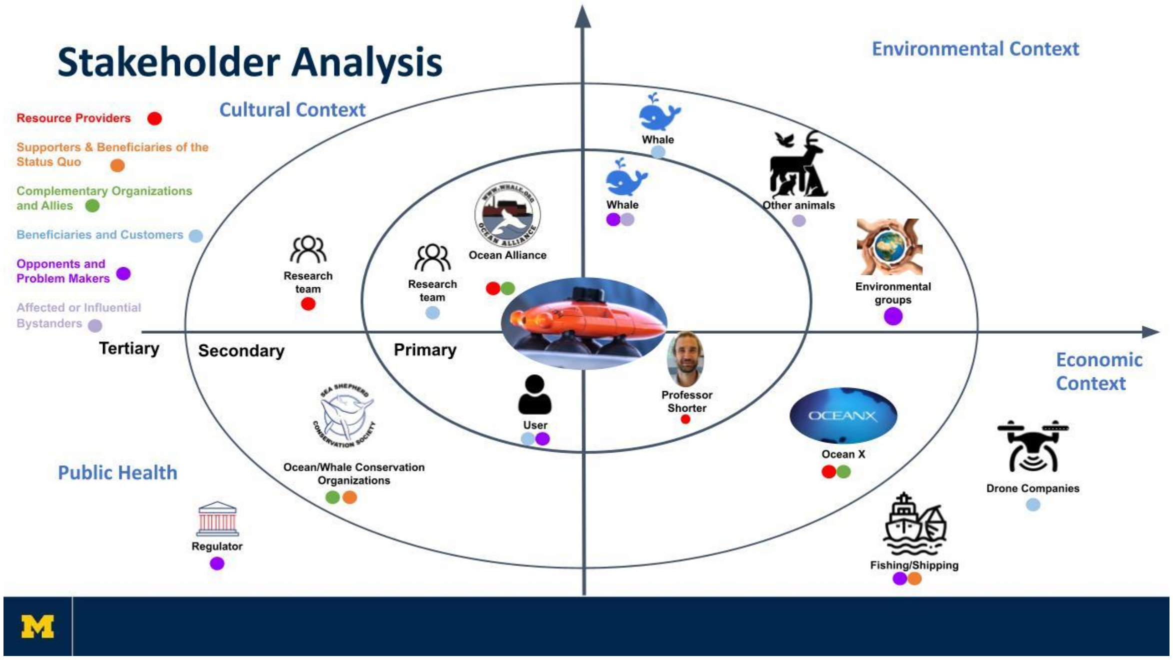


Figure 7: Stakeholder map

Priorities in stakeholders are arranged by circles. The stakeholders inside the first circle are primary stakeholders whose work is directly impacted by the drone tagging project, development of our analysis model and tagging design. Secondary stakeholders are located between the first circles and the second circles who are an essential part of the ocean/environmental context but may not need the tagging project solution themselves or may not directly be impacted by our solution. The stakeholders outside the third circle are tertiary stakeholders, who are outside of the our problem context but may have the ability to influence the success or failure of a whale tagging project. Ten stakeholders are grouped into four design contexts based on two axes: cultural context, environmental context, public health, and economic context.

The environmental context refers to the biological factors in a specific environment that can influence the design of a project aimed at preserving whale health. As a result, stakeholders related to the sustainable development of the environment and population will be placed in this context. As a result, whales, whose habitat and long-term development could be impacted by our whale tagging project, are listed as our stakeholders in the environmental context. The cultural context focuses on the social and cultural values and beliefs in society regarding whale research and conservation. Thus, research organizations or entities that raise public awareness about ocean and whale research will be placed here. Therefore, the research team and ocean Alliance who support the research team will be placed in cultural contexts. The public health context pertains to the practice of promoting health and preventing disease to improve life expectancy, and the stakeholders in this context will be concerned with overall public health. Therefore, the user of the tag, whose health could be directly related to the tag-release mechanism, is placed in a public health design context. The economic context pertains to business and profit interactions relating to the drone tagging project. Any organization or individual who would have an economic impact, either positive or negative, on the drone tagging project will be categorized under this context. Professor Shorter, who is a direct sponsor of our project, as well as Ocean X, a sponsor of Ocean Alliance, are listed in economic context here.

In the map, there are six stakeholder categories- which are resource providers, supporters and beneficiaries, complementary organizations and allies, beneficiaries and customers, opponents and problem makers, and affected bystanders- represented by colored circles under each stakeholder. We will introduce the primary stakeholders and their categories as follows: Professor Shorter and ocean alliance will be the direct fund sources for the drone tagging project and the research team will be potential knowledge supporters/technology advisors for our project. As for the user of our project who directly performs the drone, the user will be benefited through the enhanced drop mechanism which saves more time and energy. However, there could also be potential troubles/user-unfriendly aspects of our mechanism which may result in the user being an opponent. Whales, as a special stakeholder, are directly impacted by the tagging. Whales might not favor the artificial extra part attached to their body and could be intimidated by the tagging mechanism, so we list them as opponents. However, health data tracked by the tagging could potentially be beneficial for whales' future development which makes whales an influential bystanders. In summary, in the primary stakeholders, all primary stakeholders could be benefitted through the drone tagging project except the user and the whales could potentially be negatively affected by the tagging.

The social and societal aspect behind the drone tagging project is the preservation of whales and their habitats. As society becomes more aware of the need to protect these species for future generations and the health of the ocean, stakeholders are placing a high priority on social and environmental impacts over profits. Despite this, the project design is not greatly affected. There is little chance of the drone tagging device being commercialized, as only a select few people can interact with the whales as a result of restrictions from the Marine Mammal Protection Act and Endangered Species Act [17]. Since there is no market and the project sponsor desires an open-source approach, the issue of intellectual property is minimal, and no individual or entity will claim ownership of the project's intellectual property.

There are several inclusivity elements we have considered for our project. First, we want to ensure the operation of the tagging system is user friendly. The current research team has an engineer piloting the drone, and we are designing from the perspective of engineers. We want to make the tagging system accessible to anyone who can fly a drone, without need of understanding from an engineering background. The second inclusivity element we have considered was making sure that the project is accessible to people on boats. This means that people that are on a boat will not need to fine tune anything or make modifications while they are on the boat and in the field. All basic operations should be easy to perform with no additional tools, and setup and teardown of the drone should also be reasonable to perform on a boat.

Lastly, we are also going to co-design with Professor Shorter. We want his feedback and input during the design process to improve our designs, and to make him feel like he is involved in the decision making process so the end result is something that he wants. Improving our communication is important since we have had some miscommunication during our design process that caused us to go off track slightly. Our miscommunication turned into a misunderstanding of the scope of the project. We thought we were going to need to create a model of the system but in reality Professor Shorter wanted us to create a prototype. We want to make sure large misunderstandings do not happen again and that we are on the same page as our sponsor. To further increase stakeholder involvement, we also plan on reaching out to the Ocean Alliance team. Their perspective would be incredibly valuable to learn about usage challenges and additional design requirements they may have as the end user.

User Requirements and Engineering Specifications

The project requirements and specifications were developed based off of the initial meeting with Professor Shorter, as well as further research into considerations that must be made in a payload delivery system. These requirements were then further refined in our second meeting with Professor Shorter, where we cleared up several misunderstandings and received additional clarification for several points. The requirements fall into three categories; physical requirements, performance requirements, and usage requirements. Tables 1-3 contain all of the requirements, specifications, and their priorities which are further explained on the following pages.

Table 1: Physical requirements and specifications

Requirements	Specifications	Priority	Source
The darts must fit within the drone body dimensions	● < 634 mm using DJI Matrice M210 V2	High	DJI Spec
Drone payload capacity is not exceeded by tag and mechanism	● < 1.34 kg/2.954 lbs Using DJI Matrice M210 V2 ● Weight cannot exceed 25% more than existing system	High	DJI Spec, Shorter
Stabilizer must mount to tag body	● DTAG: 82 mm wide x 148 mm length	High	Wiley
Within Budget	● <$500	High	Shorter
Material	● 3D printed for ease of manufacture	Low	Shorter

First, the physical requirements establish the release mechanism and tag system must physically conform to the current hardware being used. The research team uses the DJI Matrice M210 V2 drone to drop DTAG tags, so our system must be compatible with these. The payload carrying capacity of the drone limits the size and weight of the tag and release mechanism system. The DJI Matrice M210 V2 has a diagonal between the propellers of 634 mm [19]. The tag and stabilizer must fit within the landing gear of the drones to prevent collisions during the drop of the tag. The drone must also be able to carry the tagging system, so the total mass of the system must not exceed the drone payload of 1.34 kg for the DJI Matrice M210 V2 [19]. Practically, this means our design must not weigh more than 25% more than the existing system in order to fly the drone [3]. These requirements are critical to the success of the system, since the tagging system will be implemented on the drone available to the research team. If the tag does not fit on or weighs too much for the drone, it will not be functional. Furthermore, the stabilizer should be able to attach to the DTAG tags, which are the tags currently being used with the stabilizer system [4]. These DTAGs have dimensions of and 82mm by 148mm, which must be secured to the drop system. We must also remain within the budget, which is $500 [3]. This has a high priority, as although we do not expect to run into budget issues, price should absolutely be a consideration in the design. With this in mind, the material the drone is made out of should be 3D printed. The current 3D printed design provides enough durability, with the additional benefit of high manufacturability [3]. This is of low priority, since if we find a superior material it should be used.

Table 2: Performance requirements and specifications

Requirements	Specifications	Priority	Source
Generate sufficient contact impact force	● Between 5 N and 26.6 N of force generated	High	Shorter, Wiley
Maintain the orientation of the tag during drop	● <25 degrees of orientation deviation from initial position	High	Shorter
Reduced drop height compared to current design	● <6m from target	High	Shorter
Drop Accuracy	● < 0.5m spread radius from below drone	Medium	Shorter

Second, the prototype must meet the performance requirements for successfully tagging a whale. The system must generate enough force for the suction cups to stick to the target, which from prior testing done by Wiley requires about 5 N of force [4]. There is an upper limit placed on the impact force of 15 N, or triple the minimum threshold, to prevent injury to the whale [3]. Force generation has high priority, since generating enough force is critical for the tags attachment and the success of a drop. The tag must also maintain its orientation during the drop, which is essential for the tag to attach in the front forward low drag position, as well as to land flat on the back of the whale to ensure a solid connection. The <25 degrees of deviation specification ensures that the tag will land in an acceptable orientation [3]. In order to make drops easier, the height that the tags must be dropped from should also be reduced. Currently, the DTAG system is dropped from 6m [4], but reduction of that height will make accuracy and orientation easier to obtain, increasing the success rate. Since reducing drop height is central to the drop mechanism refinement goals, the requirement is of high priority. Finally, the tag must be able to accurately hit the portion of a whale which is exposed above the water, which is estimated to be a circle of radius 0.5m based on the target used by Wiley [4]. The size can vary based on the species of whale being tagged, but this is a reasonable estimate for the blue and fin whales initial testing was performed on. Accuracy is of medium priority, since if the tag is stable and maintains its orientation in flight then most of the accuracy will come down to the skill of the pilot, and not the design of the tag.

Table 3: Usage requirements and specifications

Requirements	Specifications	Priority	Source
Compatibility with existing mechanism	● Release mechanism uses existing pin and servo	High	Shorter
Easy to use	● No special tools	Medium	Shorter
Single person operation for drone flight and release	● Release mechanism remote control must mount to the drone remote	Medium	Wiley
Ease of installment	● No modifications required to drone mounted parts	Low	Shorter

Finally, the tag should meet the ease of use needs of the research team using it in the field. In general, these requirements are all nice to have, but are not necessarily critical to the success of the project. With this in mind, the first requirement in the category, compatibility with the existing mechanism, is essential. The release mechanism must use the existing pin and servo design in order to maintain compatibility [3]. Next, the tag should be easy to maintain in the field, and not require special tools to operate. Since the drones are being deployed from a boat, limiting the complexity of the use process would be helpful [3], although it is not critical to the success of the project resulting in a medium priority. An additional ease of use requirement is the device should be triggered by the pilot of the drone. This reduces the need for communication between the pilot and another operator. The specification that the trigger for the release mechanism is connected to the drone remote control is important, since higher ease of operation will increase the number of successful tagging attempts [4]. However, it is not critical to the performance of the drop, so it has a medium priority. The final requirement is ease of installment. This specifies that no modifications are required to parts mounted to the body of the drone. Ideally, the new tag we produce is "plug and play" with the current release mechanism, and so the new tag will be able to immediately be used with the current system [3]. While convenient, this would be very difficult to accomplish while also adding additional components to improve the functionality of the drop, and so it has a low priority.

Concept Generation

While keeping the project's requirements and specifications in mind, each member generated around 40 different design concepts through various methods. We used methods including brainstorming, morphological chart analysis, design heuristics, and mind mapping. These ideas were unconstrained, so all ideas were recorded regardless of how good or poor they may have seemed at the time. The ideas were not extensively developed, as only about one to two minutes was spent generating each idea. The goal of this portion of concept generation was for everyone to have a good stockpile of ideas before we began team generation, in order to improve the productivity of our team session.These individual team concepts can be viewed in Appendix A.

Following the individual concept generation, a group concept generation session was conducted and all 160 design ideas were consolidated into one mind map. The group concept mind map was divided into four subsystems which appeared in several of our individual morphological chart analysis and based on the requirements and specifications.. The chosen subsections were the forcing component, securement, release, and accuracy/stability systems. Each design idea added to the mind map was classified according to its corresponding subsystem, and connections were drawn between design ideas and subsystems in order to classify or combine them. Some ideas fit into multiple categories, and many concepts sparked further concept generation as shown by the many subtrees that formed off of particular concepts. Once again, all ideas were accepted regardless of their feasibility, as we were promoting creativity in the concept generation process. In the group concept mind map, we filtered out some similar ideas and kept the distinct ideas in the group concept mind map. Distinct ideas are usually different in physical mechanism or rely on different tools. However, distinct ideas under the same subsystems usually contribute to the same functionality. The complete team mind map can be seen in Figure 8.

Figure 8. The group concept mind map

In addition to the individual design ideas proposed, the team also created innovative ideas by combining existing ones and continued brainstorming using these ideas as inspiration. Finally, each design concept was further elaborated upon by attaching a design sketch upon completion of the mind map. This step was essential in providing a more detailed visual representation of the ideas, allowing the team to better evaluate the feasibility and practicality of each concept.

After our concept generation, we had a decent idea of our most likely to be chosen components. Firstly, we believed that spring could be a cost-effective and efficient forcing component. It would be attached to the mounting rack, and the compressed spring could launch the release mechanism and the tagging part. Secondly, for the securement part, we liked the concept of using a pin attached to the top of the tagging mechanism through the holes. Thirdly, for the release mechanism, we considered connecting a servo to the pin so that when it pulls out the pin, the tag dropped. Fourthly, to ensure that the design concept met the accuracy requirement, rails would be installed on the drone to help guide the tag while dropping so that it will not deviate from the target during the drop-off.

Concept Selection

Following our concept generation process, we again met with Professor Shorter to discuss our requirements and specifications and to get his input on our design concepts. We were given a new requirement that our design must use the current servo and pin release mechanism on the drone. This was a requirement which we had not considered during the concept generation. As a result, this changed what we brainstormed together as we no longer needed to focus on how the tag was secured and released from the drone. From this revelation, we used the two remaining categories, forcing component and accuracy/stability, to create pugh charts. The pugh charts helped us to visualize how each component from its respective category ranked against the base component that is currently being used on the drone to eventually select a subsystem to use in our design. Each sub-function has completely different key areas to focus on, with different relative scales of priority. Each pugh chart has a different selection of criteria we used to judge each concept, which were taken directly from, or were a breakdown of, a user requirement. The weights were given a range of [1, 5], with a higher weight meaning higher perceived importance. Each concept was rated on a scale of [-2, 2] which then was multiplied by the weight of the user requirement. A score of zero indicates the concept was equally as good as the baseline, while a 2 was much better and a -2 was much worse. The scores were compared against the existing design which was given a baseline value of 0. This allowed us to gauge how effective each concept would be.

The first pugh chart was created to select from the main concepts for the forcing component, which can be seen in Table 4. Four concepts were looked at in the pugh chart which are a spring on the drone, a spring on the tag, a slingshot design, 3and pressurized gas. We wanted to see how each of these concepts would rank against the current existing design, which is the servo and pin release. Each of the selected concepts are ranked and considered in order from most to least important, here is a breakdown of each:

1. **Cause Impact of > 5N (Weight = 5):** The tag needs enough force after being released in order to attach to the whale.
2. **Compatibility with Pin Release (Weight = 4):** The new system needs to be able to release the forcing component with the current servo and pin on the drone.
3. **Light Weight (Weight = 3):** In order for the drone to be able to operate correctly while airborne, we want the component to be light.
4. **Manufacturability (Weight = 3):** We want the component to be easily made and not be

overly complex.

5. **Ease of Use (Weight = 2):** The user should be able to attach the tag to the forcing component without any issues.
6. **Price (Weight = 1):** Needs to be cheap due to the possibility of parts possibly breaking.

Table 4: Pugh chart for the forcing component.

Requirements	Weight	Base Design (Servo+pin)	Spring On drone	Spring on tag	Slingshot	Pressurized gas
Cause Impact of >5 N	5	0	+1	+1	+1	+2
Compatibility with pin release	4	0	+2	+2	+2	-2
Light Weight	3	0	0	0	-1	-2
Manufacturability	3	0	-1	-2	-1	-2
Ease of Use	2	0	+1	+1	-1	-2
Price	1	0	0	0	-1	-2
Total		0	12	9	7	-16

Looking at the pugh chart, we can see that the highest scoring concept for a forcing component is the spring on the drone. The advantage of this concept is that it retains all of the benefits of being compatible with the pin release and causing an impact of greater than 5N. Even so, it does rank lower in some of the other requirements but those requirements are weighed much lower and the spring on the drone ranks highly in our most important requirements. We do expect it to be sufficient to clear these requirements while also offering more benefits than the other concepts do with regards to how the user would operate the device.

Next, a pugh chart was created from the accuracy and stability concepts that were chosen, which can be seen in Table 5. There were three concepts examined in the pugh chart, which were expanding fins, guide rails and a parachute. We wanted to see how each of these concepts ranked against the existing design, which are the stationary fins. Each of the selected concepts are ranked and considered in order from most to least important, with the breakdown as follows:

1. **Maintains the orientation of the tag (Weight = 5):** The tag needs to be able to maintain the correct orientation while airborne, otherwise it may not hit land on the whale correctly.
2. **Manufacturability (Weight = 3):** The part should be easy to replicate, and not overly complex.
3. **Light Weight (Weight = 3):** If the part is over cumbersome it may affect the drone during flight, so the parts weight should be only what is needed.
4. **<.5m spread radius from below the drone (Weight = 2):** Precision is not as important, but the tag still needs to land on the whale and not miss entirely.

Table 5: Pugh chart for the Accuracy/Stability

Requirements	Weight	Base Design (Stationary Fins)	Expanding fins	Guide Rails	Parachute
Maintains the orientation of the tag	5	0	0	+2	+1
Manufacturability	3	0	-2	0	-1
Light Weight	3	0	+1	-1	+2
< 0.5m spread radius from below drone	2	0	+1	0	-2
Total		0	-1	7	4

From this pugh chart, we saw that the highest scoring concept for accuracy and stability was the guide rails. The guide rails scored the highest compared to the other concepts for maintaining the orientation of the tag, which is the most important criteria we have after the tag is released from the mechanism. The guide rails do rank lower for some of the other criteria than the other concepts, such as light weight. This was not a major cause for concern though as it was considered a lower priority as we have some flexibility regarding adding additional weight to the design.. It is something to keep in mind and adjust accordingly depending on the weights of the other components.

Given the pugh charts generated, the concepts that were selected was the spring on the drone with guide rails. We also discussed and decided on keeping the fins that are currently on the dart which connects to the tag. This will add extra weight, but the type of guide rails we are thinking of using consists of a type of thin wire, allowing us to keep the weight to a minimum. Since the perturbations that are being caused by the drones rotors are an issue, having the guide rails will help the tag maintain orientation until the tag is outside of the perturbations.We still wanted to ensure that the tag maintains this orientation, which keeping the current fin design on the dart would allow us to do. If weight becomes an issue, through testing and iteration the fins may be reduced in size. Given all of this, we are satisfied with how our selected concepts were scored and judged. We believe the current selected concept should satisfy the given criteria.

Selected Concepts

The “Alpha design,” shown in figure 9, combines all of the selected subsystems from our concept selection process into a fully developed design. The release mechanism uses the existing servo pulling a pin as required by our sponsor. The securement also uses a similar system to the current design, as the pin passes through a 3D printed topper to hold the tag to the drone until the servo is triggered. The topper for the Alpha design (shown in black) is significantly longer than the topper for the tag currently in use in order to make room for the forcing component. The forcing component is a compression spring, shown in pink, which will be mounted to the underside of the servo release mechanism. The topper will fit through the ring shaped spring mount so that when attached, the spring will be compressed surrounding the topper. The bottom of the topper will have a widened circular portion for the spring to push against while compressed. When the pin is pulled, the spring will uncompress, and the tag will be launched downwards. The accuracy/stability component is a combination of fins, and a rail/guide hook system. The fins currently have the same shape and size as the existing fins, with plans to make alterations following aerodynamic analysis and physical tests. They will be 3D printed, which will allow for rapid and inexpensive prototyping while still providing a design which is sturdy enough for field use [Shorter]. Two rails (shown in dark blue) will be made of thin but stiff metal wire and protrude downwards from the drone. The body of the fins will have two sets of hooks (shown in light blue) which will loop over the rails and prevent the tag from changing its orientation as it is pushed away from the body of the drone. Ideally, these rails will be able to be detached from the mounting bracket in order to facilitate easy storage. The bottom of the fin body will attach to the currently used TPU flexible mount for the DTAG, since there are no issues with the current implementation of that part.

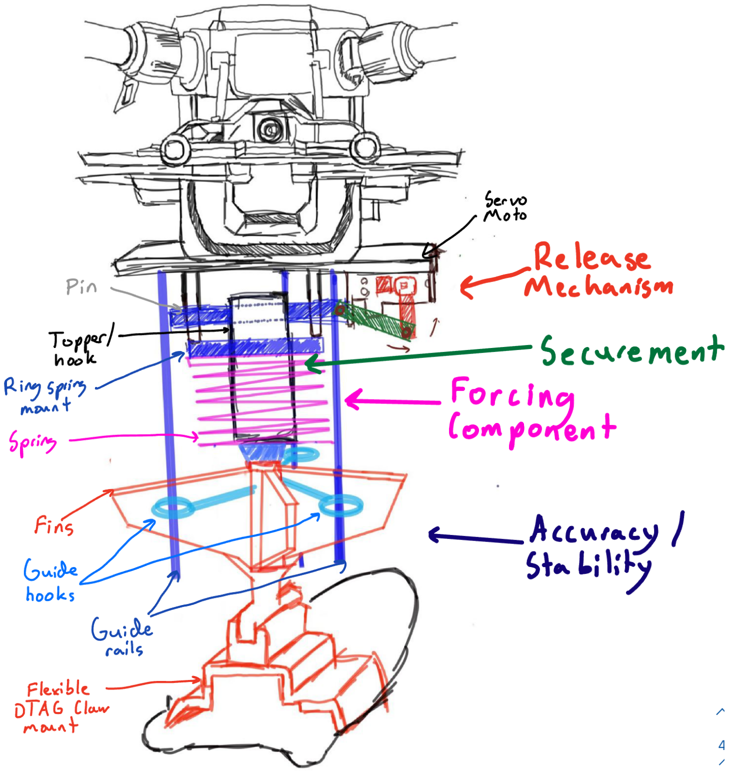


Figure 9: Alpha design, the spring mechanism is attached to the drone.

We also further developed two "Beta designs," which offer alternatives to the subsystems chosen in the Alpha design. The first beta design, shown in Figure 10, primarily alters the forcing component and securement subsystems by mounting a compression spring to the tag as opposed to on the body of the drone. This modification to the Alpha design aims to reduce the amount of changes that would be necessary to make to the parts currently mounted to the drone, as only a circular force plate with a hole in the middle (shown in green on Figure X) would need to be added to the current servo mount. Then, a very similar securement topper (dark blue) would be used in order to reach through the compressed spring to loop over the pin of the servo. The spring would then mount to the circular base plate on the topper and wrap around the stem of the topper. We would expect this design to have similar performance to the alpha design, with the benefit that it would more successfully meet the low priority ease of installment requirement which specifies there are no modifications required to mount the new tagging system. However, while this design would certainly be effective, requiring a spring for every tag will increase the complexity of manufacturing tags. This is something we would like to avoid, since multiple tags will be manufactured for actual use compared to the single drone mount that will need to be made. Currently, we are prioritizing the ease of manufacture of tags above the requirement to make few changes to the existing parts mounted on the drone.

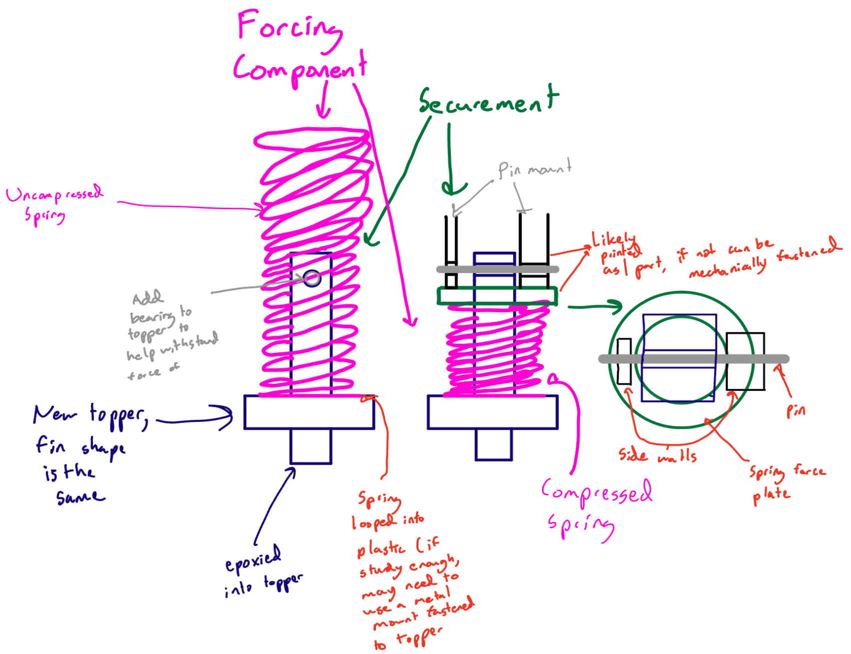


Figure 10: Beta design, the spring is attached to the tag topper.

The second Beta design, depicted in Figure 11 on the following page, is designed around using an elastic band as a forcing mechanism. The band (shown in orange) will be connected to rails mounted to the body of the drone and loop over the topper of the tag (blue) when it is ready to be released. Then, when the servo motor pulls the pin from out of the topper, the elastic will launch the tag downwards, guided by the rails. The release mechanism remains as the servo and pin mechanism. The securement topper now uses two hooks that loop over the servo motor in order to make room for the elastic band to pass through the middle and loop over the top of the tag when loaded on the drone. The body of the tag has two guides on each side which fit into the grooves on the rails in order to prevent the tag from changing its orientation while being accelerated by the elastic. Uniquely, the slingshot design does not use fins on the tag, instead relying on the velocity generated by the elastic combined with the initial stability of the rails to prevent changes in its orientation. This design would probably be the most intrusive to the current parts mounted to the drone, due the large rails that need to be mounted to it. The rails would also add a significant amount of weight, but this would be counteracted somewhat by the removal of fins from the body of the tag.

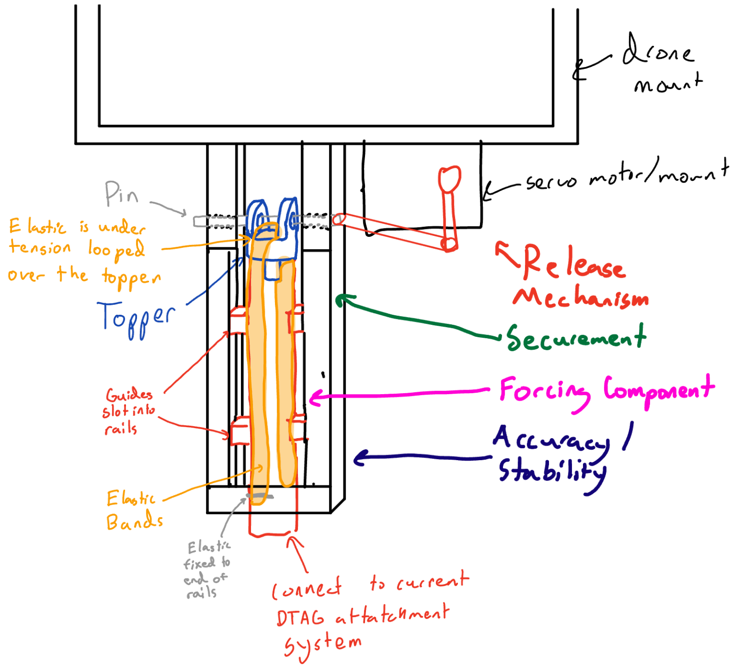


Figure 11: Second Beta Design, A slingshot mechanism which is attached to the drone.

Overall, our design choices had a fair mix of influence from our sponsor as well as our own decisions. Professor Shorter helped us significantly narrow our design space by limiting the release mechanism we could use and by emphasizing design ideas we had generated which were compatible with the existing system. Additionally, since the scope of our project is improving an already existing design which is already finding success, our Alpha design reflects a lot of aspects of the current design which already seem to function well. The Alpha design aims to add functionality to the current positive traits of the drone tagging system, as opposed to redesigning it from the ground up like in the slingshot second Beta design. The pugh chart analysis we performed in our concept selection pointed out there were several strong candidates for both the forcing component and the accuracy/stability components, which are represented in the Alpha and Beta designs. While we did have a general idea of which concepts were stronger than others before making the pugh charts, they did provide honest insight into the strengths of other designs we may have overlooked. For example, we did not strongly consider using a rail system for our Alpha design until after our analysis showed its benefits. Our realization of a prototype should absolutely be feasible within the remaining time frame that we have. Since our design relies heavily on 3D printing, we should have no issues creating and testing our design to verify it meets our requirements and specifications.

Engineering Analysis

Part I: UAV(Unmanned Aerial Vehicle) Downwash Analysis and Fan Selection

To replicate the downwash of the DJI M210 V2 drone during the drop test, we plan to use four fans with airflow velocities similar to those of the M210. These fans will be mounted on a task rig that corresponds to the four rotors of the M210, with their positions determined based on the locations of the rotors on the drone. By simulating the downwash in this way, we can more accurately evaluate the performance of the tag and spring under conditions similar to those experienced during actual drone flights.

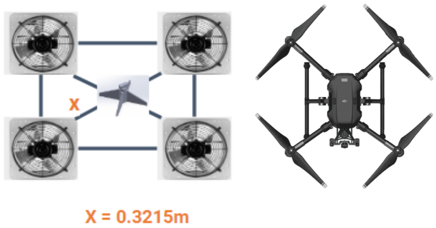


Figure 12. The Comparison with the setup of the fans and M210

The first step in our process will be to determine the downwash velocity of the DJI M210 V2 drone. As we noted in our DR2 analysis, we plan to generate a CFD model of the M210 in order to simulate the downwash and turbulence generated by the drone. However, since a physical model of the DJI M210 V2 is not available for testing, and there is limited information on the UAVs specifications, we have decided to reference downwash analyses and CFD models of other UAVs to estimate the range of possible downwash velocities for the M210. By utilizing this approach, we can develop a reasonable estimate for the M210's downwash velocity and accurately simulate it during the drop test.

Here are the four most important references for us to determine the M210 downwash velocity. We also attached the existing DJI M210's information for comparison.

Figure 13. DJI M210 V2 Specifications
Dimensions: 883×886×398mm
Weights: 4.8kg
Propeller Diameters: 432 mm

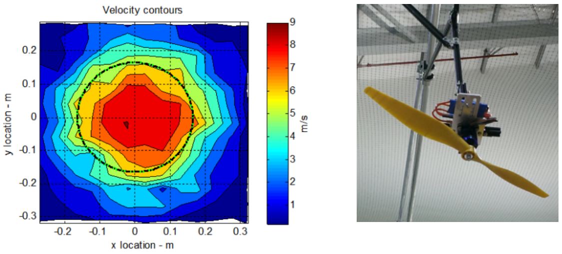


Figure 14. CFD model of downwash from an isolated propeller
Propeller Diameters: 406 mm
Hovering State Maximum Downwash Velocity: 9m/s
[21]

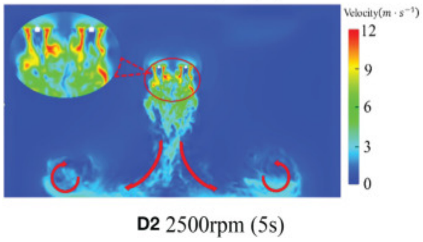
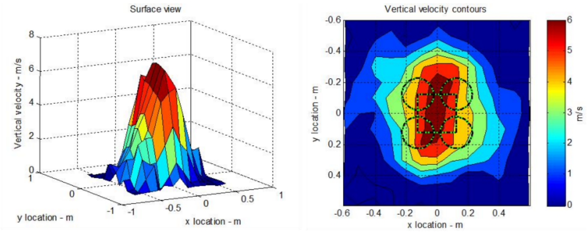


Figure 15. CFD model of 410S quadrotor plant protection UAV
Dimensions: 1075×1075×490mm
Weight: 5kg
Propeller Diameters: 1400 mm
Hovering State Maximum Velocity: 12 m/s
[22]



(b) Velocity surface

(c) Velocity Contours

Figure 16. CFD model of DJI Phantom
Dimensions: 392 × 328 × 222 mm
Weight: 1.375 kg
Propeller Dimensions: 203.2mm
Hovering State Maximum Downwash Velocity: 6 m/s
[21]

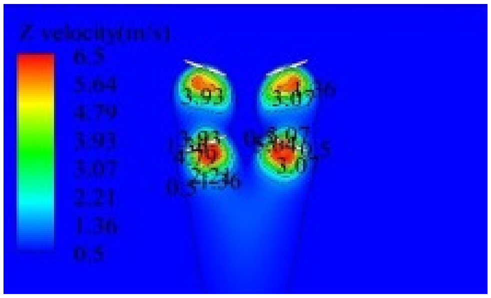


Figure 17. CFD model of Agriculture Drone X4-10
Dimensions: 1635mm x 1080mm x 550mm
Propeller Diameter: 700mm
Weight: 10kg
Flight velocity of 1 m/s Downwash Velocity
6.50 m/s(H = 0.75 m)
6.17 m/s (H = 1 m)
[23]

Figure 14 shows an isolated propeller that is similar in size to the propeller on the DJI M210 V2 drone. According to a CFD model, this propeller produces a maximum downwash velocity of 9 m/s at 3500 RPM, which is comparable to the M210's hovering RPM, which is 4000 RPM [24]. Figure 15 depicts the 410S quadrotor plant protection UAV[22], which has dimensions slightly larger than the M210 and is similar in weight. This reference point provides a maximum hovering downwash velocity of 12 m/s. Additionally, we considered the DJI Phantom and X4-10, shown in Figures 16 and 17, respectively, which differ significantly in size from the M210 but have a low maximum downwash velocity of 6 to 6.5 m/s[21][23]. Based on these references, we estimate that the downwash velocity of the DJI M210 V2 will fall between 9 m/s and 12 m/s. This estimate will be used to simulate the downwash during the drop test using four fans that replicate the airflow velocities produced by the M210.

In order to maintain the stability of our tag release mechanism, we have implemented an upper limit for the downwash velocity in simulations where fans are used for testing. Specifically, we have set the maximum testing downwash velocity to be 14 m/s.

To ensure that we are using qualified fans, we utilize the fan cross-sectional area and CFM parameter found on the data sheet. We then apply Equation 1 to convert the fan's air flow velocity.

$$V_{air} = Vol_{air}/A_{air} \tag{1}$$

Where V_{air} is the air flow velocity produced by a fan. Vol_{air} represents the airflow volume generated by a fan and A_{air} indicates the cross-sectional area of a fan.

The fan selected for testing and downwash simulation achieves maximum airflow of 14.78 m/s with a speed controller so we will test our release mechanism under different airflow speeds from 0 m/s to 14 m/s.

Furthermore, the CFD model of an isolated propeller shows that the downwash speed decreases significantly from 6 m/s to 1 m/s at a distance of 0.3 m from the propeller's center. Similarly, CFD simulations of the Agriculture Drone X4-10 and the 410S quadrotor plant protection UAV also demonstrate a sharp reduction in downwash velocity from 12 m/s to 6 m/s at the center of the four rotors. Based on these findings, we anticipate that the tag and the spring will be subjected to downwash speeds of approximately 3 m/s to 6 m/s at the center of the drone.

Part II: Spring Stiffness Selection

The spring is vital to our mechanism because it is the forcing component that gives the tag an initial velocity during descent. The spring helps determine outputs like the impulsive force of the tag upon impact with the whale, the velocity of the tag at any point during descent, and the difficulty for the user to load the mechanism. By varying the stiffness of the spring we can partially control some of the aforementioned outputs, so we conduct engineering analysis to determine what spring stiffness we should use in our design.

We begin by examining how the spring stiffness affects the impulsive impact force when released from 2 meters above the target. Solving the energy equation below (Equation 2) for velocity at impact (V_f) gives us Equation 3 below. The variables and assumed values of Equations 2 and 3 are listed in Table 6 below. By combining Equation 3 with Equation 4 below we get an Equation 5, which is the equation for the impulsive force upon impact. Plotting Equation 5 gives us Figure 18 shown below.

$$P \cdot E_{gravity} + PE_{spring} = KE_f + W_{drag}$$

$$mgh + \frac{1}{2}K\Delta x^2 = \frac{1}{2}mV_f{}^2 + \frac{1}{2}\rho A\frac{V_f{}^2}{4}hC_D \qquad (2)\ [25]$$

$$V_f = \sqrt{\frac{2mgh + K\Delta x^2}{m + \rho AC_D\frac{h}{4}}} \qquad (3)\ [25]$$

$$F_{impulse} = \frac{mV_f{}^2(dt)}{4d} \qquad (4)\ [25]$$

$$F_{impulse} = \left[\frac{2mgh + k\Delta x^2}{m + \rho C_D A\frac{h}{4}}\right] \cdot \frac{m\ (dt)}{4d} \qquad (5)\ [25]$$

Table 6: Variable Names, Symbols, and Values

Variable Name	Symbol	Value [units]
Velocity at impact	V_f	Dependent Variable [m/s]
Spring Stiffness	K	Independent Variable [lbs/in]
Impulsive Impact Force	$F_{impulse}$	Dependent Variable [N·s]
Mass of Tag	M	.602 [kg]
Gravitational Constant	g	9.81 [m/s^2]
Height of Drop	h	2 [m]
Spring Compression Distance	Δx	.035 [m]
Density of Air	ϱ	1.225 [kg/m^3]
Cross-sectional Area of Tag	A	.0116 [m^2]
Coefficient of Drag of Tag	C_D	3.15
Time Elapsed During Impact	dt	.025 [s]
Suction Cup Compression Distance	d	.015 [m]

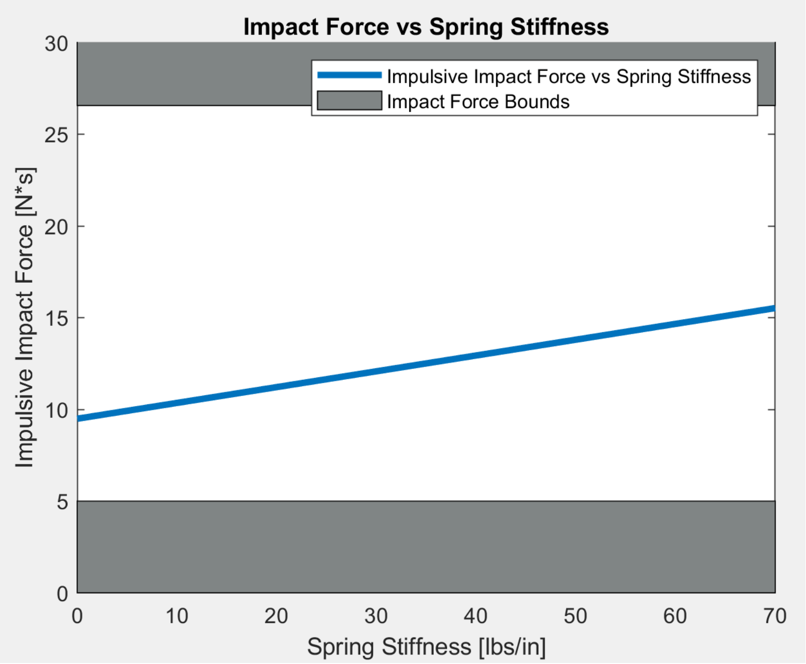


Figure 18: Impact force vs spring stiffness graph

The gray lower bound at 5 N·s represents the minimum impulsive force required for the suction cups to stick to the whale. The gray upper bound at 26.6 N·s represents the maximum impulsive force that does not disturb the whales. This impulsive force upper limit is the impulsive force of an unforced drop from 18m. We chose this as the upper limit because this is the drop height that the research team currently drops from, so we know the impact force does not disturb the whale. From this graph we can see that the spring stiffness does not have a very large impact on the impulsive force and that the impulsive force is not near either of the bounds. So, we will look to use the propeller downwash and compression force of the spring to determine the spring stiffness for our design.

Plotting Equation 5 with a drop height of h=.75 m we obtain the graph in Figure 19 below.

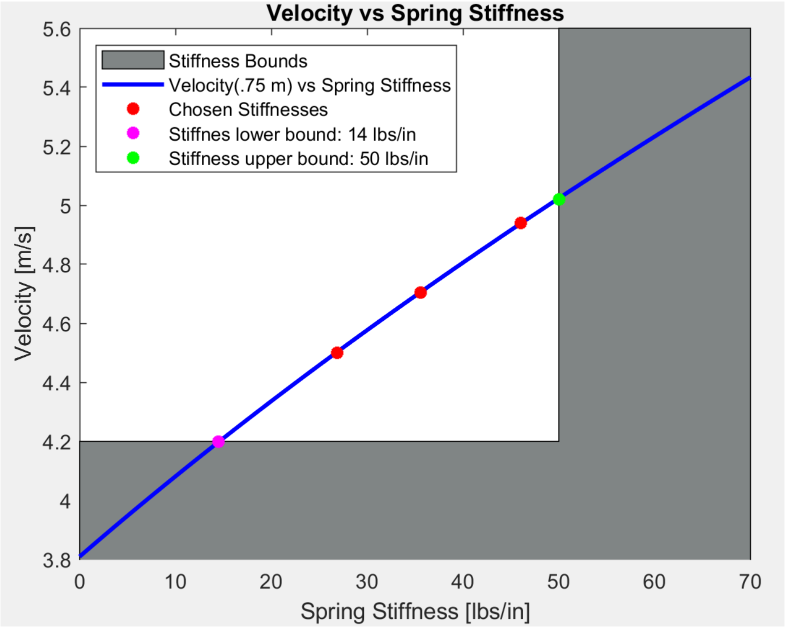


Figure 19: Velocity after .75 m vs spring stiffness

The gray upper bound on the right of Spring Stiffness, K = 50 lbs/in represents the maximum spring stiffness that the user would be able to compress by hand. This is an upper bound because one of our specifications is that the mechanism can be loaded by hand by a single user, so the spring needs to be flexible enough to be compressed by hand by the user. To get to this upper bound value we divided average grip strength of 116 lbs [26] by the compression distance of the spring (1.5 inches) and by a safety factor of 1.55. The gray lower bound on the bottom of 4.2 m/s represents the minimum velocity of the tag to overcome the propeller downwash at .75 m below the center of the drone. This value was determined in *Engineering Analysis Part 1.* It is important that the tag velocity be greater than the downwash velocity so that air is flowing past the fins and the fins can help keep the orientation of the tag stable. 4.2 m/s corresponds to a spring stiffness of 14 lbs/in. This leaves is to pick spring stiffnesses between 14 and 50 lbs/in. We decided to pick three different stiffnesses spread over this range to test. The chosen stiffnesses are 26.96, 35.60, and 46.04 lbs/in.

Build Description

Cad Designs

The alpha design underwent several iterations in order to reach a manufacturable state. The largest changes made to the alpha design were related to weight reduction as well as creating parts which would be conducive to 3D printing. Additionally, the parts were designed with modularity in mind since we intended to test several different springs and fins. We wanted to be able to quickly change out parts to be able to test different combinations without reprinting the entire prototype. As a result, most of the parts are press fit together in order to allow for quick combination changes. In the final design, these press fits would be secured with additional fasteners or by two part epoxy for a more permanent assembly. Figure 20 below shows the CAD assembly of the release mechanism design.

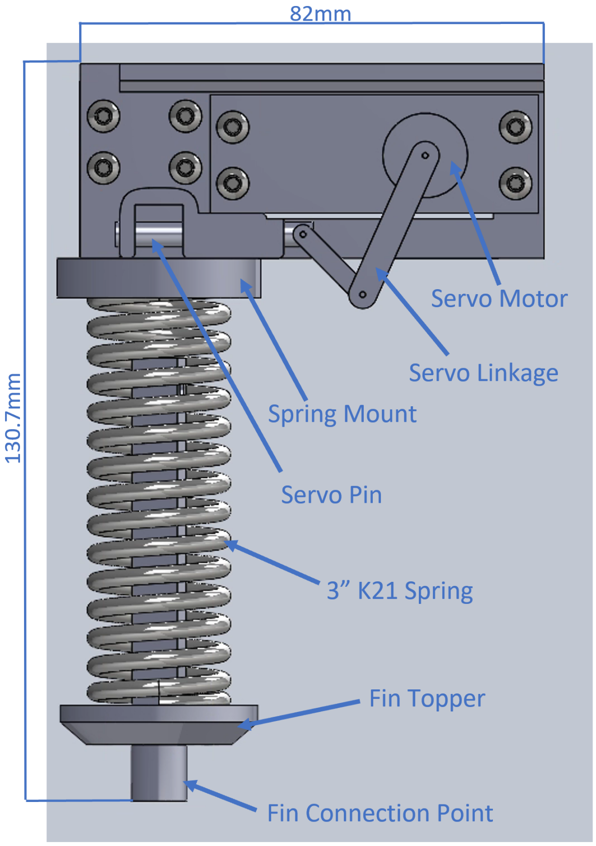


Figure 20: Assembly of the release mechanism

The release mechanism is made up of four 3D printed components. The servo mount and spring mount connect to the drone, while the fin topper and fin topper disk connect to the top of the fins. The servo motor, mounted in the servo mount, drives a linkage which is used to pull the servo pin. When the pin is pulled, a spring mounted into the spring mount is uncompressed, which forces the tag assembly downwards. The tag assembly consists of the fin topper, fin topper disk, fin, clamp, and tag. The clamp and tag used in the testing are unmodified parts which were provided to us by Professor Shorter. Figures 21, 22, 23, and 24 show detailed designs for the 3D printed release mechanism components using K21 spring.

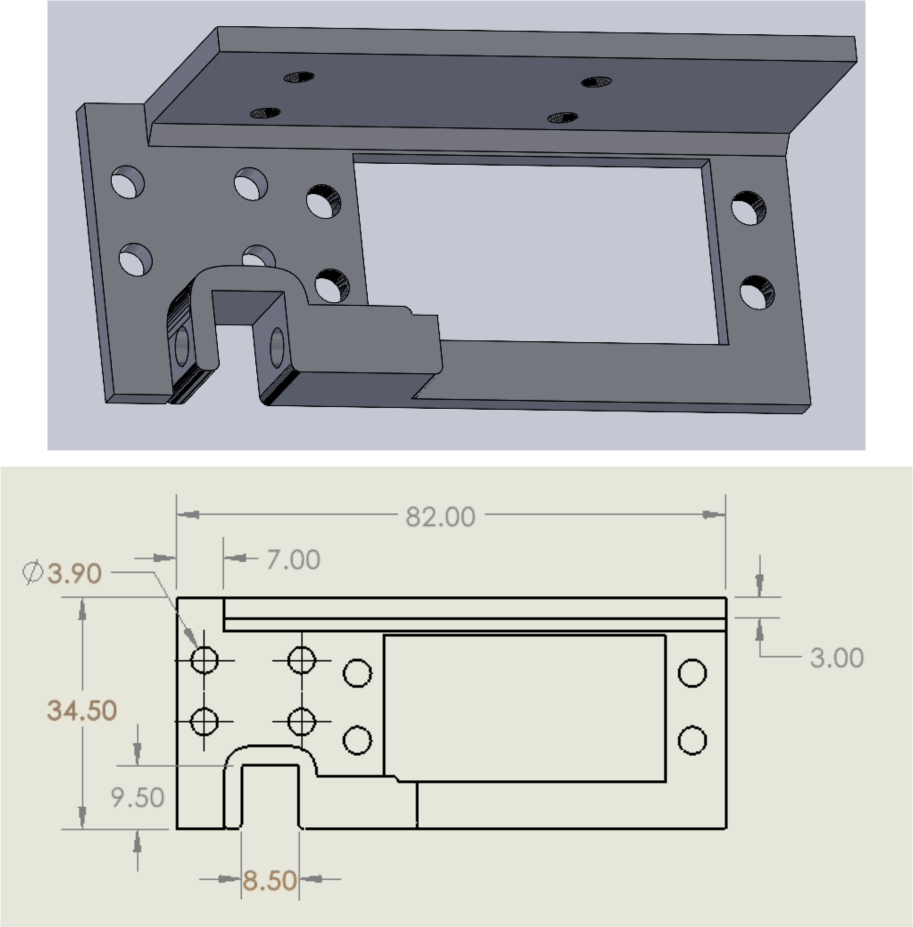


Figure 21: Servo Mount Design

The servo mount is largely unchanged from the original design. The only modification was to extend the length of the part slightly to the left to make room for attaching the spring mount.

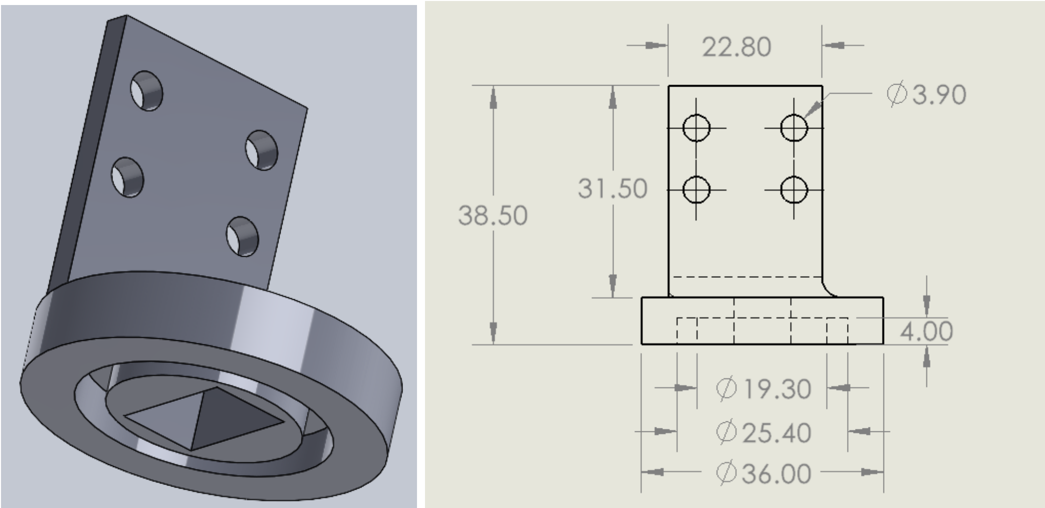


Figure 22: Spring mount design

The spring mount consists of a circular disk with an offset plate. The disk has a cutout to allow the catch of the fin topper to pass through, as well as a groove in the bottom that the K21 spring presses into with a slight interference fit. The part can be reprinted with various groove diameters to accommodate different sizes of spring. Screws are used to mount the part to the servo mount.

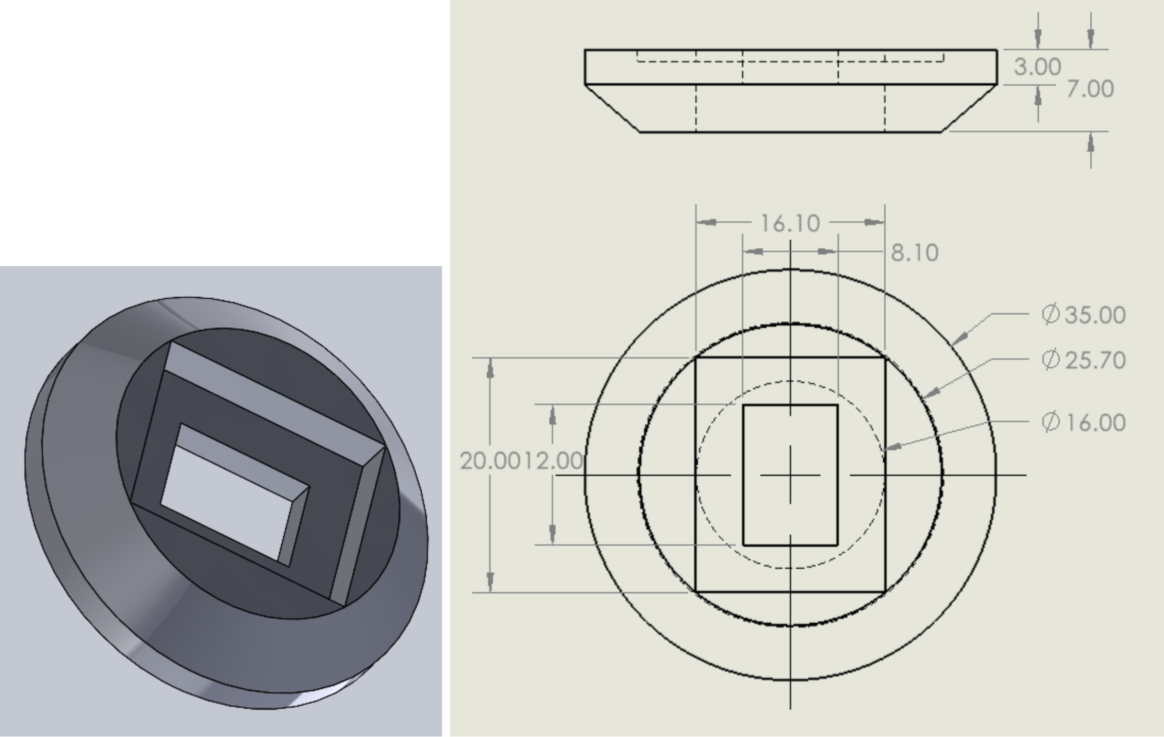


Figure 23: Fin topper disk design

The fin topper disk rests on the shoulder of the fin topper, and has a recessed section on the back in order to keep the spring centered while compressed. It is printed separately from the fin topper to minimize overhangs and because it does not need modification to accommodate different springs.

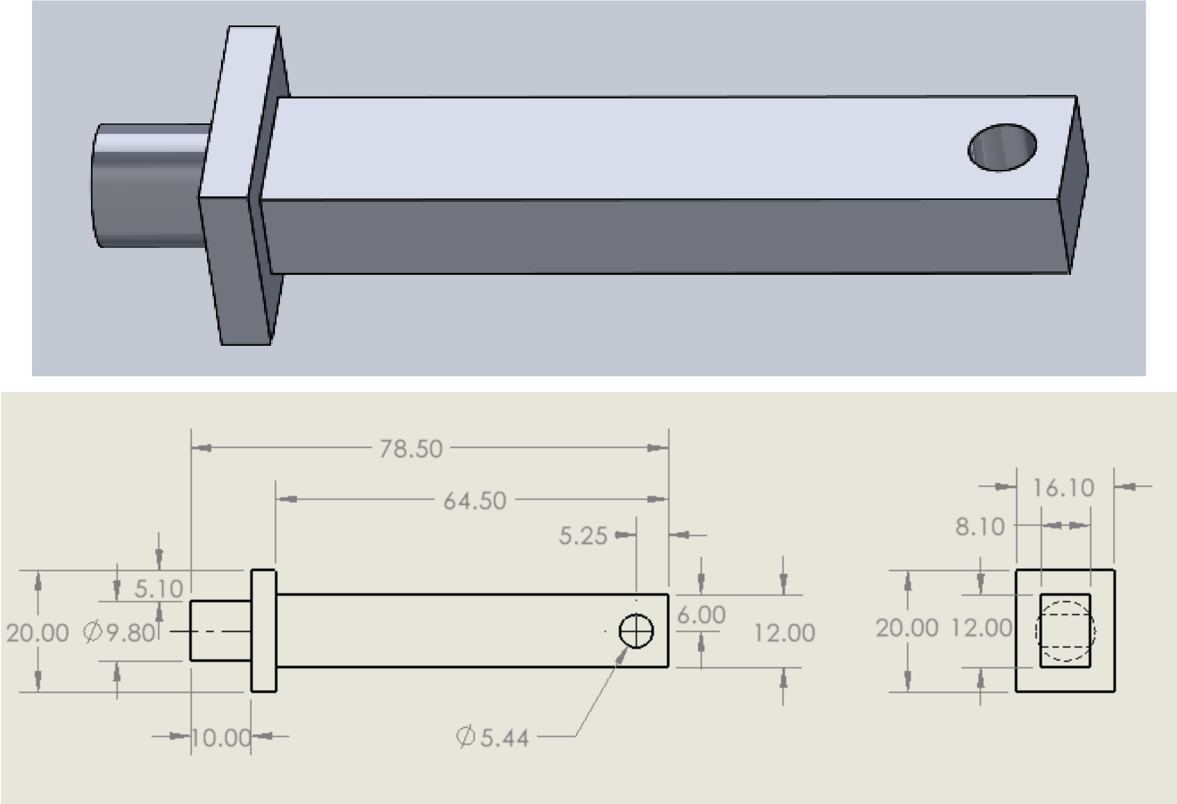


Figure 24: Fin Topper Design

The fin topper is elongated compared to the original design, and is printed horizontally so the layer lines provide strength along the axis under tension from the spring. The length of the rectangular topper shaft dictates the amount of the compression of the spring, which is set to be slightly less than the listed maximum compression length of the spring on McMaster Carr. The cylinder on the left of the part is press-fit into a corresponding hole on the top of the fin, which from our testing stays secure without epoxy for ease of assembly while testing various combinations. The tip of the topper fits securely through the spring mount into the pin section of the servo mount to prevent misalignment of the tag.

We additionally created four new fin designs to test in addition to the original design used. The new designs, shown in Figure 25, are primarily variations on the original design which use the same head for mounting the DTAG clamp and hole for inserting the fin topper.

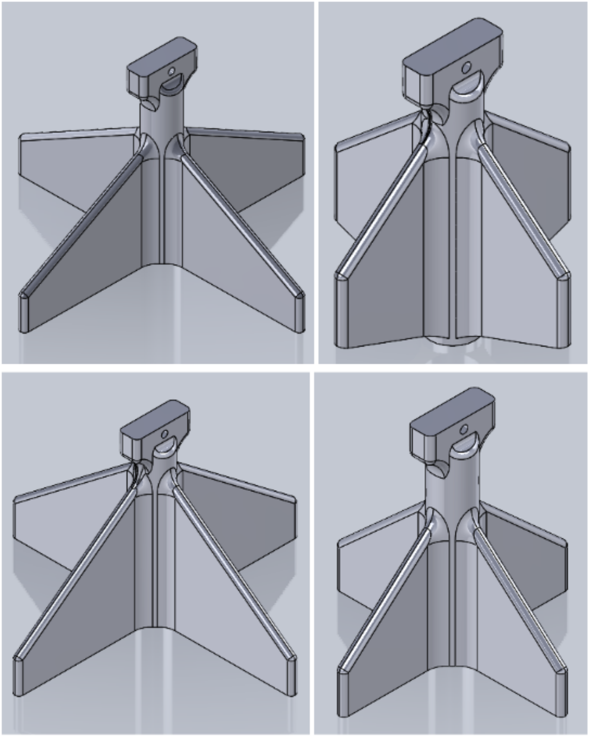


Figure 25: New fin designs in order from left to right and top to bottom: rotated, trapezoidal, larger, and smaller.

The intent of the rotated fin was to move the fins into the cross-shaped region of less turbulent lower velocity air between the drone rotors. The trapezoidal fin shape mimics the shape of a dart fin, and the angled back may make the fin more stable at lower tag velocities when the downwash flows past the tag. The larger and smaller fin designs were created to test the effect changing the surface area of the fin had on the tag's stability.

Manufacturing Plan

All 3D printed parts were printed on a Ultimaker 3 Extended printer using Ultimaker Tough PLA. Tough PLA was chosen for its strength and print reliability. The release mechanism parts were printed in two printing sessions in batches. Print set 1 contained the original designs for the fin, fin topper, and DTAG clamp. Print set 2 contained the servo mount, two fin topper disks, three lengths for the fin topper, and three spring mounts. The fin toppers and spring mounts were sized to fit the K21, K441, and T483 springs selected from McMaster Carr using our spring analysis. Additional fin designs, including the rotated fin, large fin, small fin, and trapezoid fin were be printed individually due to the build plate size limitations of the printer. All parts were printed using the default settings for Tough PLA, using Tough PLA for supports where required. All parts were printed with 20% triangular infill, which was chosen due to its ability to be printed rapidly, with the compromise of sacrificing some strength. Table 7 shows an overview of the costs of parts ordered for the prototype build which were not printed.

Table 7: Prototype Bill of Materials

Part	Number of Parts	Price ($)	Total Price ($)
9657K21 Spring	1	18.07	18.07
9657K441 Spring	1	12	12
9002T483 Spring	1	7.98	7.98
4oz Coin Sinker Weight	1	16.99	16.99
Servo Motor	1	14.99	14.99
High Performance Servo	1	18.99	18.99
Total			89.02

In addition to the prototype, we also built a test rig which is described later in Figure 34 on page 43. The test rig was assembled from seven eight foot two-by-fours, which were cut to length using a chop saw. The test rig was then assembled using deck screws. The servo mount was attached directly to the crossbar on the mount, and the fans were mounted using additional wood in positions which correspond to their real locations on the drone. Table 8 gives an overview of the costs of the parts needed for the test rig.

Table 8: Test Rig Bill of Materials

Part	Number of Parts	Price ($)	Total Price ($)
Fans	4	49.99	199.96
Speed Controller	2	21.99	43.98
8 ft 2x4s	7	3.35	23.45
3 ½ in Deck Screw Boxes	2	8.97	17.94
Total			285.33

Final Design Description

The final design will be fairly similar to our build prototype, but use the final combination of spring and fin shape determined to be most effective in our verification process. It will function in the same manner as the build design, which is shown in Figure 26 below.

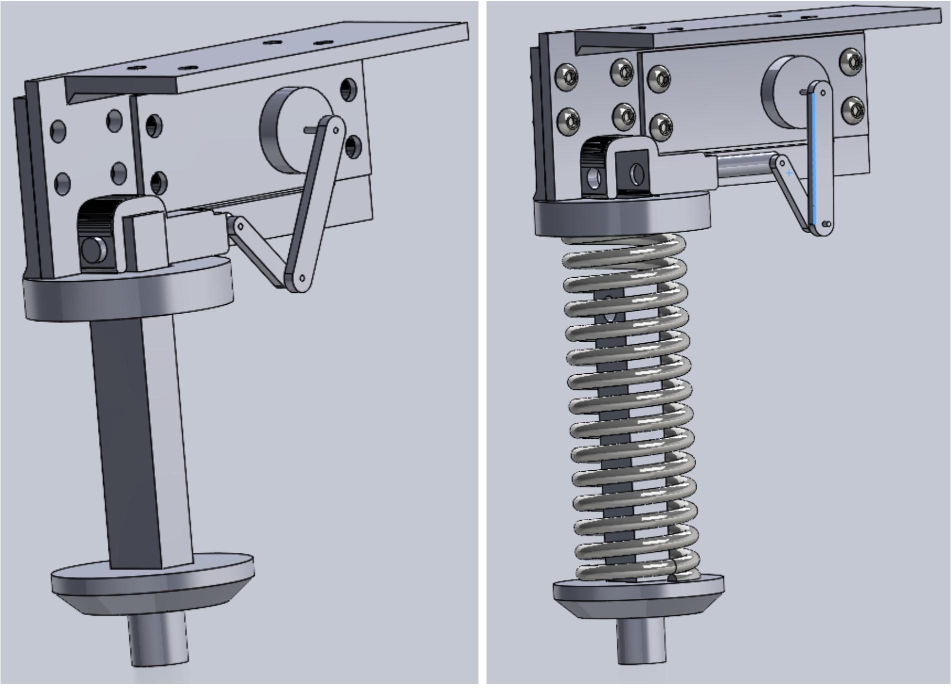


Figure 26: Release mechanism before and after the pin is pulled. The compressed spring on the left image is not depicted for clarity.

The spring is initially compressed, until the servo pin can be pushed into the catch on the fin topper. Then, when the pin is pulled the spring is uncompressed and the tag is launched downwards. The final fin design will be mounted to the bottom of the topper, in an assembly similar to the one shown in Figure 27, and the additional initial velocity from releasing the energy of the spring allows the tag to travel faster than the drone downwash. As a result, we believe the tag will be more stable in flight since higher velocity air moving over the fins will create a larger corrective moment [27].

Figure 27: The assembled tag and release mechanism prior to being mounted to the test rig.

The final variations of printed fins, fin toppers, and spring mounts are shown below in figures 28-30. The modular system worked well as we were able to quickly swap fins and springs on the test rig for testing purposes. Despite prioritizing speed of prints, the print quality was acceptable with some filing required to allow press fit parts to fit together.

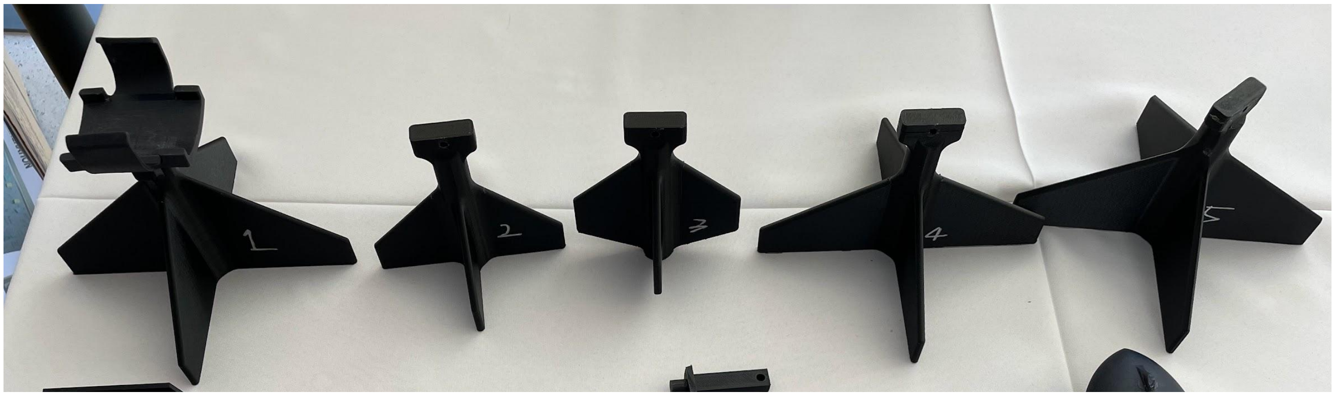


Figure 28: From left to right; 1: Larger, 2: Smaller, 3: Trapezoidal, 4: Rotated, 5: Original

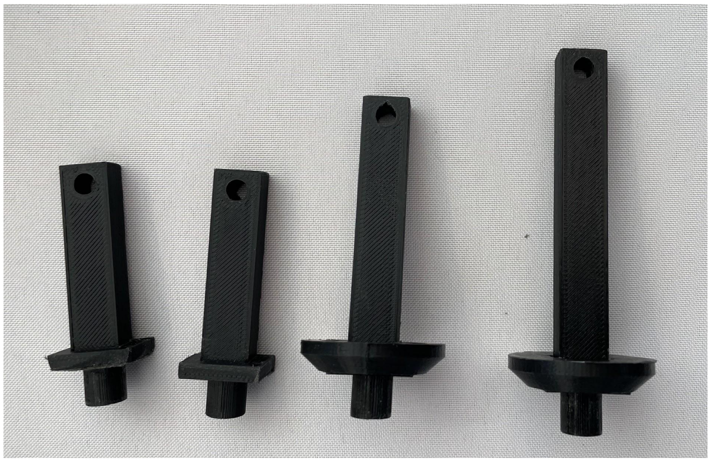


Figure 29: Fin Toppers. From left to right: T483, K441, K21, and additional extended topper.

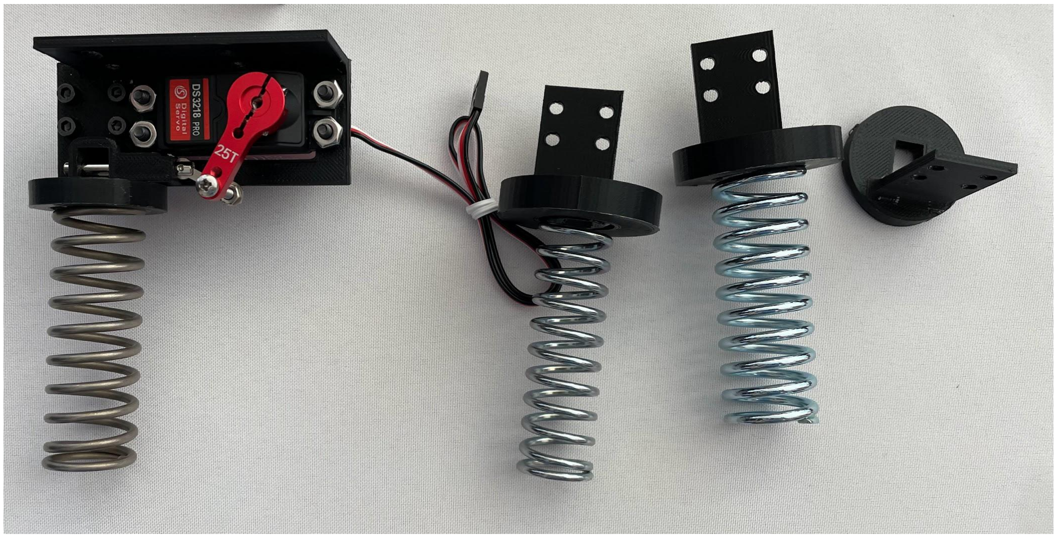


Figure 30: Servo mount as well as assembled springs and spring mounts. From left to right: T843, K441, K21.

Verification Plan

Part I: Orientation Angle

The orientation of the tag while falling through the air must remain less than 25° to meet our specification. We will verify this by using the mechanism to drop the tag from a test rig which is modeled in Figure 31 below. We will record these drop tests and use the software Tracker to measure the maximum orientation angle of each drop. A screenshot of the Tracker software can be seen in Figure 32 below. The orientation angle over time is plotted in the top right corner of Figure 32. We can verify whether the orientation angle is less than 25° for each drop by looking at this plot.

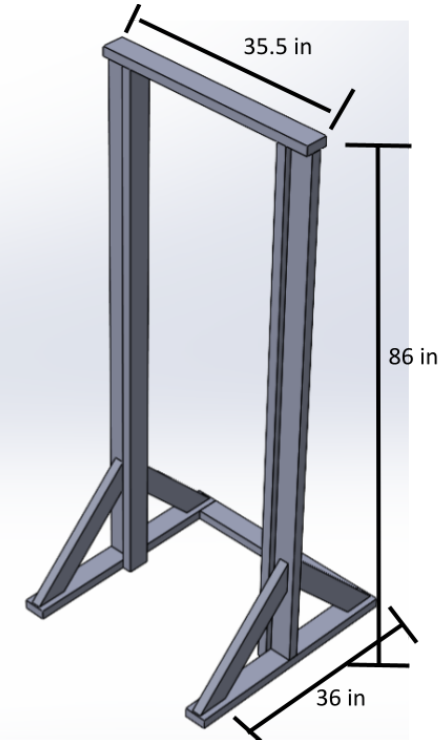
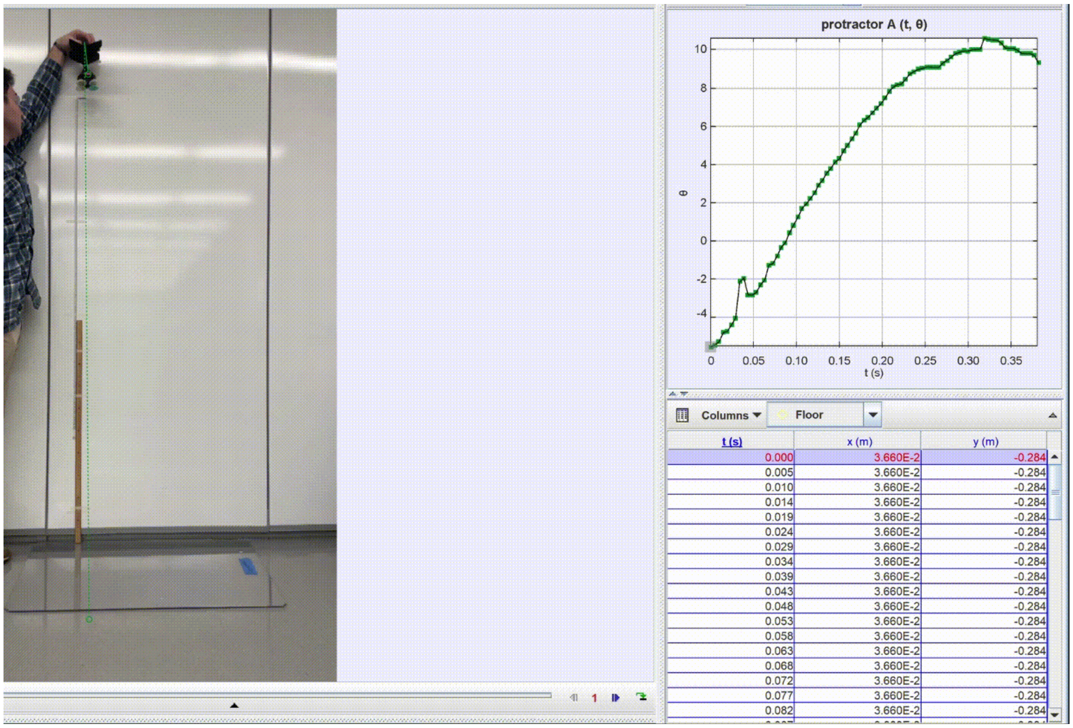


Figure 31: Drop test rig CAD model

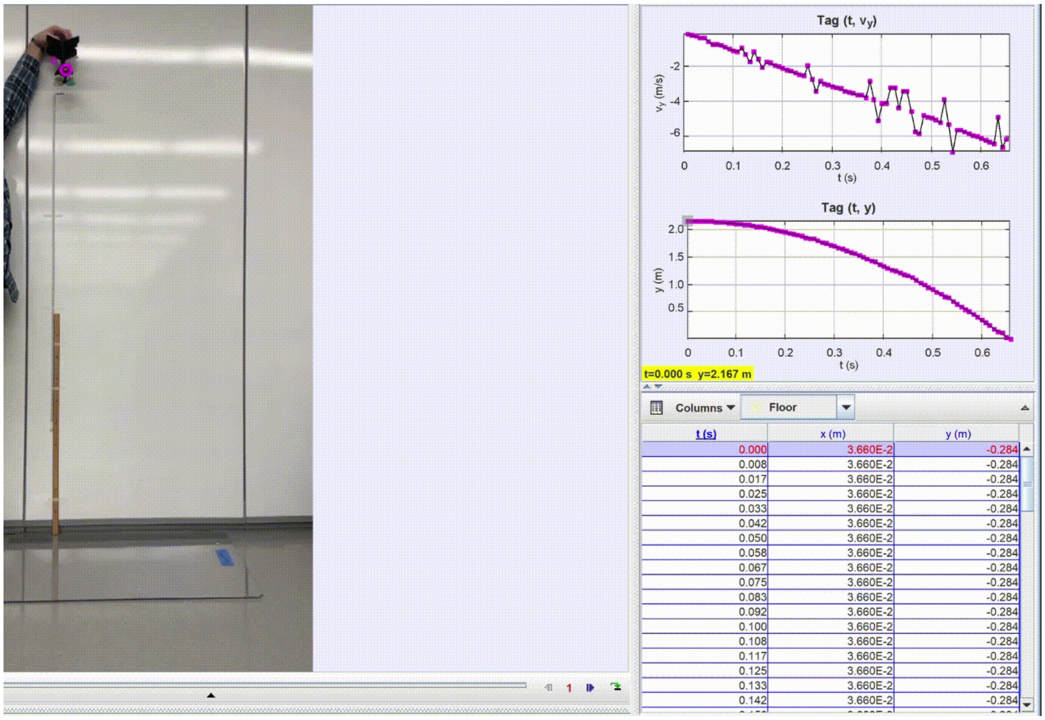


t (s)	x (m)	y (m)
0.000	3.660E-2	-0.284
0.005	3.660E-2	-0.284
0.010	3.660E-2	-0.284
0.014	3.660E-2	-0.284
0.019	3.660E-2	-0.284
0.024	3.660E-2	-0.284
0.029	3.660E-2	-0.284
0.034	3.660E-2	-0.284
0.039	3.660E-2	-0.284
0.043	3.660E-2	-0.284
0.048	3.660E-2	-0.284
0.053	3.660E-2	-0.284
0.058	3.660E-2	-0.284
0.063	3.660E-2	-0.284
0.068	3.660E-2	-0.284
0.072	3.660E-2	-0.284
0.077	3.660E-2	-0.284
0.082	3.660E-2	-0.284

Figure 32: Screenshot of Tracker software measuring orientation angle

Part II: Impact Force

The impulsive impact force must be between 5 and 26.6 N·s in order to meet our specifications. We will verify this in a similar way as we verified the orientation angle, by using the Tracker software on a video recording of a physical test drop. The Tracker software in this case will measure the velocity of the tag during the descent. A screenshot of the Tracker software measuring velocity can be seen in Figure 33 below. We can plug the final velocity at impact into Equation 4 to determine the impulsive impact force based on this final velocity. From here we can verify whether the impulsive impact force of each drop test meets our specification of being in between 5 and 26.6 N·s.



t (s)	x (m)	y (m)
0.000	3.660E-2	-0.284
0.008	3.660E-2	-0.284
0.017	3.660E-2	-0.284
0.025	3.660E-2	-0.284
0.033	3.660E-2	-0.284
0.042	3.660E-2	-0.284
0.050	3.660E-2	-0.284
0.058	3.660E-2	-0.284
0.067	3.660E-2	-0.284
0.075	3.660E-2	-0.284
0.083	3.660E-2	-0.284
0.092	3.660E-2	-0.284
0.100	3.660E-2	-0.284
0.108	3.660E-2	-0.284
0.117	3.660E-2	-0.284
0.125	3.660E-2	-0.284
0.133	3.660E-2	-0.284
0.142	3.660E-2	-0.284

Figure 33: Screenshot of Tracker software measuring tag velocity

We are also verifying that there is sufficient impact force by looking at the suction cups after each drop. We are dropping the tags onto a clear polycarbonate plate so that we can look at the adhesion of the suction cups. An example can be seen in Figure 34 below. We are looking to see that all four of the suction cups have been fully compressed and that there is no air between the suction cup and the plate.

Figure 34: Fully compressed tag suction cups on polycarbonate plate

Part III: Accuracy

Once we have the rig and new mechanism assembled and ready for testing, we will start measuring for accuracy. What we plan on doing is once the tag is dropped, the horizontal distance from where the tag was dropped and where it landed will be measured. This process will be repeated several times, allowing us to see how accurate the new mechanism is and any adjustments we may need to make.

Part IV: Compatibility with Existing Mechanism

To ensure that our new design is compatible with the servo and pin that is mounted on the drone, we made sure that the dimensions for the holes on the part matched the dimensions of the pin. We were able to ensure this because we received the CAD models from the research team for the current design. From that we looked at the dimensions for the hole in the topper for the dart, which allowed us to make sure that the new topper would work.

Part V: Weight

To determine the weight, we used solidworks to find the volume of each component that is attached to the drone. We then found the density of the material we are using to 3D print all of these parts and the density of the springs that are being used. Since we had the CAD models for the springs, we were able to find the volumes of the springs. Taking the known densities and multiplying them by the volumes, we were able to get the weights of each of the components. Here are the weights of all of the components of the current system that is being used.

Current system:

- Tag + fin and topper: .602 kg
- Servo: .081 kg
- Servo Mount: .0105 kg
- Mounting Bracket: .108
- Total: .8015 kg

Then we did this process again with the new parts that have been designed.

New System:

- Servo Mount: .018 kg
- Servo: .081 kg
- Springs: .0636 kg
- Tag + Fin and topper: .607 kg
- Mounting Bracket: .108
- Total: .8776 kg

From this we compared the total weights from the new and current systems and found that our design is about a 10% increase in weight. Which meets our requirement to stay under a 25% increase in weight. If we make any iterations on the current design then we will do these calculations again to make sure it's not too heavy.

Part VI: Bill of Materials

As seen from tables 7 and 8 the total amount of money that has been spent on the project is $330.28 which is lower than our budget of $500. We may need to spend some more money if anything comes up at the last minute but those purchases will need to be soon due to the amount of time left on our project.

The data collected in our drop tests to verify the impact force, tag orientation, and drop accuracy can be seen in Table 9 below. All drop tests were conducted with a box fan on top of the test rig to simulate drone downwash.

Table 9: Results from testing fins while a fan is running with and without the spring release.

	No Spring			**Spring (stiffness = 26.96 lbs/in)**		
	Impact Force	**Tag Orientation**	**Drop Accuracy**	**Impact Force**	**Tag Orientation**	**Drop Accuracy**
Fin 1	9.1 N	7°	< 0.5m	12.9 N	25° - 35°	< 0.5m
Fin 2	8.2 N	11°	< 0.5m	12.4 N	3.2° - 10°	< 0.5m
Fin 3	8.2 N	6°	< 0.5m	13.4 N	10° - 35°	< 0.5m
Fin 4	8.9 N	10°	< 0.5m	11.8 N	14.6° - 17°	< 0.5 m
Fin 5	8.5 N	3°	< 0.5m	N/A	N/A	N/A

Our overall requirements, specifications and verification results can be seen in table10 below.

Table 10: Overall requirements, specifications and verification results.

Requirement	**Specification**	**Priority**	**Verification Results**
The darts must fit within the drone body dimensions	< 634 mm using DJI Matrice M210 V2	High	The dart still fits
Drone payload capacity is not exceeded by tag and mechanism	Weight cannot exceed 25% more than existing system	High	About 10% increase
Stabilizer must mount to tag body	DTAG: 82 mm wide x 148 mm length	High	Fins were mounted to the tag body
Generate sufficient contact impact force	Between 5 N and 26.6 N of force generated	High	11.5 - 13.5 N
Maintain the orientation of the tag during drop	<25 degrees of orientation deviation from initial position	High	3 - 35 degrees
Reduced drop height compared to current design	<6m from target	High	Suction cups not properly compressed
Compatibility with existing mechanism	Release mechanism uses existing pin and servo	High	Untested, Servo and pin came in late
Within Budget	<$500	High	BOM less than $500
Drop Accuracy	< 0.5m spread radius from below drone	Medium	.25 - .4m
Easy to use	No special tools	Medium	Hard to compress with current spring
Single person operation for drone flight and release	Release mechanism remote control must mount to the drone remote	Medium	Untested, as we did not have the means to do so.
Ease of installment	No modifications required to drone mounted parts	Low	Will need to change current servo mount
Material	3D printed for ease of manufacture	Low	Only used 3D printed material

In table 9, for the results from our experiments, the reason fin 5 is N/A for the spring with fan tests is due to the part being too broken to use at this point. Fin 5 is the original fin and had already been dropped more than the others, we did try to glue it back together but it didn't last long enough after that for continued use.

In table 10, for the verification results, text in green is for our requirements that were successful or met our specifications. Red text is for requirements that failed to meet our specifications and will need further iterations. The blue text is for anything that could not be tested.

Validation Plan

In order to validate that our design will meet the requirements and specifications of our primary stakeholder and sponsor, we planned on inviting him to a showing of the final design. Due to parts breaking and running out of time, we were unable to conduct these final validation tests. We would have gone through the process of using our new mechanism with him and provided him with our final prototype. Since further testing and iterations need to be done, we are giving him all of our data and CAD models in a google doc that will have a small presentation in the form of a powerpoint summarizing what we found from our experiments.

Problem Analysis and Iteration

We have many specifications we will have to verify for our design, from our physical, performance, and usage requirements. The physical specifications are size, weight, budget, and material specifications. These specifications can all be initially confirmed through our final CAD model with proper dimensions and materials. We can use the CAD model to verify that our parts will mesh with models of existing parts, and use the built in weight estimation tools in Solidworks to get a weight estimation. We can also judge the mass and price of 3D printed parts using the CURA slicer for the Ultimaker 3D printer we plan on using for the majority of our manufacturing. The usage specifications, including release mechanism uses existing pin and servo, no special tools, release mechanism remote control must mount to the drone remote, and no modifications required to drone mounted parts are all design driven rather than performance driven, so they can be verified by inspection once the final design is produced. Rather need to be constantly monitored to make sure they are being adhered to during the design process. For example, we must use the existing pin and servo release mechanism. Our current alpha design does adhere to all of the usage specifications. In order to verify the performance specifications we will perform physical testing using the test rig depicted in Figure 35 below.

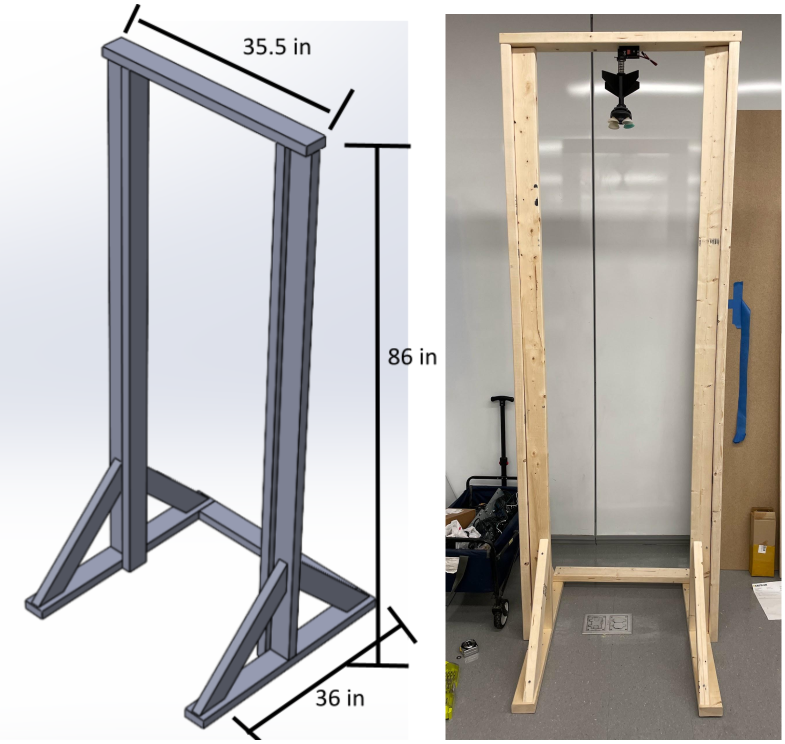


Figure 35. Physical test rig for verification of performance specifications. Left: CAD model and dimensions. Right: Assembled test rig with tag ready to drop.

The physical test rig illustrated in Figure 35 contains a mounting plate at the top of the structure for the different iterations of our release mechanism. The test rig may also have fans above the release mechanism to simulate the downwash of a drone in order to add the perturbations of the real-world application. It also contains a polycarbonate landing area to simulate the texture of a whale's back, in addition to providing a clear plate we can view the suction cup adhesion through. The testing procedure involves releasing the whale tag from the release mechanism and having it strike the landing area. We will then verify the specification of the force generated on impact by using a manometer to measure the pressure in the suction cups after they adhere to the polycarbonate board. From these pressures we can derive the force generated on impact by using the geometry and stiffness of the suction cups. We can verify the specification regarding maximum orientation deviation by setting up a series of cameras and looking frame by frame at the maximum deviation from the vertical orientation as the tag drops. We can verify the accuracy specification by measuring the distance between where the tag landed and the point directly underneath the release point. We can also verify the successful drop height by varying the height of the test rig and looking at which heights the other performance requirements are met. We will begin this analysis by running these tests and taking this data with the current release mechanism. This will provide a baseline set of data that we can compare our new design's results to. Additionally, we will be able to verify the specification values we established for force, orientation deviation, and drop height required for the base model in order to accurately judge the performance of our model.

In order to determine the required size and stiffness of the spring in the release mechanism we will utilize the spring equation, kinetics, and energy methods. We will also use dynamics to determine the optimal fin size and shape to give the tag the most stability while falling through the air. In order to determine what fan type, size, and airflow can model the downwash of a DJI Matrice M210 V2 drone we will research CFD simulations used to analyze the downwash velocities of similar drone models in order to compare and contrast the flows from the drone to different fan setups. We should then be able to use the analysis to estimate the downwash speed at different heights, which will allow us to select a target initial velocity for the tag after being released from the drone. Ideally, these performance analysis tools will allow us to minimize the number of iterations we will need to manufacture for our design by starting us as close to the optimal solution as possible before any tests are performed.

Problem Domain Analysis and Reflection

A major challenge with assessing the feasibility of our specifications is our lack of understanding of the dynamics of the system. We will need to first analyze the potential effects of the initial conditions on the tags when they are released. These will include determining the optimal values for variables such as: height, initial velocity, impact force, horizontal velocity of the drone, and wind speed. The initial velocity when the tag is released will have varying effects on the stability of the system depending, which makes setting a measurable specification difficult without more prior understanding. Therefore, our design process will likely include analyzing these effects through a model to help us determine an optimal release velocity prior to prototyping. Other factors, such as the drag force on various shapes and sizes of fins while the tag is falling should also be investigated. Once we have a better understanding of the problem dynamics, we will then be able to better assess the feasibility of our specifications and judge various designs' abilities to meet those specifications.

Because we anticipate needing to create a model which will predict the performance of the design, one issue would be the variations and assumptions that would need to be made for the variables. This is due to the fact that there are several input variables each one having its own effect on the complex system. This model would require many assumptions which need to be carefully made in order to best predict the system. As a result, testing will be a critical part of our design process. We will need to validate any models and prototypes we produce, use these models to fine tune the prototype, then retest the prototype to see if it meets our performance specifications. The research team has an already working system which they use on the drone which we can potentially use for initial testing, which would allow us to compare our results to their field tests and get a good step off point for our design.

The gaps in our knowledge primarily stem from how to execute on producing models useful enough to gain valuable insight, as well as how to execute effective tests. There are numerous ways to predict dynamics, so we will need to perform further research on which will be most useful to us. Testing will also be challenging, since we will need to acquire technical equipment for measuring factors such as force and launch velocity in addition to finding a location where we can test high drops in a controlled environment. Organizing the logistics of testing may be challenging as a result due to the scope of our planned testing, if a part breaks during testing, then it will need to be remade again which could lead to concerns with the budget as well as timing if we need to remanufacture often. Furthermore, we will need to look into what type of materials would work best for making the new mechanism for the drone, as well as the stabilization system. We also need to be wary of any tolerance issues on any of the parts. Tolerance problems may arise from the mechanism manufacturing, as well as in attaching the mechanism to the drone.

As mentioned in the design process, one of our potential solutions was to use a computer-based CFD/FEA model to meet the requirements and specifications. Our plan was to utilize CFD to simulate and visualize the airflow, allowing us to compare the downwash produced by the drone with the airflow generated by the fans in the tag drop-off process. However, this approach ended up posing large technical challenges to our project. Our team members lack experience and familiarity with CFD software, which could result in inaccurate models and longer time frames for completion of the models than initially expected.

For example, selecting the appropriate model for fluid analysis of a drone can be challenging, as different models may vary in accuracy and computational cost. Choosing the wrong model could lead to inaccurate results or a simulation that is overly complex. Additionally, selecting the appropriate boundary conditions in CFD can also be challenging, particularly when accurately specifying boundary conditions for a CFD simulation. Errors in boundary conditions can result in unrealistic or inaccurate results. To address this issue, we will rely on related publications on drone downwash and CFD simulation. We will also seek assistance from experts in CFD analysis to ensure the accuracy of our models. By using CFD/FEA software, we hoped to achieve a comprehensive understanding of the airflow characteristics in the tag drop-off process and optimize our design accordingly. To address these difficulties, we are now shifting to a more experimental approach to determining fin stability.

Moreover, finding an appropriate fan to simulate the downwash by a drone is proving to be a challenging task. Our understanding of the fluid properties of the airflow produced by the drone is not yet precise, which may make selecting the right fans difficult. Nonetheless, we can use flow rate, rpm, and downwash velocity comparisons to determine the best choice of fans, and the CFD model can also serve as a useful reference in the fan selection process.

The final challenge we anticipate is managing overlapping tasks in the project plan. After returning from spring break, we will need to conduct tests with rigs, the CFD model, and revise the Solidworks model all within the same timeline. As a result, there is a risk that a failed task may lead to delays in subsequent tasks. To mitigate this, our team members will stay organized, conduct first principles tests, and divide into two groups to work on multiple tests simultaneously to avoid delays and manage various tasks concurrently.

Discussion

Problem Definition

With more time, resources, and hindsight, we would have conducted more interviews with our sponsor. We also would have seen if we could have reached out to the research team and talked with them about the problem they are facing. This would have given us even more first hand knowledge of the problem. Having a drone or even a drone motor which we could have attached propellers to would have been something we would have bought if we had more resources. This would have allowed us to more accurately test the perturbations on the tag with our different fin designs and the new mechanism.

Design Critique

One of the real strengths of our design would be how modular it is, being able to switch out parts easily when needed. This allowed for different compression lengths of the springs, which meant for different amounts of force being generated on impact. Another thing this allowed was for the use of different springs, which made for testing different springs quick and easy.

One of the main weaknesses of our design would be the spring not compressing perfectly straight. Due to the dart being released at this angle the suction cups on the tag did not properly compress when landing on the polycarbonate plate. During testing we noticed the tags orientation was off and this is due the spring at times compressing at a slight angle which caused issues at release. When we analyzed the videos in the tracker software we saw the orientation be between 10 to 35 degrees. There are inconsistencies with the drops right now due to this angle, where we have a good drop that has a minimal change in orientation but then the next drop has a large variance. Another factor to those inconsistencies could have also been due to the fact we were unable to test with the servo and pin, and had to use a small screwdriver as our way of locking and releasing the dart. Using the screwdriver may have increased friction when pulling it for release causing some of the angle issues as well. We would have needed to properly test with the servo and pin to see what the difference was, but due to the servo and pin coming in late we were unable to test this. If we had more time we would have run tests with the servo and pin to see what those differences were.

This made us realize that in order for us to ensure the correct orientation the body of the dart will need some type of guide attached to it. Having the guide would allow us to force the spring to be straight. We originally wanted a guide on the body of the part but dropped it due to weight concerns. Now that we know what our mechanism weighs and we know that we have extra weight to work with, with more time we could have looked into guide rails made out of 3D printed materials or a similar lightweight material.

An additional weakness of our design would be the current springs we ordered are too stiff. From our calculations we ordered three different springs all with different stiffnesses. Once they came in we realized that two of them were rather difficult to compress while the third one, while still being somewhat difficult to compress, was still usable. We ran our tests with the weakest spring of the three, and ended up ordering two more springs that were even weaker than the one from testing. Unfortunately they came in late and we ran out of time, so we were unable to run any tests with those springs. If we had more time we would have run tests with those new springs.

Another weakness of our design is the topper that connects to the dart is small. Due to it being so small it makes compressing the spring difficult, this is from not having enough surface area for a person to really push up with. Increasing the size of the base of the topper would allow for a person to more easily grip onto it when they are trying to get the spring in position for the servo and pin to lock it into place.

Fin Design Discussion

The last weakness of the design is that the current darts are breaking after being released from the new mechanism. They were only lasting around four drops before they started to break from the impact force. Where the darts are breaking is where they screw together to the claw that holds the tag, at that point they are shearing from the impact force. The new impact force from when we analyzed the videos is between 11.5 to 13.5 N. Compared to the free fall force of only 5.3 N this is over double, which explains why the darts with a low infill are breaking quickly. The darts are currently only being printed at a 20% infill. If we had more time we would have increased the infill to somewhere between 50 to 60% and tested them to see if the higher densities would have withstood the impact force.

We ended up creating four fin designs different from the original. The first of the designs was making the fins even larger. When testing the new fins with spring power and perturbations from a box fan there was high variance in orientation of around 25 - 35 degrees. Part of this problem is due to the inconsistencies previously mentioned, and the fact we were only able to get a couple of tests done. We feel more testing needs to be done.

The next design was making the fins much smaller to the original design, we wanted to see how a smaller surface area would affect the drops. During the drops the smaller design had a minimal orientation change between 3 to 10 degrees. The suctions cups compressed a bit better with this design but an issue is the orientation we saw on the video was harder to measure. As the dart fell the orientation change during descent was in the same plane as the camera, which we can not measure with the tracker software. To fix this we would need more than one camera recording the drops so we have multiple views to work with. This was not possible in the x50 lab where testing was performed due to space limitations. Also, the leg of the test rig may be in the way of a side on view, which could pose issues if another camera was used directly to the side.

The third design was making the fins resemble the fins of a dart. During the drops with this design we saw a larger orientation change between 10 to 35 degrees. This again can be attributed to the inconsistencies mentioned before. Due to the large variance in orientation the suctions at times were unable to compress. For this design, if we had more time we wanted to reprint this fin design again but make it bigger. When it was first made we didn't realize how small it was going to be until it was printed, and our observations showed much more success from larger fin designs compared to smaller designs so testing a larger iteration of the shape would be beneficial.

The final design we tested took the original design and rotated it 45 degrees. We made this choice after observing a cross shaped area where the downwash was minimal in the CFD analysis performed in research papers we viewed [21][22][23]. During the tests, this design performed rather well with only an orientation of 14 to 17 degrees. One issue is even though the orientation was low the suction cups were still having some issues compressing correctly, this could have been due to the impact force or from sideways motion folding over the edges of the cups during impact causing improper adherence to the polycarbonate plate.

Unfortunately the original design was unable to be tested with the new spring powered mechanism with a fan running as the fin head broke off during unperturbed testing. With more time we would have reprinted the original design and tested it with our new mechanism. One thing we noticed during our testing was the servo mount holes where it held the spring in place to be released were beginning to shear. The energy that is being held there seems to be too much for the 3D printed material. A change of material for the servo mount would be required to ensure that it does not suddenly break. A new material could also provide the benefit of reduced friction on the servo pin.

Overall, when each fin was released with the new mechanism they had a consistent initial velocity of around 2.3 m/s. The impact velocity for each was between 6.8 to 7.3 m/s which gave us our range for the impact force of 11.5 to 13.5 N. We noticed that the fins with larger surface areas worked better overall than the smaller ones.

Risks

Throughout our design process, we did our best to minimize the risk and maximize the likelihood of our success. One challenge we faced was with our springs, if we made them too stiff then the user would be unable to compress them, which then would make it impossible to use our mechanism. To overcome this issue we ran empirical analysis to find optimal spring stiffnesses we could use and then ordered a range of them to see what would work and what would not work.

There are minimal risks associated with our final design, though one injury that could happen is when someone is trying to get the dart locked into place and they accidentally release it into themselves. Otherwise, the only other injuries would be from getting pinched from spring being compressed or potentially injuring the hand from repeated loading of the mechanism.

Reflection

This project is primarily relevant to the public health, safety, and welfare of whales rather than humans. The data collected by the biologging tags will give insight into the whales' habits so that human behavior can be adjusted to have less of an impact on whales. This design is not a commercial design, and thus will not have a great impact on the global marketplace. However, there are many different research groups that tag marine animals for data and this design could be very useful to those groups because it could improve their tagging success rate while decreasing the impact on the subject animal. Almost all parts of this design were 3D printed using PLA filament which is both recyclable and biodegradable. The manufacture and disposal of the design have no social impacts and can be done completely by the user. The social impact is through the usage of the design as the data collected by the biologging tags will give insight into the whales' habits so human behavior can be adjusted to have less of an impact on whales. As for economic impacts, 3D printing with PLA filament reduces most significant impacts associated with the manufacture and disposal of the design. There is some waste created from support material during the manufacturing process. However, this is not a commercial product and will just be used in research applications, so there will be no significant economic impact associated with the usage of the design. We characterized the potential societal impacts of our design using the stakeholder map in Figure 7.

Cultural, privilege, identity, and stylistic similarities and differences affected each team member's approach to different aspects of this design project in many nuanced ways. Our varied backgrounds gave us each a unique perspective and allowed each of us to see the problem and possible solutions from all different angles. This allowed us to get a wide range of solutions in our ideation and concept generation phase. This was also beneficial during our concept selection because each member saw different pros and cons within each different subsystem design. Cultural, privilege, identity, and stylistic similarities and power differences between the team and the sponsor also influenced our design process. Due to potential similarities, our sponsor, Professor Shorter, had the same initial reaction to the design problem that we did. That was to impart an initial velocity on the tag to overcome the perturbations caused by the drone downwash. This similar view on what we thought was the best solution greatly narrowed our concept generation process because we only considered initial velocity to overcome the perturbations rather than any number of other creative solutions.

Inclusion and equity play an important role in determining our group's design strategy and manufacturing process, and even affect the way we advocate for our design. One of the most influential factors behind our decision-making is power dynamics. Our stakeholders and sponsors hold more power and influence in the project than teammates, as they provide more resources, support, and funds. This power dynamic can make it challenging for team members to advocate their ideas and decisions if they conflict with the stakeholders' interests. Fortunately, our sponsor is supportive and collaborative, so we do not have this issue. The end user also has a certain level of power, as they will ultimately be using the whale tag release mechanism. Therefore, we have updated and revised the release mechanism based on the user's feedback, for example, by selecting a spring that fits their grip strength.

As a mechanical engineering student, our own identity and experience make us pay more attention to the physical property and design of the release mechanism. In comparison, the user, who might be a whale expert, might pay more attention to the welfare of the whale and the release mechanism techniques. Meanwhile, our team has more hands-on experience in manufacturing, CAD modeling, and simulation, which impacts other aspects of the design. To include diverse viewpoints of stakeholders and team members, we conducted a stakeholder analysis (shown in the stakeholder map above) to analyze their design context and essential needs in terms of the project. To balance the ideas from stakeholders and team members, we used a Pugh Chart to select the best approach in different subsystems of the design.

Cultural similarities and differences can have a significant impact on team dynamics and the approach taken to complete the project. When team members come from different cultural backgrounds, they bring with them different ways of thinking, communicating, and problem-solving. Understanding the sponsor's cultural background, values, and preferences is crucial in developing a product that meets their needs and expectations. Designing a product for a sponsor from a similar cultural background may be easier since the design team is likely to have a better understanding of their preferences, tastes, and expectations.

The ethical dilemmas we faced in the design of our project will relate to the inclusivity of our design. Since we already know the user profiles for our release mechanism, an ocean expert at middle-aged with great health conditions, we designed the release mechanism with a spring that our user can press in. However, this design may not be user-friendly for people who are disabled because they are not able to compress the spring to release the tag. However, since this tag will not be commercialized and get into the marketplace: it will only be utilized by a specific user in the research team, the dilemma has been solved. However, if the project product was to enter the marketplace, this may be criticized by the customers for inclusivity.

Regarding the difference between personal ethics and professional ethics, we potentially disagree with one statement in the ethical guidelines, which states that "Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved." In actual engineering positions, there are often various engineering disciplines involved. For example, a validation intern may require knowledge of industrial engineering, mechanical engineering, and computer science. If only individuals who were proficient in all of these areas were qualified for the position, there would be fewer validation engineers available. However, we agree with all of the other ethical codes outlined by the University of Michigan and intend to follow the professional ethics code of any future employer.

Recommendations

To improve the tag release process, we recommend implementing the following suggestions. Firstly, we suggest integrating the servo into the testing process to enhance the reliability of the tests. Unfortunately, we were unable to test the servo due to delays in shipping. Therefore, our specification of the design functioning with the current servo release mechanism still needs to be verified. Additionally, using the servo motor will help remove perturbations to the system due to human variation. When hand pulling the pin, there was often a large amount of vibration introduced into the test rig which led to large initial deviations in orientation. We recommend installing the four fans which were ordered but not installed on the test rig. These fans, which were selected to simulate the drone's downwash, will generate more precise results than the box fan we used to imitate the drone propellers. With the four fan design, we should be able to measure the impact of the rotated fin designs in comparison to the original non rotated versions.

To further reduce variability, more trials should be conducted using different fin designs to obtain dependable data. The fragility of our fins limited the number of forced tests we were able to perform, so it is not clear if all of the deviation was caused by perturbation of the fan or by a poor drop. Additionally, more testing should be performed with additional springs with varying stiffness and length, as well as new fin designs to achieve an accurate and user-friendly release process. We only tested with a single spring stiffness, since only one of the springs we ordered was feasible to compress by hand on the test rig despite our grip strength analysis. For these additional tests, we propose using higher infill for 3D-printing fins or alternative infill patterns which will provide additional strength to the part. We focused too much on the speed of our initial prints, so printing with strength as a priority over speed should solve the issues we had with breaking fins. The material of the servo mount could also be improved in several ways. Since we are under the weight budget, machining the part out of aluminum could be beneficial to provide additional strength to the pin holes. Alternatively, metal bushings could be press fit into a larger hole in order to reinforce the area without drastically increasing the manufacturing difficulty or price.

Another aspect of the drop mechanism that could be improved is the consistency of the release angle of the drop. While the spring does a fantastic job at damping out any vibrations which could cause the tag to change orientation while attached to the body of the drone, the spring often forces the tag to become locked in a position which does not point directly downwards. There are several potential fixes to this issue. First, and potentially most simply would reduce the freedom of movement the spring has on the topper disk. Adding a groove for the spring to rest in would ensure the spring will be centered around the topper shaft and prevent the spring from providing a moment to the tag. Furthermore, a guide to keep the tag aligned while the spring is pushing on it would be very helpful. This guide could be as simple as the rails used when launching model rockets. It would help ensure the compression of the spring, which does not always occur evenly, does not impact the launch angle of the tag.

Finally, the ergonomics of the loading mechanism must be improved. Our design is difficult to get a good grip on, and is awkward to load onto the test rig without another person to stabilize the rig. An easy improvement to the loading of the device is to increase the surface area of the fin topper disk as well as the spring mount so there is a place to grip the device. Adding a dedicated spot to rest your fingers, potentially with grooves to get better grip, would be ideal. Alternatively, if stiff springs are required to generate sufficient velocity but are not easy to compress by hand an additional compression tool could be made to be used for loading. This could be hooked over the tag to provide a mechanical advantage to the user so they do not have to strain their hands, then be removed once loading is completed to maintain the aerodynamics of the system.

Conclusion

Biologging tags that are used to study whales' habits are now being used in tandem with drones to create an improved tagging method. Through our problem analysis and conversations with our sponsor, Professor Shorter, we have determined that the critical problem with current drone tagging is external perturbations on the tag during the drop process are causing inaccurate drops, resulting in a large amount of unsuccessful tag deployments. The goal of this project is to design a new release mechanism that will make the tag more robust to perturbations and external factors, resulting in an increase to the deployment success rate of the biologging tags. Our major requirements are split into three main categories: the tag release system conforms physically to the drone and tag, performance requirements for successfully tagging a whale, and ease of use needs. We generated an array of design concepts using a mind map, morphological analysis, design heuristics, and functional decomposition. We then utilized a series of Pugh charts as well as new requirements from our sponsor to select a spring forcing component, guide rails and fins for stability, and a pin and servo for securement and release. Our alpha design creates an initial velocity on the tag using a spring attached to the drone, and our beta designs use a spring attached to the tag and an elastic band attached to the drone respectively. Our engineering analysis consists of two major components, drone downwash velocity approximation and spring analysis, based on both empirical model and engineering analysis. The build description covers the detailed build solution with CAD and Engineering drawings along with the material and manufacturing analysis. Our final design description indicates a comprehensive justification on the final design with a detailed design solution presented by our CAD model. In addition, the verification and validation plan outline our different verification methods to address each specification. We conducted an experiment to test five different fin designs with varying spring stiffnesses, followed by subsequent verification and validation. The results of the testing can be found on page 41, and show that while we are meeting our impact force goals, we are frequently out of the range of acceptable orientation deviation. Based on the experimentation, we generated various suggestions for future experiments and design improvements, which include revisions to our test rig, testing methods, materials, stabilization, and ergonomics. In the reflection section, we analyze the impact of design contexts, power dynamics, cultural background, and ethics on the project, and eventually how these all tie together to eventually benefit the whales which are being tagged. The appendices include a full and well-documented set of details on the final design, while the bill of materials is attached on page 34. As a result of our work, we have paved the way for further improvements to be made to the drone tagging system utilizing our test rig and modular design.

Acknowledgements

We would like to thank Professor Shorter for the help he has provided us during this project and the research team from Ocean Alliance for providing us with the current CAD models. We also would like to thank Professor Barton and the students from our section for their feedback throughout the semester.

References

[1] Meynecke, J.-O., & Liebsch, N. (2021). Asset tracking whales—first deployment of a custom-made GPS/GSM suction cup tag on migrating Humpback Whales. *Journal of Marine Science and Engineering*, *9*(6), 597. https://doi.org/10.3390/jmse9060597

[2] Holton, M. D., Wilson, R. P., Teilmann, J., & Siebert, U. (2021). Animal tag technology keeps coming of age: An engineering perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*(1831), 20200229. https://doi.org/10.1098/rstb.2020.0229

[3] K. Alex Shorter. Interview. Conducted by Jialu Yu, Ethan Parkham, Henry Meiselman, and David Morris. 17 Jan. 2023

[4] Wiley, D. N., Zadra, C., Friedleander, A. S., Park, S. E., Pensarosa, A., Rogan, A., Shorter, A. K., Urbán, J., & Kerr, I. (n.d.). *Deployment of Biologging Tags on Free Swimming Large Whales Using Uncrewed Aerial Systems*.

[5] Blair, H. B., Merchant, N. D., Friedlaender, A. S., Wiley, D. N., & Parks, S. E. (2016). Evidence for ship noise impacts on humpback whale foraging behaviour. *Biology Letters*, *12*(8), 20160005. https://doi.org/10.1098/rsbl.2016.0005

[6] Isojunno, S., & Miller, P. J. (2015). Sperm whale response to tag boat presence: Biologically informed hidden state models quantify lost feeding opportunities. *Ecosphere*, *6*(1), 1–46. https://doi.org/10.1890/es14-00130.

[7] Parks, S. E., Warren, J. D., Stamieszkin, K., Mayo, C. A., & Wiley, D. (2011). Dangerous dining: Surface foraging of North Atlantic right whales increases risk of vessel collisions. *Biology Letters*, *8*(1), 57–60. https://doi.org/10.1098/rsbl.2011.0578

[8] Raoult, V., Colefax, A. P., Allan, B. M., Cagnazzi, D., Castelblanco-Martínez, N., Ierodiaconou, D., Johnston, D. W., Landeo-Yauri, S., Lyons, M., Pirotta, V., Schofield, G., & Butcher, P. A. (2020). Operational protocols for the use of drones in Marine Animal Research. *Drones*, *4*(4), 64. https://doi.org/10.3390/drones4040064

[9] Murakami, R., Toyoshima, T., Furusawa, D., Suzuki, M., Masumoto, K., Owada, S., Tsumaki, Y., & Mori, K. (2021). Logger attaching system for sperm whales using a drone. *Journal of Robotics and Mechatronics*, *33*(3), 475–483. https://doi.org/10.20965/jrm.2021.p0475

[10] Christiansen, F., Nielsen, M. L., Charlton, C., Bejder, L., & Madsen, P. T. (2020). Southern right whales show no behavioral response to low noise levels from a nearby

unmanned aerial vehicle. *Marine Mammal Science*, *36*(3), 953–963. https://doi.org/10.1111/mms.12699

[11] *Drone payload release mechanism drop device for drone fishing, bait release, payload delivery, Search & Rescue, fun activities sky hook*. Drone Engr. (2020, September 7). Retrieved February 1, 2023, from https://www.droneassemble.com/product/drone-payload-release-mechanism-drop-device-for-drone-fishing-bait-release-payload-delivery-search-rescue-fun-activities-sky-hook/

[12] Kleivane, L., Kvadsheim, P. H., Bocconcelli, A., Øien, N., & Miller, P. (2022). Equipment to tag, track and collect biopsies from whales and dolphins: The arts, Dfhorten and LKDart Systems. https://doi.org/10.21203/rs.3.rs-1608576/v1

[13] *Mini projectile launcher*. Arbor Scientific. (n.d.). Retrieved February 1, 2023, from https://www.arborsci.com/collections/mechanics/products/mini-projectile-launcher

[14] Wynn, D., & Clarkson, J. (2005). Models of designing. *Design Process Improvement*, 34–59. https://doi.org/10.1007/978-1-84628-061-0_2

[15] Blessing, L. T. M. (1994). *A process-based approach to computer supported engineering design*. [PhD Thesis - Research UT, graduation UT, University of Twente]. Universiteit Twente.

[16] Dixon, J. R., & Finger, S. (1989). Editorial. *Research in Engineering Design*, *1*(1), 1–1. https://doi.org/10.1007/bf01579998

[17] Fisheries, N. O. A. A. (n.d.). *Marine Life Viewing Guidelines*. NOAA. Retrieved February 1, 2023, from https://www.fisheries.noaa.gov/topic/marine-life-viewing-guidelines

[18] *Inspire 2 - product information - DJI*. DJI Official. (n.d.). Retrieved February 1, 2023, from https://www.dji.com/inspire-2/info#specs

[19] *Matrice 200 series V2 - product information - DJI*. DJI Official. (n.d.). Retrieved February 1, 2023, from https://www.dji.com/matrice-200-series-v2/info#specs

[20] *Whale Research & Conservation*. Ocean Alliance. (2022, November 3). Retrieved February 1, 2023, from https://whale.org/

[21] Yeo, D., Shrestha, E., Paley, D. A., & Atkins, E. M. (2015). An empirical model of Rotorcrafy UAV downwash for disturbance localization and avoidance. AIAA Atmospheric Flight Mechanics Conference. https://doi.org/10.2514/6.2015-1685

[22] Chang K, Chen S, Wang M, Xue X, Lan Y. Numerical simulation and verification of rotor downwash flow field of plant protection UAV at different rotor speeds. Front Plant Sci. 2023 Jan 26;13:1087636. doi: 10.3389/fpls.2022.1087636. PMID: 36777541; PMCID: PMC9909540.

[23] Zhu, Y., Guo, Q., Tang, Y., Zhu, X., He, Y., Huang, H., & Luo, S. (2022). CFD simulation and measurement of the downwash airflow of a quadrotor plant protection UAV during operation. In Computers and Electronics in Agriculture (Vol. 201, p. 107286). Elsevier BV. https://doi.org/10.1016/j.compag.2022.107286

[24] Technical Support (2023) E-mail to Shengnan, Hong, 30 March.

[25] Young, H. D., Freedman, R. A., Ford, L. A., Sears, F. W., & Young, H. D. (2020). *Sears & Zemansky's university physics*. Pearson Higher Education.

[26] Perna, F. M., Coa, K., Troiano, R. P., Lawman, H. G., Wang, C.-Y., Li, Y., Moser, R. P., Ciccolo, J. T., Comstock, B. A., & Kraemer, W. J. (2016). Muscular grip strength estimates of the U.S. population from the National Health and Nutrition Examination Survey 2011–2012. *Journal of Strength and Conditioning Research*, *30*(3), 867–874. https://doi.org/10.1519/jsc.0000000000001104

[27] James, D., Potts, J. Experimental validation of dynamic stability analysis applied to dart flight. *Sports Eng* 21, 347–358 (2018). https://doi.org/10.1007/s12283-018-0279-9

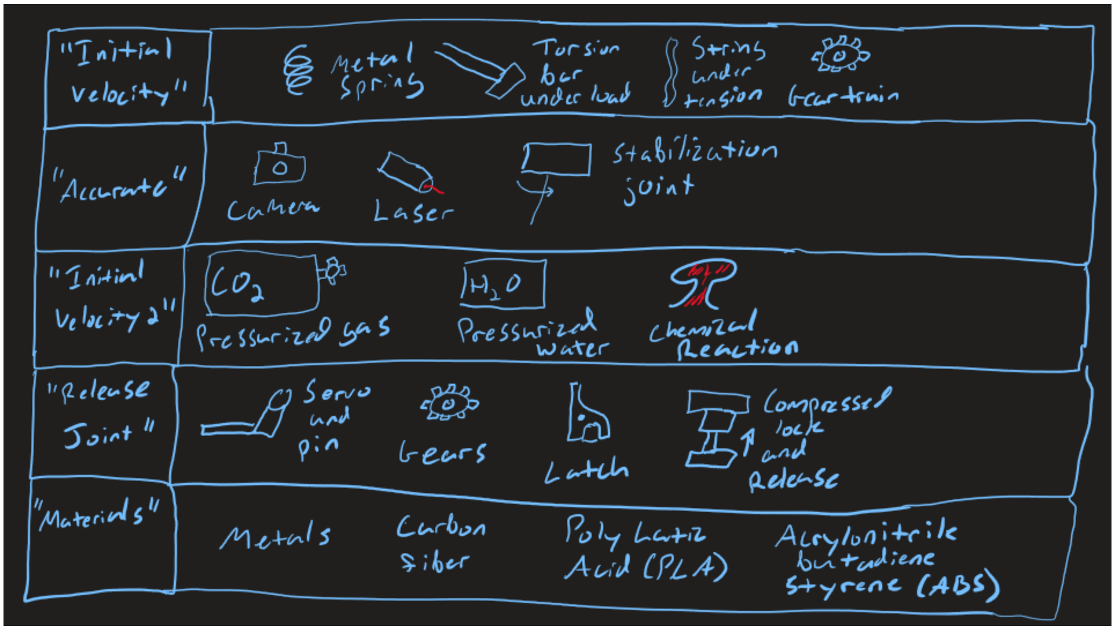
APPENDIX A: Concept Generation

Table A.1 shows some of the concepts that were generated from the team mind map for each subsystem. We used these subsystems and some of the concepts that were generated in our pugh charts that allowed us to narrow down our focus. This allowed us to create our alpha and beta designs.

Table A.1: Distinct design concepts

Subsystems	**Forcing Component**	**Securement**	**Release Mechanism**	**Accuracy/Stability**
	Chemical accelerator	**Compliant mechanism**	**Claw**	**Center of gravity manipulation**
	Pressurized gas	**Gears**	**Latch**	**Fins**
	Spring	**Servo-pin**	**Burning**	**Lasers**
	Scissor lift	**ElectroMagnet**	**Break a part**	**Rail Guides**
	Gravitational acceleration	**Rachet**	**ElectroMagnet**	**Active steering**

Each member used different methods to generate concepts for our project. The methods that we used were a morphological chart, a mind map, brainstorming, and design heuristics. Figure A.2 shows a morphological chart with different subsystems. Each subsystem has concepts generated for it. This will allow for several different designs to be created.



"Initial velocity"	Metal spring	Torsion bar under load	String under tension	Gear train
"Accurate"	Camera	Laser	Stabilization joint	
"Initial velocity 2"	CO_2 Pressurized gas	H_2O Pressurized water	Chemical Reaction	
"Release Joint"	Servo and pin	Gears	Latch	Compressed lock and Release
"Materials"	Metals	Carbon fiber	Poly Lactic Acid (PLA)	Acrylonitrile butadiene styrene (ABS)

Figure A.2: Design concepts generated by David using a morphological Chart

Next is Figure A.3 which is a mind map. Using subsystems, ideas and concepts were generated, which were either in the form of an entire idea or just a sub part of a subsystem.

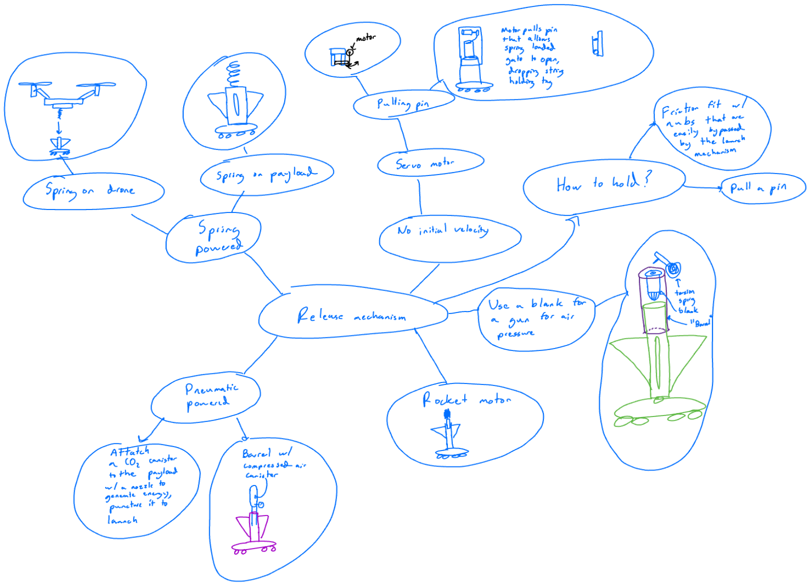


Figure A.3: Design concepts generated by Ethan using a mind map

In Figure A.4 brainstorming was used to generate entire concepts. Some of them were not entirely practical. Those were removed during the selection process.

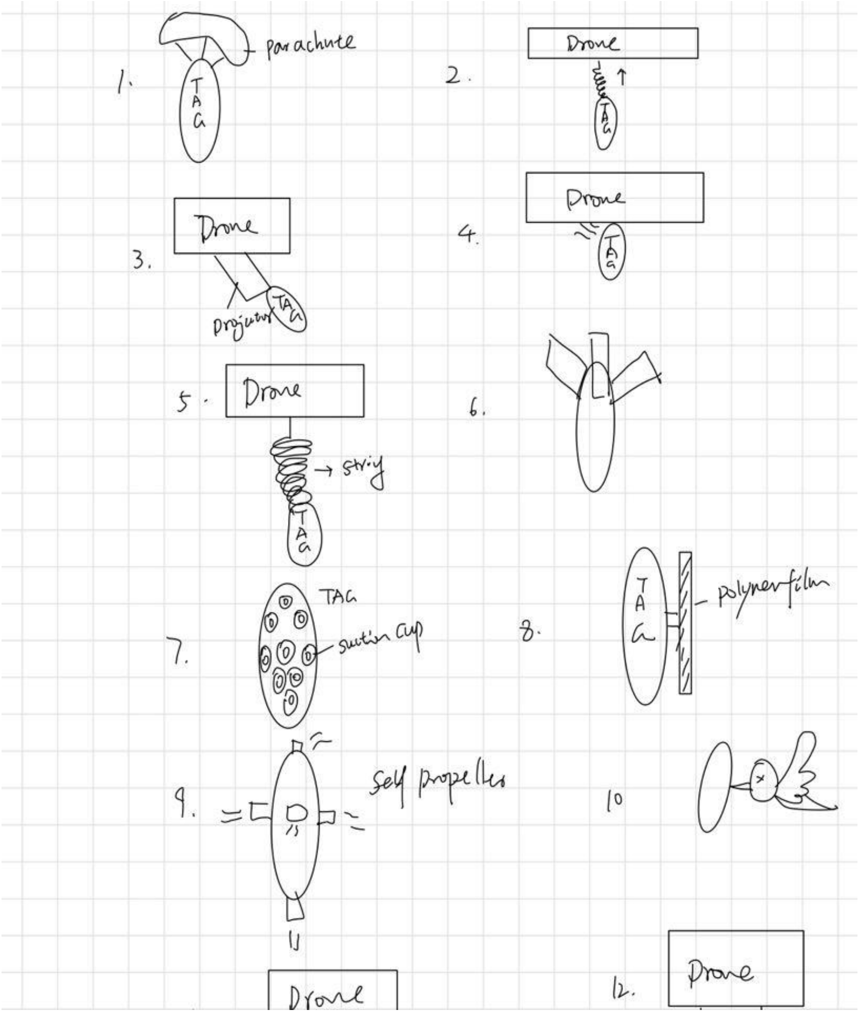
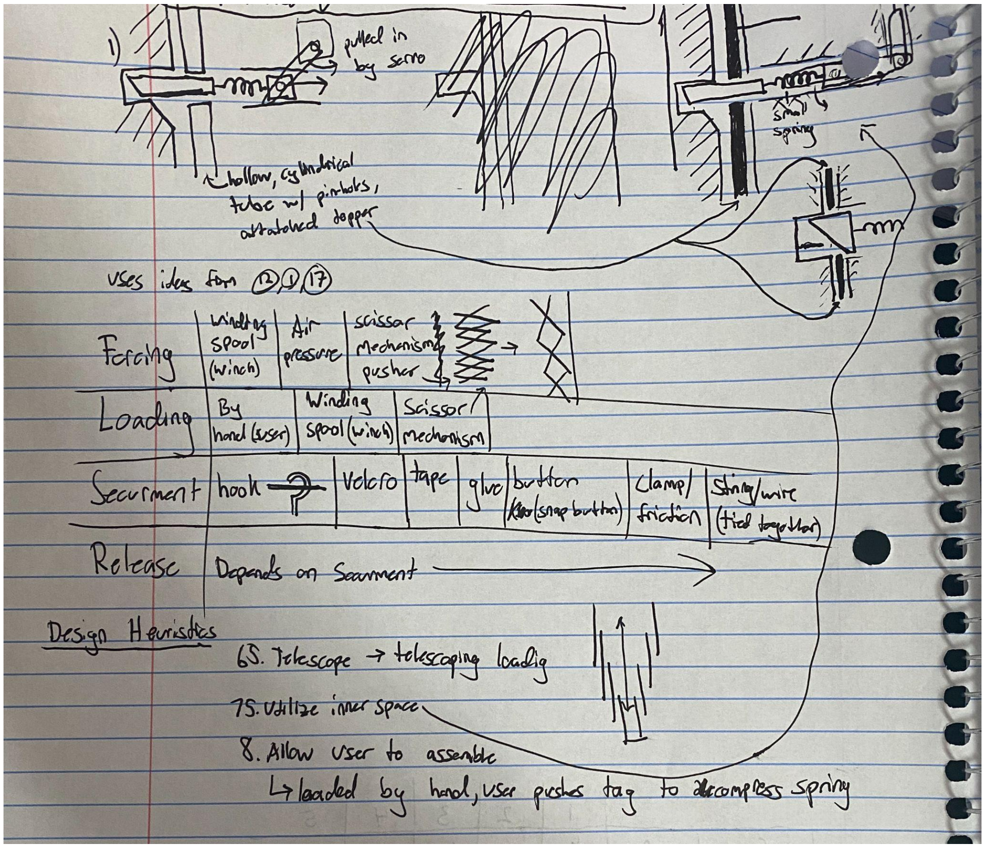


Figure A.4: Design concepts generated by Jialu

Lastly, in Figure A.5 brainstorming and design heuristics were used to generate concepts for our project. As seen from the image some heuristics were used to create parts of the design.



uses ideas from ⑫, ①, ⑰

Forcing	Winding spool (winch)	Air pressure	scissor mechanism pusher				
Loading	By hand (user)	Winding spool (winch)	Scissor mechanism				
Securment	hook	Velcro	tape	glue	button (snap button)	Clamp/ friction	String/wire (tied together)
Release	Depends on Securment →						

Design Heuristics

6S. Telescope → telescoping loadig

7S. Utilize inner space

8. Allow user to assemble
   ↳ loaded by hand, user pushes tag to ~~de~~compress spring

Figure A.5: Concepts generated by Henry

Manufacturing/Fabrication Plan

The vast majority of parts were 3D printed, so we did not have any machining manufacturing plans. All 3D printed parts were printed on a Ultimaker 3 Extended printer using Ultimaker Tough PLA. Tough PLA was chosen for its strength and print reliability. The release mechanism parts were printed in two printing sessions in batches. Print set 1 contained the original designs for the fin, fin topper, and DTAG clamp. Print set 2 contained the servo mount, two fin topper disks, three lengths for the fin topper, and three spring mounts. The fin toppers and spring mounts were sized to fit the K21, K441, and T483 springs selected from McMaster Carr using our spring analysis. Additional fin designs, including the rotated fin, large fin, small fin, and trapezoid fin were be printed individually due to the build plate size limitations of the printer. All parts were printed using the default settings for Tough PLA, using Tough PLA for supports where required. All parts were printed with 20% triangular infill, which was chosen due to its ability to be printed rapidly, with the compromise of sacrificing some strength. The parts were then press fit together or assembled with the appropriate screw and nut sizes. We used a miter saw to cut the test rig 2x4s after marking the lengths each board needed to be cut to. Then, the frame was assembled using a cordless electric drill.

Team Biographies

My name is Jialu Yu, a senior Mechanical Engineering student at the University of Michigan-Ann Arbor. I was born and raised in the southern part of China. My childhood was mostly spent in a manufacturing factory which ultimately introduced me to a Mechanical Engineering major .My decision to pursue a concentration in robotics was made after seeing the frailty that cancer brought to my grandpa in 2019. I have always wanted my work to help others, but, after personally witnessing his body become unable to support himself, my goals changed to advancing robotics to provide better care for patients like him. My next step would be to continue my academic interest in graduate school and my ultimate goal is to advance robotics to provide better care for patients as an alternative for patients to finish and Western styles for five years and was a member of UMich Equestrian team. I also have two cats called Lulu and Wuyang.

My name is David Morris, I was born in Illinois and moved around a couple of times before moving to Michigan in 2004. When I graduated high school I was unsure what I wanted to do. I ended up getting a job and moving up into management for several years. During that time my grandfather passed away, which made me realize I did not enjoy the line of work I was in. I started going to community college and found an interest in robotics, which drew me to mechanical engineering. From this I also pursued a minor in electrical engineering which focuses on control/embedded systems. This would allow me to work on how the robot would function and how it is controlled. I didn't want my degree to only focus on mechanical engineering, getting the minor I felt like gave me a broader range of opportunities to pursue. As the line of work I go into does not have to be robotics entirely, as I enjoy controls/embedded systems this will allow me to go into different fields.

Now this does make me older than my classmates most of the time, but I don't feel like it's ever been a disadvantage. My next steps would be to go into industry, I want to start my career and get real world experience. After a couple of years I would like to come back to get my masters either in robotics or something similar.

My name is Ethan Parham. I was born in Elk Grove Village, Illinois, which is a suburb about half an hour away from Chicago. One of my favorite hobbies is playing the trumpet, and I am heavily involved with the athletic bands at Michigan. In the fall, I am a part of the Michigan Marching band, and in the winter I play in the Hockey Band. I am also playing in a trumpet ensemble.

As I was growing up, my career aspirations varied a large amount. When I was little, I dreamed of being a dolphin trainer and marine biologist, and loved anything to do with the ocean. Later, in highschool, I realized I loved designing and building things, and engineering would be a perfect field for me. I also really wanted to be able to help people, so I wanted to explore biomedical engineering. In the fall of 2020, I became an engineering student at the University of Michigan, and quickly realized that mechanical engineering was the right path for me to explore my interests. Now, I am a senior majoring in mechanical engineering and minoring in computer science. I have really enjoyed the ME X50 design classes I have taken so far, and look forward to pursuing my interests in design and manufacturing further in ME 450 and beyond. I currently intend to earn a masters degree in mechanical engineering once I complete my undergraduate degree in order to continue my exploration of engineering.

My name is Henry Meiselman. I am a junior studying mechanical engineering at the University of Michigan. I was born in New York City, but grew up in Westfield, NJ. Sports have always been a very important part of my life. I love lacrosse and football and won a New Jersey Football State Championship in 2017. I still play lacrosse for the University of Michigan Club Lacrosse team and have recently started playing golf as well.

I have always known that I wanted to study engineering. As a young child I would take household objects like cameras and clocks apart to see how they worked. This fueled my curiosity and drove me to want to study mechanical engineering.

My current plan is to pursue a masters degree in mechanical engineering following my graduation in December 2023. I have had many varied work experiences within the mechanical engineering field and I think I want to pursue a design-oriented role. Eventually, I would like to get an MBA and either move to the management side of an engineering company or start my own company and develop my own product.