To: Professor Randy Schwemmin, ME 450 Section 007 Professor
2505 Hayward Street
Ann Arbor, MI 48109

From: Nate Lasinski, Young Han, Julia Zak, Luke Hausch, Max Lipari: Team 28

Subject: Final Report

Date: December 15, 2021

Executive Summary

Professor Alex Shorter has sponsored a project to develop a drone-based system for placing suction cup based biologging tags onto whales. Shorter develops the biologging tags within his laboratory at the University of Michigan. A second stakeholder, Ocean Alliance, is a whale conservation organization that has worked with Prof. Shorter in the past for whale research and is partnering with him to oversee the project. The ME 450 Team 28 is tasked with designing and testing a system that will interface in between both the drones that Ocean Alliance is providing and the biologging tags that Professor Alex Shorter provides.

Weekly meetings with Alex Shorter's team and the Ocean Alliance team brought to light the main focus of this project: reducing the impact of the biologging process on whales. Key requirements of the project are to minimize whale interactions, achieve proper suction of biologging tags, and reduce impact on flight capabilities. Corresponding specifications for the most important requirements are displayed below.

Priority (1-5)	Requirement	Ranking for Specification (1-3)	Engineering Specification	Total
5	Whale Impacts	3	Whale behavior is ≤ 1 on the 0-3 point behaviour scale for 90% of flights	15
			Whale behavior is ≤ 1 on the 0-3 point behaviour scale for 90% of flights	
	Tag Suction		Must achieve 25 Netwons* of force per suction cup	
	Flight Time		Payload weighs <0.51kg	

The team moved through three stages of concept generation and two stages of Pugh Charts to create and quantify the best high level systems and detailed subsystems to prototype. From a high level, the team decided to drop the tag from the drone. Three subsystems were identified for this approach: the release mechanism to actuate the dropping of the tag, the fin to guide the tag as it falls, and the clamp to hold the tag as it falls and then release upon impact. This concept was chosen because it disturbed the whale the least, generated sufficient force, and was compatible with the current operations of the drone.

The team detailed the necessary analytical systems and tests for optimizing the overall design. These include aerodynamics analysis for fin designs and force calculations for determining the optimal drop height. Dropping tests were performed to quantify the amount of suction associated with dropping the tag at different heights and to compare the method of dropping versus the current benchmark method. From these analyses and tests, fin and clamp geometry was determined for the final design, an optimal drop height of at least 6 ft was determined, and the conclusion that dropping provides better suction than using manpower to attach the tag. Furthermore, during the third design phase the team created numerous prototypes to compare design ideas, and developed the necessary analytical models to finalize a design. The CAD model of the final concept design was created based on several analyses and tests. The final design includes an 8 inch long fin, a servo-motor pin release mechanism, and clamp that attaches directly to the fin. The final prototype was 3D-printed using PLA. Verification and validation tests were performed on the final prototype to test for requirements such as weight, stability of the system when dropping, and adequate tag suction. The final prototype passed all validation tests.

Table of Contents

Revised Abstract

Biologging is a method of studying wild animals that involves attaching sensors to the animal in order to gather data about its behavior. This project aims to create a mechanism for attaching suction-cup based biologging tags onto whales using drones. The motivation for this project comes from a need to minimize disturbance to whales during the biologging process and to create a dependable method of attaching tags. The proposed solution involves using a dropping system actuated by a servo-motor pin system to drop tags from an airborne drone onto the surface of the whale, using fins to stabilize the tag.

Project Introduction

Biologging is a method of studying wild animals that involves placing a tag of sensors on the animal to gather data about the animal. These sensors can include microphones or hydrophone to study acoustics, accelerometers and magnetometers to determine physical orientation of the animal, temperature and pressure sensors, and more. For oceanic mammals, the most common method of securing these tags onto the animals is via suction cups. The current method for attaching these suction cups onto whales involves researchers getting close to the whale in a small boat and then using a long pole to tag the suction-cup onto the surface of the breaching whale's skin.

The sponsor of this project is Professor K. Alex Shorter who is a University of Michigan professor in the department of Mechanical Engineering. Professor Shorter has been involved in research involving oceanic mammals and in the past few years he has been involved in the process of biologging these creatures. He is responsible for the development and manufacturing of the biologging tags that researchers use to gather information about the whales. For this particular project, Professor Shorter is collaborating with a group called Ocean Alliance. Ocean Alliance is a conservation group that focuses on researching and protecting whales. As part of their research, they use drones to collect biological data from whales by attaching a petri dish to a drone and flying the drone through the water projected by the whale as it exhales. Motivated primarily by an effort to minimize the disturbance and harassment to whales that can be associated with the biologging process, Ocean Alliance and Professor Shorter are collaborating to create a method to replace the long-pole tagging method with a less invasive tagging system that involves drones.

The project that the team is tasked with this semester is supporting the mission of Professor Shorter and Ocean Alliance's collaboration. The goal of the project is to design a mechanism for attaching the suction-cup based biologging tags onto whales using drones. The team is provided with the biologging tags developed by Professor Shorter to build the final design around. Ocean Alliance has provided our group with two drones that the final design can be adapted for: one DJI Inspire 2 and one Urban Splash Drone.

Intellectual Property

Throughout the course of this project, the team did not sign an NDA nor an IP. Thus, all of the designs and findings associated with this project can be considered open source. While the design was built and tailored for the needs of the Ocean Alliance research team, any group of researchers throughout the world can theoretically access the ideas developed in this project and adapt them for their own research purposes.

Social Context Assessment

When working through this project, all potential environmental, socioeconomic, and ethical impacts that may result from the solution must be considered. This project has the capacity to have positive consequences for the environment. Ultimately, the research that will be gathered from the biologging process will support conservation efforts which aim to protect whales and thus the ecosystem and environment as a whole. While this project can certainly have positive environmental impacts, there is potential for some negative impacts as well. Increased drone activity has potential to disturb the local wildlife. Frequent drone flight may bother the birds in the area, and the noise from the drone, as well as its unnatural presence, may bother both wildlife and local community members. There is a chance the drone activity may be considered a disturbance to the peace, in which case may affect the welfare of those nearby. However, drone usage will be for purely research purposes, and there will be no compromise to public safety via use of the drone for surveillance or anything of the sort. Additionally, if any parts of the system are frequently lost in the ocean, this would be adding litter and pollutants into the ocean, which may be of concern if this problem prevails. Adding microplastics to the ocean can contribute to serious negative implications for the ecosystem, and this must be considered when designing the final product. Microplastics in the ocean can also be considered a public health concern, as humans are at risk of ingesting microplastics if they can be found within fish and other seafood that is consumed by humans. For these reasons, the retrieval of any plastic from the ocean during this project is essential. As for socioeconomic impacts, our design will be open-source so it will be accessible for everyone. Thus, it has the potential to be scaled and adapted for use by anyone, despite any financial restrictions. This applies to a global scale as well; people from all over the globe have the ability to adapt the solution for their own uses and vary the design to meet their own requirements. The team also must consider any ethical conflicts that could arise from bothering people in local areas with an increase in drone usage near their homes. In order to assess the impact of the project, the team created a stakeholders map (Figure 1) and analyzed how stakeholders of all levels would potentially be impacted by the project.

Stakeholder Analysis

Two obvious primary stakeholders in the team's project are Prof Shorter and Ocean Alliance. They have been identified as resource providers and beneficiaries, as they both provide valuable information and resources and will benefit from the success of this project and use this tool in their work. Another primary stakeholder in the project is the whales themselves. They have been identified as beneficiaries because the research gathered from the biologgig tags will ultimately benefit the whales. They were also identified as problem makers because one of the major obstacles of this project is creating a device that will work despite any obstacles put in place by the whale's behavior. A secondary stakeholder than we identified is the greater marine biology community. They were classified as an affected bystander because if the project is successful, the research and methods used can have positive impacts on the marine biology community. Tertiary stakeholders were identified as the fishermen and policy makers in the area where this technology would be deployed. Fishermen were classified as supporters of the status quo because the consequences of using this technology may affect where they are allowed to travel and work, and they likely will not want to change their current ways. Policy makers were classified as affected bystanders because the research gathered by the biologging will likely influence policies that they create surrounding conservation. A stakeholder matrix addressing the important stakeholders at each level is pictured below in Figure 1.

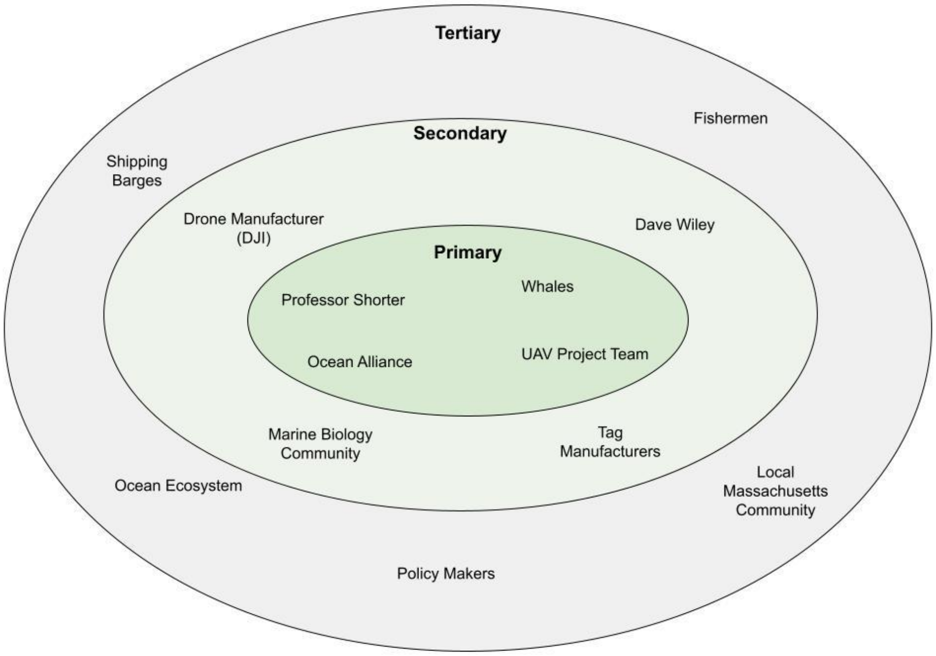


Figure 1. Stakeholder Matrix addressing the three levels of stakeholders in this project.

Library and Research

The team met with librarian Joanna Thielen in the beginning of the research process in order to help focus the research and extrapolate what was relevant to the project. She assisted the team by explaining how to use the University databases and helping the team figure out useful keywords to search for and where to search. After this meeting, several academic papers were found that helped the team better understand the context and background of the project. In order to gain a greater perspective on the whale biologging process, the team explored several academic journals and articles about biologging and whales. Szesciorka's article titled "Testing tag attachments to increase the attachment duration of archival tags on baleen whales"[1] helped the team gather an understanding of why suction cups are a desirable attachment method for biologging tags on whales. Börger's article "Biologging Special Feature"[2] in the Journal of Animal Ecology allowed the team to grasp a deeper understanding of the data that can be extracted using biologging. Mai's "Reactions of Heaviside's Dolphins to Tagging Attempts using Remotely-Deployed Suction-Cup Tags"[3] provided insight into how the biologging tags are attached and the reactions associated with marine mammals being tagged by these methods. Additionally, for developing requirements and specifications the team referred to the manuals for the DJI Inspire 2 and Urban Splash Drone[4]. One information gathering challenge that the team faced was finding relevant benchmarks. The biologging of whales is a fairly niche and specific topic and it was difficult to find academic articles about different methods of biologging these animals. The team found that most information regarding benchmarking involved finding academic journals and reports describing the biologging process that Ocean Alliance also uses.

Interviews were ultimately the best way to gather information for this project. Most of the information gathered to create the requirements came from communication directly with Prof. Shorter and Ocean Alliance. Ocean Alliance was able to provide abundant detail about both their current biologging expeditions and their current use of drones. They were very helpful in answering all of the group's questions with thorough explanations. The team has a standing weekly meeting with both of these stakeholders, and through communication in these meetings a great deal of relevant information was gathered, which has been the driving force behind the project.

Inclusion and Equity

The team's primary sponsor, Professor Alex Shorter, is a University of Michigan professor who has taught members of Team 28 in Dynamics & Vibrations class previously. With this dynamic at play, the team was often quick to accept Professor Shorter's suggestions and comments throughout the course of the project. Sometimes the information or expectations from the Ocean Alliance stakeholders would conflict with the information and expectations from Professor Shorter. This could be challenging to navigate because Ocean Alliance is the end user of the project but Professor Shorter technically sponsors the project. The team had more contact with Shorter, especially when using his lab to conduct tests, and were overall more familiar with him due to his university affiliation. Because of this dynamic, the team typically listened to Professor Shorter's ideas when there were conflicting opinions or comments between him and Ocean Alliance. Coming from the university perspective versus the industry perspective of Ocean Alliance, the team was sometimes more focused on the process of coming to final decisions compared to Ocean Alliance. This is where the team's identities as students slightly conflicted with Ocean Alliance's identity as a professional organization. The team had to go through a lengthy process of concept generation, concept selection, and analysis in order to comply with the class and to be thorough in the design process. Ocean Alliance, as the end users, were more motivated to jump right to the prototyping and testing phase because from their perspective this was the most important and useful phase.

The team is made up of five students, all with different identities and experiences. These differences brought unique perspectives to the table. Some of the group members had more experience with design classes, and brought tools and ideas from their past courses during the concept generation and selection process. One member of the team has a strong fine arts background, and brought techniques from his fine arts experience that were unique to what the other members had seen coming from less artistic backgrounds. Other members had more experience with manufacturing, both from professional and hobbyist perspectives, and these members provided helpful ideas as to how the product could realistically be built.

Ethics

The major ethics consideration that the team had to account for was the impact of the final product on the whale. When generating concepts, the team had several ideas that may have worked well for the purpose of attaching the tag successfully to the surface of the whale, such as shooting the tag onto the whale with a gun or cannon-like contraption. However, while there were certain methods that may have worked very well for attaching the tag, such a system could potentially cause distress to the whale. The group managed this dilemma by deciding to rule out any solutions that were perceived to cause unnecessary stress or harm to the whale, despite how effective they may have been at completing the rest of the requirements.

If the final product were to enter the market, a potential ethical dilemma that may arise may be that there is an increase in waste in the ocean. If users are unable or unwilling to retrieve parts that release off of the tag and into the sea, then there is plastic waste in the ocean. This may harm wildlife if sea creatures ingest the plastic and become sick or even die. This would be an ethical dilemma because the use of the product to attach tags is beneficial for the researchers, but the pollution will be harmful to the ocean ecosystem and the general public.

The personal ethics of the team members and professional ethics expected to be upheld by the University of Michigan have both their similarities and differences. Personal ethics involve morals that individuals identify with and how these individuals conduct themselves in everyday life. The professional ethics that the University of Michigan expects the team to adhere to relates to how the team conducts themselves in terms of business, such as making sure the team is not violating any NDAs or IPs, and that the team is interacting with sponsors in a professional and appropriate manner. Future employers have similar professional ethics expectations, expecting employees not to cut any corners when it comes to adhering to standards or protocol.

Design Process

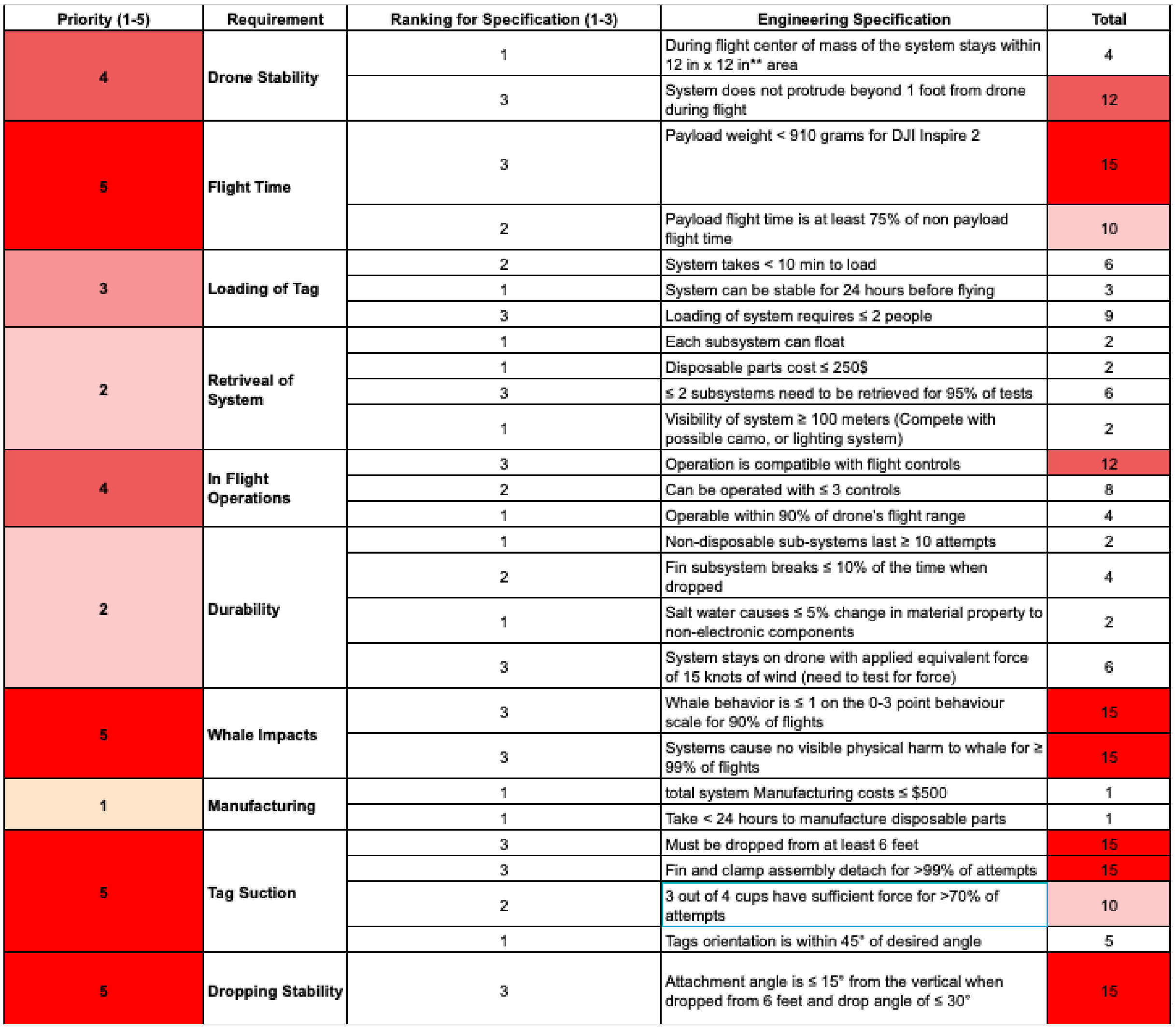
The team followed the standard design process used by ME 450 capstone project groups. This design process is iterative and flows from Problem Definition to Concept Exploration to Solution Development and Verification. Throughout each phase of the design process, the team valued stakeholder engagement and information gathering, divergent and convergent thinking, application of mechanical engineering principles, inclusivity, and evidence-based decision making. The systematic design process forced the group to take certain processes, such as concept exploration, slower than they may have wanted to at the time in order to be careful and thorough. The team was tempted to jump directly from defining the problem to prototyping, but the systematic design process forced the team to be considerate of the concept generation phase and not move forward until many different concepts were explored and thoroughly discussed.

Requirements and Engineering Specifications

Based on the meeting with sponsors and top stakeholders the team created a list of requirements. These requirements were then expanded to become a list of specifications. These specifications had numbers assigned to them in order to be able to measure how well the final product is able to meet each specification.

The requirements that were found from weekly meetings with our sponsors and top stakeholders were ranked on a scale of 1-5, where 5 is the highest importance and 1 is the lowest importance. The specifications that came from these requirements were then given a number of 1-3, where 3 is the most important and 1 is the least important. The specification's number was then multiplied to the corresponding requirement's number. This gave a total ranking scale of 1-15 to tell which specifications were the most important to consider. This is all shown below in Table 1.

Table 1. Depicts the requirements, engineering specifications, their respective ranking, and each specifications overall score. The specifications that scored over a 12 are the top priority specifications.



Priority (1-5)	Requirement	Ranking for Specification (1-3)	Engineering Specification	Total
4	**Drone Stability**	1	During flight center of mass of the system stays within 12 in x 12 in** area	4
		3	System does not protrude beyond 1 foot from drone during flight	12
5	**Flight Time**	3	Payload weight < 910 grams for DJI Inspire 2	15
		2	Payload flight time is at least 75% of non payload flight time	10
3	**Loading of Tag**	2	System takes < 10 min to load	6
		1	System can be stable for 24 hours before flying	3
		3	Loading of system requires ≤ 2 people	9
2	**Retriveal of System**	1	Each subsystem can float	2
		1	Disposable parts cost ≤ 250$	2
		3	≤ 2 subsystems need to be retrieved for 95% of tests	6
		1	Visibility of system ≥ 100 meters (Compete with possible camo, or lighting system)	2
4	**In Flight Operations**	3	Operation is compatible with flight controls	12
		2	Can be operated with ≤ 3 controls	8
		1	Operable within 90% of drone's flight range	4
2	**Durability**	1	Non-disposable sub-systems last ≥ 10 attempts	2
		2	Fin subsystem breaks ≤ 10% of the time when dropped	4
		1	Salt water causes ≤ 5% change in material property to non-electronic components	2
		3	System stays on drone with applied equivalent force of 15 knots of wind (need to test for force)	6
5	**Whale Impacts**	3	Whale behavior is ≤ 1 on the 0-3 point behaviour scale for 90% of flights	15
		3	Systems cause no visible physical harm to whale for ≥ 99% of flights	15
1	**Manufacturing**	1	total system Manufacturing costs ≤ $500	1
		1	Take < 24 hours to manufacture disposable parts	1
5	**Tag Suction**	3	Must be dropped from at least 6 feet	15
		3	Fin and clamp assembly detach for >99% of attempts	15
		2	3 out of 4 cups have sufficient force for >70% of attempts	10
		1	Tags orientation is within 45° of desired angle	5
5	**Dropping Stability**	3	Attachment angle is ≤ 15° from the vertical when dropped from 6 feet and drop angle of ≤ 30°	15

As shown above in the table, the most important requirements are Whale Impact, Tag Suction, Flight Time, and Dropping Stability. These can be validated as the top priority requirements because they will make or break this project. The purpose of this project is to reduce the impact on whales. Tagging whales with poles using boats is a very invasive process and the invasiveness is trying to be minimized by using drones. Furthermore, Tag Suction is absolutely crucial. If our product can't achieve suction of the tags onto whales then it has failed its goal of still being able to tag whales using this method. Next, for flight time, the drone pilot will need as much time in the air as possible to get options to tag the whale. Since whales are wild animals they are not always the most predictable of animals and need to be able to stay in the air as long as possible to get their opportunity. Dropping stability is an essential requirement because if the tag is not able to land in the proper orientation after being dropped, then the tag will not be attached to the whale and the project will fail to complete its purpose. Other notable requirements include drone stability and in flight operation. The Drone Stability requirement is another one for the pilot. The pilot must still be able to predict the movement of the drone and its stability must not be affected by using our product. Lastly, In Flight Operation of the drone and the system must be possible. The pilot must be able to operate both the drone and whatever system we employ to get the job done.

For the specifications there are a few that stand out. Those with a score of 12 or higher, and those scoring 15 are the absolute must meet specifications. Starting from the priority requirement, Whale Impact, both specifications were given the highest number of 3, as reducing impact and avoiding the physical harm to whales were decided to be the really important to consider. With the requirement of Tag Suction, as tagging suction cups onto whales are the most crucial part of our project, reaching enough force to attach suction cups was decided to score the highest rank of 3 compared to other specifications under the Tag Suction requirement. Additionally, the fin and clamp must detach from the tag after it has been placed because if the fin and clamp remain attached, then the radio signal used in the tag is interfered with. For the dropping stability requirement, the most important specification is that the attachment angle must be ≤ 15° from the vertical when dropped from 6 feet and a dropping angle of 30°. This dictates that the tag must be at a sufficient position to stick onto the whale's body at the time of impact. For the requirement of the Flight Time, payload weight is the most important specification to consider as the system including suction cup and dropping mechanism should be able to be flown by drone, and this is the reason why the specification of payload weight ranked the highest score of 3. These were the specifications that scored the maximum score of 15 for the total ranking scale.

Next, for the Drone Stability, the limited area of the payload fixture is critical for the stability of drone flying, and this is the reason why the limiting area of 1 foot ranked the highest score of 3. Finally, the operation of the overall system must be manageable with the flight controls, and this is the reason why the compatibility of operation ranked the score of 3.

There are, however, some requirements and specifications that compete. For example, lightweight and durability are competing. The lighter the weight, the less durable. Fortunately none of the top priority specifications explicitly compete with each other. For the example posed, the product doesn't need to be very durable, but it needs to be especially lightweight so the aim will be to meet the weight requirements and to try and make it as durable as possible in doing so. Most of our highest scoring specifications work hand in hand. For example the specification for weight and center of mass. If design keeps the product small and lightweight there will be less change to the center of mass of the drone system.

Concept Generation

The team used a three stage divergent approach to generate various concepts. In between each generation pugh charts were used to converge on a narrower scope for the next generation phase. Each of the three generation sessions lasted roughly 90 minutes, with the team approaching each with an open mind for ideating both plausible and non-plausible ideas, allowing for the design space to be explored in more depth. Photos from all concept generation sessions can be found in Appendix B.

Concept generation started with the highest level of system design. The team broke our entire system into two categories, short range and long range. Some examples of long range designs include creating a potato gun like structure and launching the tags from afar, using a fishing rod to cast down a tag and real back in the clamp that holds the tag, or simply dropping the tag with some sort of orientation correction device. The short range ideas had examples such as scissor lift style arms that can push the tag onto the whale, using a springboard to allow the drones to fly directly into the whale, and having a vacuum system allow the tag to be gently placed onto the whale.

After selecting our higher order system design (dropping the tag with a stabilization fin) the team moved to the second stage of concept generation. Using functional decomposition, the team was able to organize their work and improve the design process. The team had iterative conversations about each sub component where the team drew diagrams on a white board to illustrate concepts then built off of eachothers designs through discussion. The three subcomponents for generation are the drone release mechanism, the fin, and the tag clamp (each are illustrated in the *Selected Concept Description* section below). The release mechanism brought about lots of promising ideas such as an electromagnetic system and servo and pin ideas. The tailfin ideas were broken up into different ideas for shapes of the actual fins, and designs that involved different styles of moving fins. Lastly the clamp that holds the tailfin to the tag was iterated upon to figure out the best ways to have the clamp release from the whale on impact, while maintaining proper clamping during flight and descent.

The third phase of concept generation utilizes the TRIZ engineering format. The team ran each of the three components by all 40 triz engineering principles. The initial goal was to get five concepts that could be easily be used for low fidelity prototyping. This tool was very successful for the fin and clamp sub-components, however our team struggled to come up with more solutions for the release mechanism. This is mostly due to the release mechanisms having more mechatronic systems be a large factor. The team ended up generating roughly ten of each idea, with a handful of easy to prototype concepts. Overall, many of the TRIZ engineering concepts seemed hard to apply, but ultimately sparked lots of good offshoot ideas that the team will prototype and test.

Concept Selection Process

The group underwent several rounds of concept selection to arrive at the final selected concepts. Each round involved using Pugh charts to score each concept and compare them against each other. One of the concepts was selected as a baseline and had all of its requirements assigned to a score of 0. Then all competing designs would score a +1 if it was deemed better than the baseline and a −1 if it was deemed worse than the baseline.

The first round of concept selection involved weighing the concept of a long range solution vs. a short range solution. A long range solution would involve using the drone to attach the tag from far away and a short range solution would involve flying the drone in very close proximity to the whale (roughly closer than five feet). For this Pugh chart, each requirement had an associated weight from 1-3. The requirements with a weight of 3 were Force Generation and Whale Impact because these requirements were the most important requirements for our project from a high-level perspective, and at this point concepts were being generated on a very high-level. As demonstrated in Table 2, ultimately the long range outscored the short range solutions with a score of 0 compared to a score of −2.

Table 2. Pugh chart comparing long range solutions to short range solutions. The Long Range solution prevailed with more points than the Short Range solution.

Requirements	Weight	Long Range	Short Range
Force Generation	3	0	0
Whale Impact	3	0	-1
Drone Flight Characteristic	2	0	0
Weight	2	0	0
Inflight Operation	1	0	1
Manufacturability	1	0	0
Total		0	-2

The second round of Pugh charts involved comparing the three dominant “long-range” solutions. When brainstorming possible long-range solutions, the team realized that every solution fell into one of three categories. The first of these categories was shooting the tag down from directly above the whale using some sort of generated force. The second of these categories was dropping the biologging tag from above the whale, and using gravity to drive the falling of the tag. The final category was shooting the tag in both the X and Y direction, which would essentially involve using projectile motion. Similar to the last Pugh chart, a scale of 1-3 was developed and the highest weighted requirements were force generation and whale impact as the system was still being viewed from a high-level perspective and those are the overarching highest priority requirements of the whole project. As shown in Table 3, the dropping method was the highest scorer of the Pugh chart with a score of +2, with shooting straight down at 0 and shooting in X and Y with −9.

Table 3. Pugh chart comparing three long range solutions. The dropping method prevailed with 2 points when compared to the baseline of shooting straight down and shooting in X and Y.

Requirement	Weight	Shooting Straight Down	Dropping	Shooting in both X and Y
Force Generation	3	0	-1	-1
Whale Impact	3	0	0	0
Drone Flight Characteristics	2	0	1	-1
Weight	2	0	1	-1
Inflight Operation	1	0	0	-1
Manufacturability	1	0	1	-1
Total		0	2	-9

When functional decomposition was utilized to break the system down into the subsystems of fin, clamp, and release mechanism, different concepts were generated for each subsystem. The first subsystem analyzed was the fin subsystem. The purpose of this subsystem is to assure that the tag falls in the desired orientation when dropped from the drone.

Overall, eight different general concepts were generated for the fin subsystem. When weighing these concepts against each other, a weighing scale of 1-10 was developed. A higher scale was used for this Pugh chart because the team wanted there to be more distinction between the scores of the final concepts. The requirement of correcting its position while dropping was given a weight of 10, because self position correction is the essential function of the fin. Repeatability was also given a weight of 10 because it was decided that the fin absolutely must be able to perform within a strict margin of error across drops. Proximity to the drone was given a weight of 7 since it is not as critical as the other two requirements but still heavily impacts flight characteristics of the drone. As shown in Table 4, the overall winner of the Pugh chart was the baseline rigid fin with a score of 0, with the spring loaded fin notably close behind with a score of −2.

Table 4. Pugh chart comparing different fin concepts. The highest scoring option was the baseline rigid fin.

Requirements	Weight	Rigid	No Fin	Pivot	Retractable	Fabric Fin	Spring Loaded Fin	Food Fin	Only Fins
Correcting its position while dropping	10	0	-1	0	0	-1	-1	0	-1
Weight	5	0	1	-1	0	1	1	-1	1
Proximity to drone	7	0	1	1	1	1	1	0	0
Manufacturability	4	0	1	-1	-1	0	-1	-1	0
Repeatability	10	0	-1	-1	-1	-1	0	-1	0
Total		0	-4	-12	-7	-8	-2	-19	-5

The next subsystem analyzed was the release mechanism. This subsystem is the method of releasing the biologging tag from the drone. A weighing scale from 1-10 was used. Seven general concepts were generated for this subsystem and compared against one another in the Pugh chart in Table 5. The requirement with the highest weight of 10 was repeatability. The group decided that this was the most important requirement because the release mechanism absolutely must be able to consistently drop the tag in a predictable manner for the system to be used as intended. The next highest priority requirement was weight with a scoring weight of 8. This was given high priority because the group wanted to make sure the solution would not significantly increase the payload weight of the drone, which would have significant effects on the overall performance of the system. Additionally, manufacturability was assigned a weight of 6 as a check to make sure that whatever concept selected was reasonable for the team to manufacture when taking the course timeline into consideration. The overall winners of the chart were the pen clicking mechanism with a score of +20, the pin concept with a score of +20, and the electromagnet drop with a score of +16.

Table 5. Pugh chart comparing possible release mechanisms. Pin clicking mechanism and pin mechanism were top scorers with overall +20.

Requirement	Weight	Claw	Trap Door	Pin	Electromagnet Drop	Vacuum	Instant Dissolve Adhesive	Pen Clicking Mechanism
Drone Flight characteristics	2	0	-1	1	0	-1	1	1
Weight	8	0	-1	1	0	-1	1	1
Inflight Operation	4	0	0	0	0	0	-1	0
Manufacturability	6	0	0	0	1	-1	-1	0w
Repeatability	10	0	0	1	1	1	-1	1
Total		0	-10	20	16	-6	-10	20

The final Pugh chart selection was for the clamp subsystem. The purpose of this subsystem is to hold the tag as it is falling and then release from the tag after it has been attached to the whale. Each requirement was weighted on a scale of 1-10. Five different clamp concepts were compared against one another in Table 6. The requirement with the highest weight was repeatable releasing with a weight of 10. This was decided to be of top importance because the clamp must be able to release from the tag or else the radio signal from the tag's antenna will be interfered with and the tag may not be able to be recovered, which would amount to a failure. The next highest priority requirement was securement to tag because that is the other overall purpose of the clamp subsystem; to hold the tag securely until it is attached to the whale. The winners of this Pugh chart were the spring-loaded release with a score of +9 followed by the break-apart clamp with a score of +4.

Table 6. Pugh chart comparing different clamp concepts. The highest scorers were the spring-loaded release with a score of +9 and the break-apart clamp with a score of +4.

Requirement	Weight	"Robot" with small clamping force	Dissolvable Clamp	Spring-loaded release	Break-Apart Clamp	Inflatable Clamp
Retrieval/floatation	1	0	0	0	-1	1
Weight	4	0	0	-1	0	-1
Manufacturability	5	0	0	-1	-1	-1
Repeatable Releasing	10	0	-1	1	1	0
Securement to Tag	8	0	1	1	0	-1
Number of Uses	3	0	-1	0	0	-1
Total		0	-5	9	4	-19

During the selection process the pugh chart requirements initially had a weight of 1-3. This led to the designs all having quite similar numerical outcomes. The weights were then changed to a 1-10 scale. This gave a more clear outcome but brought up some reservations. With more clear outcomes there is a worry that a better outcome is being ignored or losing due to the subjectivity of the pugh charts. While there is not enough time to leave tons of designs on the table there is a fear that subjectively picking the numbers for the weights of the requirements and subjectively picking the -1, 0, or 1 for the designs is eliminating designs that may be better than the ones we can conceptualize easier. However, given the scope of this class and the timeframe there is not a lot of time to test lots of different design ideas, the worries and hesitation still remains.

Selected Concept Description

Based on the process of concept selection in the previous section, the group selected two or three high-scored concepts of each subsystem including fin, release mechanism, and clamping mechanism based on the scoring result of the pugh charts.

Subsystem 1: Fin

The rigid fin design is a hard plastic cylinder with four fins attached to the outside of it. This fin design is inflexible and holds its shape constant. This design is similar to the current version of the fin that has been prototyped, as shown below in Figure 3.

The spring-loaded design is a fabric-attached spring concept benchmarked from the design of the pet tunnel as shown in Figure 5 below. This design can retract and expand upon itself. The design can be compressed to absorb impact and has fins to assist the correction of the tag position while dropping.

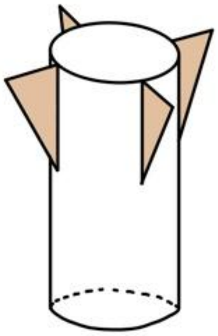


Figure 2. Sketch of the rigid fin design.

Figure 3. Currently existing design of rigid fin concept.

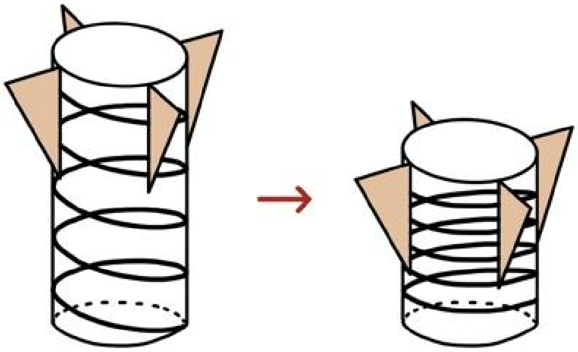


Figure 4. Sketch of the spring-loaded fin design, and the concept sketch if it is compressed.

Figure 5. Pet Tunnel used as the benchmarked model of the fabric based spring-loaded design [8].

Subsystem 2: Release Mechanism

The pin concept of the release mechanism secures the tag at the initial position, when it is on the drone, with a small pin. To release the tag, the pin should be removed by applying external force with a servo motor. This concept is pictured in Figure 6.

For the electromagnet drop concept, the electromagnet can hold the tag at the initial position while the drone is in flight and can release the tag by operating a switch to turn the current running through the electromagnet on and off. This concept is pictured in Figure 7.

The pen clicking mechanism is a further ideation of the pin concept. A ball can serve as the position-locking mechanism for the tag. The ball is connected with a spring that will allow the ball to have a retractable move of back and forth from the locking position as shown in the Figure 8 below. If the ball is retracted from the original position by compressing the connected spring, the tag will be released.

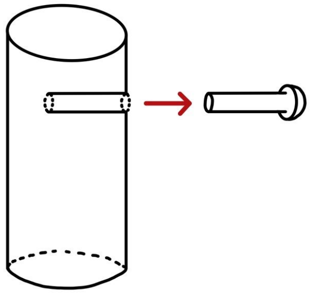


Figure 6. Concept sketch of Pin.

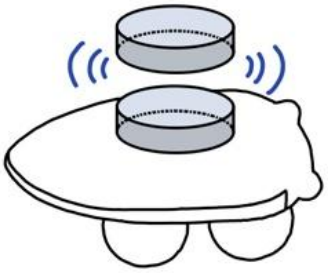


Figure 7. Concept sketch of Electromagnet Drop.

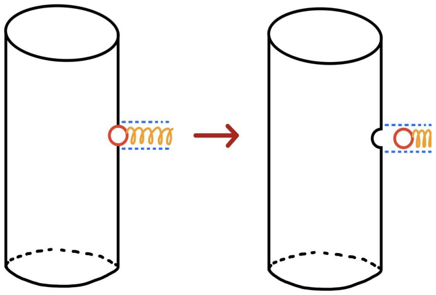


Figure 8. Concept sketch of Pen Clicking (ball) Mechanism.

Subsystem 3: Clamping Mechanism

Robot with Clamping Force concept is designed to have two “fingers” that hold the tag as shown in the Figure 9 below. These fingers will wrap around the underside of the tag and hold the tag in place with a small clamping force. Once the tag hits the surface of the whale, the force of the impact will cause the clamp to pop off of the tag.

The break-apart clamping mechanism holds the tag as one unit at the original setting. When the mechanism breaks apart into two pieces upon impact on the whale, the tag will be released and the pieces of the clamp can be retrieved.

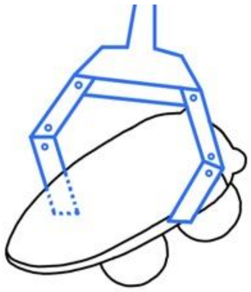


Figure 9. Concept sketch of Robot with Clamping Force.

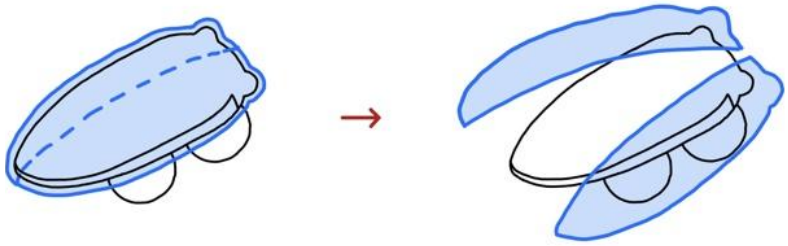


Figure 10. Concept sketch of Break-Apart Clamp.

Initial Engineering Analysis & Testing

Suction Cup Testing

Figure 11. The types of suction cups that were provided to us from our sponsor and used in the proceeding tests: “22” Blue, “23” Blue, Black and White

Table 7. Measured data of the overall cup weight. This parameter would need to be taken into consideration while we are ideation due to the limited payload weight that the DJI Inspire 2 can deliver.

Cup Type	Weight of Cup (g)
"22"Blue	13.9
"23" Blue	12.9
Black	9
White	9.6

While coming up with ideas on what sort of parameters that will be essential to the team's success, it was determined that the forces generated by dropping the tag will be key. More specifically the force generated from the fall from will be key, the pressure differential within the cup after placement also the force that each cup will take to compress it fully. All of these parameters will help the team design an adequate force generation solution to the drone attachment release mechanism. The first test was run with an Instron whoses limits were set to when the suction cups were fully compressed. There was a provided silicon platform that the tests were run on due to its similar nature of the back of the whale 4 different types of cups were used and the minimum input force that would yield the maximum displacement of the cup walls were both measured. This data will help us select the cup that will hold the best while on the whale based off of the height it is dropped from. Soapy water was applied to the silicon plate to promote the maximum possible suction. The second test that was run compressed the cups fully on the silicon plate while a tube was extruded from the base of it that ran into a manometer. That manometer measured the pressure differential. This data point provided the team with the strength of the suction at the maximal compressent of the cup. Similar conditions were used in this test with soapy water and a silicon and acrylic plate.

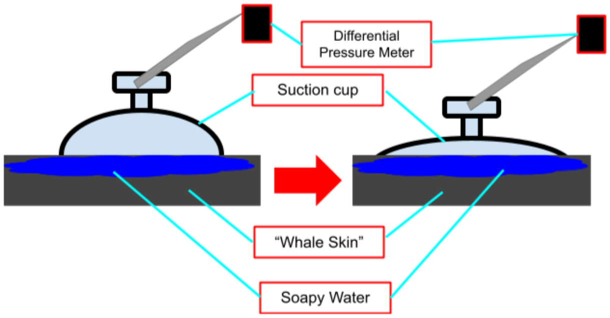


Figure 12. A general schematic of the set-up of the suction cup experiment that measured the pressure differential read from the meter. The cups were completely compressed on the silicon/Acrylic plate to maximize suction.

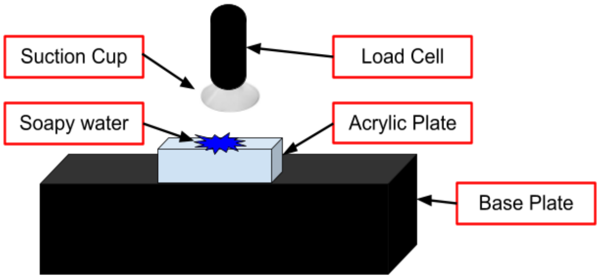


Figure 13. A general schematic of the set-up of the suction cup experiment that measured the minimal force that yields the maximum suction cup displacement. The load cell is attached to the instron that applies a linear force downward.

Table 8. Raw data collected from each of the instron force test tests based off the acrylic plate. The minimal load was the force that the Instron applied to the cup. The maximum displacement was the vertical height that the cup traveled down once compressed. The pressure differential was read off of the meter that will aid in determining the suction force of each cup.

Cup Type	Minimum Load (N)	Maximum Displacement (mm)	Pressure differential (KPa)
"22"Blue	44.5	25	2.3
"23" Blue	105.1	31	3.7
Black	472.33	34.4	1.1
White	260.98	35	1.3

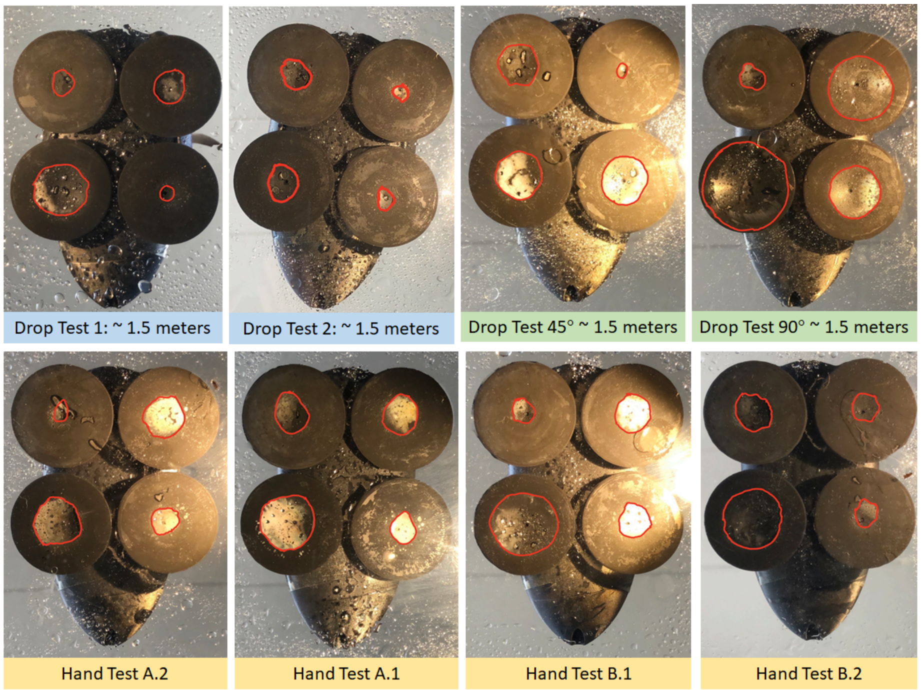
Table 9. Raw data collected from each of the instron force test tests based off the silicon plate that simulated whale skin. The minimal load was the force that the Instron applied to the cup. The maximum displacement was the vertical height that the cup traveled down once compressed. The pressure differential was read off of the meter that will aid in determining the suction force of each cup.

Cup Type	Minimum Load (N)	Maximum Displacement (mm)	Pressure Differential (KPa)
"22"Blue	109.4	25	2.7
"23" Blue	184.34	26	2
Black	56.3	25	1.4
White	51	25	1.2

Fin and Pressure Validation

Drop tests using a simple prototype are used to get a real world sense of how well a fin design works, and to benchmark the pressures achieved from dropping the tag versus the current pole method of tagging.

The first test protocol consisted of dropping the tag, clamp, and fin assembly onto an acrylic plate from roughly 5 and a half feet off the ground (While interviewing our stakeholders, the pilots mentioned not being comfortable flying within roughly five feet of the whales). After each drop a photo was taken of the underside of the suction cups to visibly see how much vacuum was inside each cup. This test was repeated where two different team members would slam the tag onto the acrylic. This was considered analogous to the modern pole method of attaching tags, and is our benchmark for suction. The hand slamming tests were conducted twice for each of the two team members (four total tests) while the drop tests were performed twice with the tag pointing straight down, once with the tag dropped at a 45degree angle, and once with the tag dropped at a 90 degree angle. The off angle testing allows the team to gauge how much correction is necessary for a reasonable vacuum. All of these tests were recorded in slow motion to review the location of the drops and the orientation of the tag when it lands.



Drop Test 1: ~ 1.5 meters

Drop Test 2: ~ 1.5 meters

Drop Test 45° ~ 1.5 meters

Drop Test 90° ~ 1.5 meters

Hand Test A.2

Hand Test A.1

Hand Test B.1

Hand Test B.2

Figure 14: Blue label tags show vacuum created by dropping tags straight down from a height of roughly five and a half feet. Green labeled tags were dropped from the same height but at various angles. Yellow label tags were slammed into acrylic by hand from two different researchers A, and B. Through visuals we can see that blue labeled tests have less air/water inside the suction cup than the average yellow label. This signifies that dropping can be considered comparable to the current method, and a drop style approach is viable for further testing and design.

The second set of testing is based on using slow motion footage to review the correction of a tailfin during the drop of the tag. A tag was dropped from roughly 15 feet with both a 45 and 90 degree angle of release. The increase in height allows for the stability to be tracked over a longer distance, and an easier evaluation of correction. The test did validate the ability of fins and allowed the team to move forward. This test will be used more to compare different fin designs for future testing.

Concept Analysis and Iteration

The three sub components of our system will need to be analyzed separately in order to develop a better system. Some analysis that will be done on the fin design involve fluid dynamic simulations or calculations to determine the stability of the system. We will also work with CAD models to manipulate the center of mass for the fin to optimize the stability of the falling tag. Real world drop tests with slow motion video will validate the optimization of the fins. The clamp's force to detach from the tag can be calculated using a spring balance, and the required clamping force can be found with inertial analysis of the system in flight. These can be used for finding different variables such as the buoyancy needed for the clamp to release underwater, if the team decides to go down the route of a buoyancy release. This would necessitate tests on how much force it takes for the tag to release, then a buoyancy analysis on both the clamp and the fin design. This can also be tested quickly by placing the clamp and fin underwater. Lastly the release mechanism will need to be able to securely hold the tag system in place during flight. Whatever system we create will have to be able to withstand the weight of the tag, the inertia of the tag during flight, and be able to release at great distances. While not as much engineering analysis will be applied, the team will stress test any components as the course progresses to make sure the system is robust.

The greatest design challenge at the moment is going to be testing and finding ways to implement incredibly long range mechatronic solutions for the system. So far even the most rudimentary clamp and fin designs that have been tested are performing considerably better than expected. The other issue for our team could come in the form of source materials. Some of our solutions involve using fully biodegradable materials, which can be harder to acquire. The expertise of professor Shorter and the engineering team at Ocean Alliance will both be useful when it comes to trouble shooting many of these problems.

The overall main design drivers come down a lot to the functionality of the overall final product. If our design can satisfy our top requirements and specifications, we will take it and run. Those main points will address the attachment of the tag to the whale after the drop, this is the main goal of our project. The main difficulties about the design range from the feasibility of the design to the implementation of it. The scope of the class will give us limited time to prototype and create our ideas. The major problems that we anticipate is our design mechanism failing or not dropping it in a good enough manner to attach securely to the whale.This will be addressed by doing slight redesign of the mechanism that will be simple due to the nature of the mechanism not being complicated. We will have to order out of a catalog (i.e: McMaster-Carr, Grainger, etc.) but it could be difficult for those products to get shipped to us on time. Another problem that could potentially arise is going above the $400 limit set for the class. The more expensive each raw component is the less opportunities we get at prototyping and confirming our design feasibility.

Engineering Design Parameter Analysis

Analysis of Dropping Force

To analyze the dropping force of this system, we first needed to investigate the free body diagram of this system. For our system, downward gravity force and upward drag force are the forces considered. Thus, the total force working on this system, F_{Total}, can be determined as the difference between gravity force and drag force.

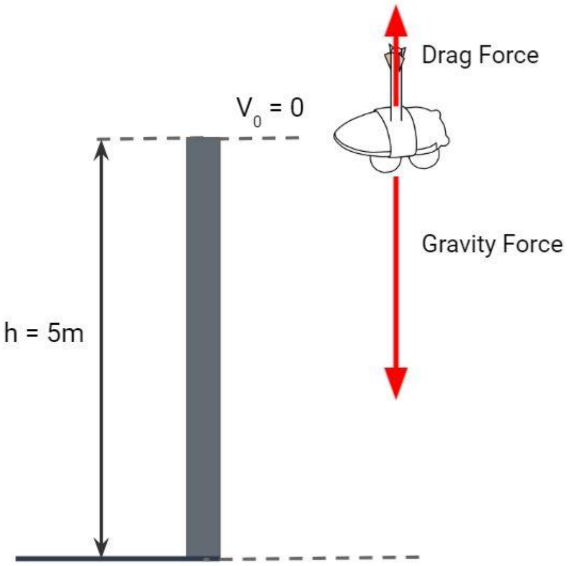


Figure 15. Free Body Diagram of the system.

$$F_{total} = F_{gravity} - F_{drag} = m \times g - \frac{1}{2}C \times \rho \times A \times v^2$$

Above is the equation used to derive total force working on the system, where m is mass of overall system, g is acceleration of gravity, C is drag coefficient, ρ is density of air, A is area of bottom of the tag, and v is the free fall velocity. Free fall velocity of the system was calculated by using the following equation.

$$v = \sqrt{2gh}$$

For estimation of dropping the system from the drone, we set the height as 5m, and calculated accordingly, giving the result of $F_{gravity}$= 2.94N, F_{drag}= 0.0474N, and F_{total}= 2.89N. For our project, the drone will be operated definitely below 30m and the drag force of this system was relatively small as less than 2% compared to the gravity force even up to 30m of dropping height. Thus, our team decided to neglect the drag force when considering the free fall dropping of this system.

Impact Force Vs. Drop Height

The team's theoretical analysis was based on using an Excel model for impact forces vs. drop height, and experiment using Instron to displace the suction cups. We have created an Excel model to vary the mass of the fins and drop height to be able to quickly calculate the optimal drop heights and the force generated for the inserted dropping heights.

As stated above drag can be neglected since it is so much smaller than the force of gravity. To find the impact force versus drop height the energy at impact must be calculated. Due to neglecting drag the energy at impact is the same as the potential energy at the drop height $E_{Drop\ Height} = mgh$ (where E is the potential energy at the drop height, m is the mass of the object, g is the acceleration due to gravity, and h is the height of the object). Once the energy is known impact force can be found by $F_{impact} = \frac{E_{Drop\ Height}}{D}$ (where F is the impact force, and D is the cup depression). An excel model was then built so that the drop height and mass of the object could be varied and the model would return the impact force. In doing so the minimum height to create maximum depression was found to be 16.7 Feet. However, this is quite different from what the real world tests showed.

For the testing with Instron, there is a low impulse associated with this method compared to dropping. Because of this difference in impulse the team wanted to verify a real world drop height and benchmark it against the current pole method. This height will ultimately determine the appropriate range of heights to suggest for drone pilots. The two similar tests are described below with the appropriate findings.

The test setup consisted of a dummy tag with four suction black suction cups, the clamp and fin prototype assembly, a manometer, an acrylic plate, soapy water, and a tape measure. The manometer was attached to one of the suction cups, and the clamp and fin prototype were attached to the tag. This tag assembly was dropped in one foot increments ranging from 1-8 feet onto the acrylic plate that was covered in soapy water. The tag was dropped three separate times at each height to account for error. The error was deemed to be negligible which allows for the use of attaching the manometer to only one suction cup. The results for this test can be found in Table 10.

The second test consisted of the same Tag and Manometer setup, and utilized the same acrylic plate covered in soapy water. For this test, however, the tag was forced onto the acrylic plate by a researcher as quickly and with as much force as possible. Three separate researchers forced the tag onto the acrylic three times each, and the average was recorded. It is seen below under the “Hand Testing” section of Table 10.

Table 10. Test Results of the pressure differential at various heights. The heights were incrementally increased by 1 foot. The last box highlights the pressure differential generated from the hand method that the team used to simulate the pole method.

Height (feet)	3	4	5	6	7	8	Hand Testing
Pressure Difference (bar)	0.153	0.160	0.173	0.180	0.180	0.183	0.159

From these tests our team was able to see that after 6 feet there is a drop off in increased pressure. The results can be extrapolated to higher heights, and the assumption will be made that dropping beyond 6 feet will result in little to no increase in pressure differential in the cups. It is also possible to see that the average pressure from the current pole method is comparable to dropping the tag at roughly 4 feet. With these two benchmarks for height (4 feet being comparable to the current pole method and 6 feet being the minimum height to obtain the maximum pressure) our team recommends that drone pilots drop the tags from at least 5 feet. This is a minimum drop height and will allow for the highest accuracy for dropping, however, drone pilots may not feel comfortable flying this close to any animals and are able to drop from any height above this.

Optimizing Fin Design

The ultimate purpose of including a fin in the final design is to stabilize the tag as it falls through the air from the drone, correcting the position of the tag so that it falls in the desired orientation and is able to stick onto the surface of the whale. When designing fins, there are many different possible shapes and sizes. The team wanted to develop a method of comparing the stability of different fin designs.

Initially, the team found a free rocket design software called OpenRocket. This software is primarily used by hobbyists to design and simulate their model rockets before actually building them. Part of the simulation provided by OpenRocket involves outputting an arbitrary stability number, which characterizes the stability of the rocket design. The team felt that this software was a good place to start exploring different fin designs, as it was a quick and easy way to get some rudimentary feedback on different fin geometry and what may be considered a stable fin design. Figure 16 provides an example of different fin geometries tested in the OpenRocket software.

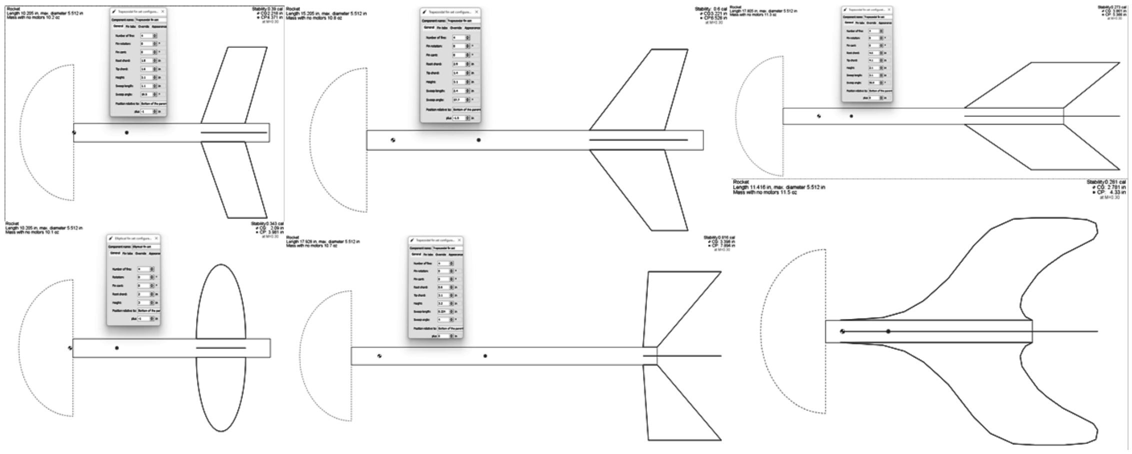


Figure 16. Different shapes and sizes of fins tested in the OpenRocket software, Each of these designs is associated with a stability number that was output by the software and was used as insight into what may be a more stable fin geometry.

Based on the feedback from OpenRocket, the team identified a few fin designs that had potential and prototyped them with cardboard. The arbitrary stability number from OpenRocket influenced the shapes and lengths of the fins prototyped. Once a few of the fin designs were built, slow-motion videos were taken of the tag falling with each of the fins attached. The slow-motion videos were visually analyzed to determine which fin design appeared to be most successful in stabilizing the system.

While the rudimentary OpenRocket software and low-fidelity fin prototyping allowed for some insight into the stability of different fin designs, the team wanted to validate this with high-level analysis and also be able to determine metrics to quantify the stability of different designs. In order to accomplish this, the team conducted a stability analysis that was based on David James "Experimental Validation of Dynamic Stability Analysis Applied to Dart Flight"[9] research paper, which detailed how to quantify the stability of a playing dart. The geometry of the dart was very similar to the geometry of the fins the team had developed, therefore much of the analysis detailed in the paper was applicable to the team's system, with only slight modifications. The team sought help from University of Michigan dynamics professor Noel Perkins[10] to further understand exactly which values to optimize for the fin and how these values would correspond to the stability of the system.

The first value that the team sought to optimize was the static margin. The static margin is the distance between the aerodynamic neutral point and the center of gravity. The center of gravity is the point on the system where gravitational forces act. The aerodynamic neutral point is the point on the system where aerodynamic forces act. The static margin is directly proportional to the moment arm of the moment caused by the aerodynamic forces about the center of gravity. This moment is what causes the fin to upright itself, so a greater moment corresponds with a more robust upright correction. Therefore, the team wants to design for a large static margin in order to create a more stable fin. The location of the center of gravity and aerodynamic neutral point, and thus the static margin, are determined by the geometry of fin. Major geometric factors that influence these locations are the wingspan, the height, the leading angle of the fin, the root chord, and the tip chord. These key geometric features can be found in Figure 17.

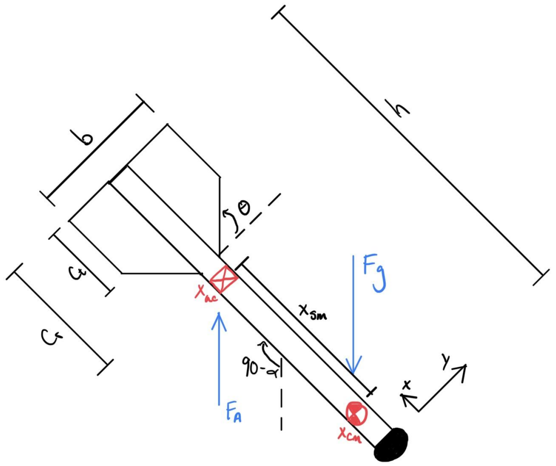
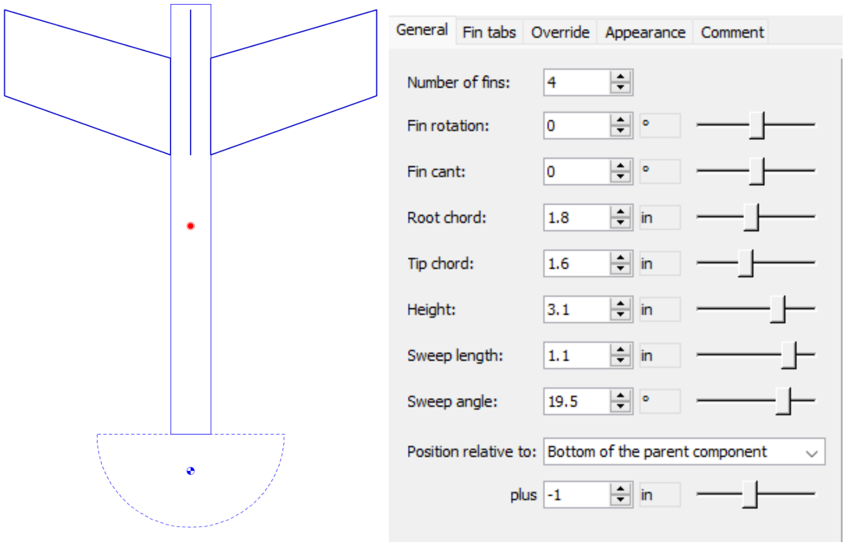


Figure 17. A rough drawing of the fin and its key geometric attributes. X_{cm} is the center of gravity where gravitational forces F_g act. X_{ac} is the aerodynamic neutral point where the aerodynamic forces F_A act. X_{sm} is the static margin. The wingspan is labelled as b, the root chord is labelled C_r, the tip chord is labelled C_t, Θ is the leading angle, and h is the overall height.

Once the team had identified the need to optimize the static margin, Professor Perkins suggested the team also look to calculate the natural frequency, ω_n, and the damping ratio, ζ, and optimize these values as well. The natural frequency corresponds to how quickly the system will right itself into the vertical position from a starting position that is not perfectly vertical. To optimize this value, the team would want to find the largest natural frequency, as this would indicate the quickest response. Along with the natural frequency, the team looks to optimize the damping. The damping ratio relates to how quickly oscillations about the perfectly vertical equilibrium will die out. An optimal damping ratio would be close to 1, as a damping ratio of 1 corresponds to a critically damped system, and a critically damped system means that the system will return to equilibrium without oscillating back and forth about this position.

In order to determine the natural frequency and damping ratio of the system, a differential system was derived from the model of the tag falling through the air directly after being released. The equation was derived relative to the angle of attack, a, which is the angle between the position the tag is dropped at and the vertical equilibrium position. The resulting differential equation is: $\ddot{a} - M_a\dot{a} - M_a a = 0$. In this equation M_a is the stability derivative, which is a function of the static margin, moment of inertia, surface area, and velocity. From this equation, natural frequency can be defined as $\omega_n = \sqrt{-M_a}$ and damping ratio can be defined as $\xi = \frac{M_a}{2\sqrt{M_a}}$.

The team developed an Excel sheet that allowed them to input the different parameters of different fin designs, and the Excel would calculate the static margin, natural frequency, and damping ratio based on the input parameters. With designs that scored well in OpenRocket and appeared to be stable via prototyping as a baseline, the team compared the parameters of different fins in the Excel sheet to compare their natural frequencies, damping ratios, and static margins. Ultimately, the design that achieved one of the highest stability ratings in OpenRocket also resulted in optimal values in the Excel spreadsheet. This fin design is depicted in Figure 18 and was selected to be implemented in the final design. The static margin of this design is 6 cm, ω_n is 1.844 rad/sec, and ξ is 0.922.



Number of fins: 4
Fin rotation: 0 °
Fin cant: 0 °
Root chord: 1.8 in
Tip chord: 1.6 in
Height: 3.1 in
Sweep length: 1.1 in
Sweep angle: 19.5 °
Position relative to: Bottom of the parent component
plus -1 in

Figure 18. The optimized fin design geometry and its key dimensions as defined in OpenRocket software.

Selecting a Release Mechanism

Based off of the Pugh Charts from the concept generation phase, there were two release mechanisms to decide between for the final design: an electromagnet system and a servo-motor based pin system. In order to choose between these two mechanisms, they were both prototyped and tested for their capabilities.

The electromagnet prototype consisted of a small 9V electromagnet, a 9V battery holder, a small circuit breadboard, and a simple receiver and transmitter. The team set up the wiring of the electromagnetic system so the transmitter could be used to turn the system on and off with the push of a button. A piece of metal was attached to the top of the cardboard fin prototype that allowed the tag system to be attached to the electromagnet when the magnet was turned on, and thus be able to be released when the magnet was turned off. Upon testing the releasing mechanism with this prototype, the team found some success in that the tag was typically able to be released once cutting the power to the electromagnet. However, the prototype also brought up some concerns with the electromagnet system. It was not unusual for the metal piece to become magnetized after the electromagnet was turned off, meaning that it would often remain attached to the electromagnet for several seconds after the current was turned off. This could lead to issues when trying to tag whales, as there is a very limited time frame when the whales are breached enough to be tagged, and ideally the system would be able to be released simultaneously with the press of the button in order to tag the whale. Similarly, the unpredictability of when the metal would magnetize and for how long it would remain attached to the electromagnet after cutting power compromises the repeatability of this release mechanism. Additionally, the team realized that this system would require the electromagnet to be kept on for most of the drone's flight, and only turned off at the end when the tag was to be released. This would cause significant battery usage which could easily escalate into becoming a problem of constantly draining the battery and needing to replace it. A visual of the electromagnet prototype can be found in Figure 19.

Figure 19. The fin system is attached to the electromagnet. The electromagnet is turned on and is holding up the fin system via a piece of metal attached to the top of the fins.

The pin system was prototyped by Ocean Alliance in Massachusetts using their Splash Drone. Ocean Alliance provided the team with videos of this system and general feedback on its capabilities. This system (seen below in **Figure 20**) works similar to the electromagnetic system by having an operator press a button on a transmitter and having a receiver trigger the release of the tag. The main difference is that the receiver triggers a servo motor to pull back a pin that is pushed through a loop on the fin and tag assembly. By pulling the pin out of this loop, the tag would be released.

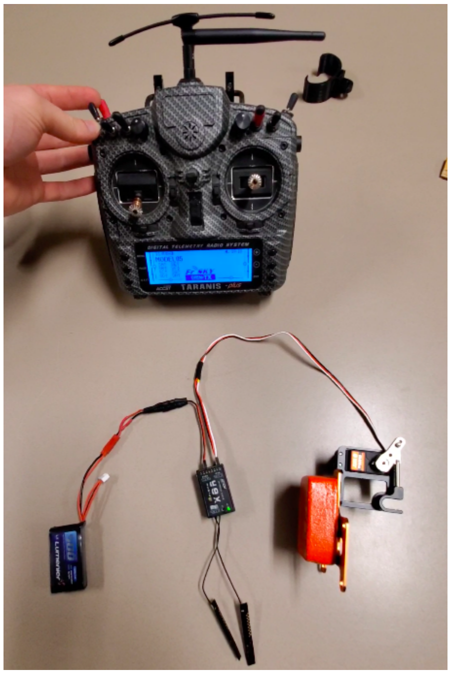


Figure 20. RC Controller (transmitter), lipo battery, receiver, and servo-motor used to power the pin release system prototyped by Ocean Alliance for their Splash Drone.

From watching multiple videos and interviewing Ocean Alliance, the team found that this system was very repeatable and would release the tag almost immediately after the controller button was pressed every time. In contrast to the electromagnet solution, this system would be “always off”, and only need to be turned on for the brief moment that the pin was to be moved. This would have a much smaller impact on the battery needed to power the system and would not drain the battery nearly as quickly as the electromagnet. Ocean Alliance shared some concerns with the stability of their prototype, as sometimes it would release the tag in undesirable orientations which would become a problem for attaching the tag correctly. The team feels capable of designing around this concern by integrating housing for the fin into the design that would hold the fin and tag at a constant orientation before being released. The team will also be making multiple prototypes of this coupling system to account for binding issues upon release.

Ultimately, the pin release mechanism was selected because it appeared more repeatable and energy efficient upon prototyping.

Clamp Design

The team utilized the clamp design provided for all of the tests and modified the design slightly for some prototypes. The modifications were based around the coupling between the fin and the clamp. These alterations were to increase rigidity between the two parts, but was later reverted back to the original design to increase compatibility. The final design consists of two wide sections that wrap around portions of the tag and provide a hold onto the tag.The clamp has four smaller sections that do not wrap all the way around the tag, but rather nest into sections along the top of the tag for keeping the tag aligned. This clamp design can be seen below in Figure 21.

Figure 21. A rendering of one prototype clamp (black), overall function is identical to the final design.

During every drop test performed this clamp design allowed for the clamp and fin assembly to pop off of the tag upon impact. When the tag/clamp/fin assembly lands on a surface, the assembly's momentum causes the assembly to want to bounce. However due to the suction cups the tag remains stuck to the surface, while the clamp and fin assembly have enough momentum and force to break free from the tag. This releasing is due to the flexibility of the wider section that wraps around to the bottom of the tag and the low clamping force that the clamp provides. The team has decided that because the clamping force is high enough for the pole method, and low enough for the fin and tag to be released that it is suitable for drone operations as well.

If given more time for testing, the team would have explored the idea of changing the dimensions such as thickness, width, and length of multiple components to optimize the balance between clamping during flight and release upon impact. However, through verification testing the team found that 3 feet is the required height for the tag to release. Ocean Alliance will be flying around 10 feet, and the recommended height for dropping is 6 feet. Because of this the team allocated more time to optimizing other portions of the design.

Engineers at Ocean Alliance performed tests on the clamps they have to find the pull off force required. Using this pull off force a redundancy can be created using buoyancy, to have the clamp release from the tag when underwater. Ocean Alliance conducts validation tests utilizing a simple keychain float to see if this is a viable option. The team decided to increase the buoyancy of the fin design to increase the likelihood of this redundancy working. However, with the current success of the clamps releasing, this redundancy is something that future engineers will have to experiment with in terms of necessity and feasibility.

Final Design Description

Figure 22. (Left) All three sub assemblies combined with a DJI phantom for testing. (middle and right) The final design for the fin and clamp, with a 3D printed tag.

The final design consists of three sub components. The release mechanism, the fin, and the clamp. Below are the final designs used for testing.Through testing and research the team decided to utilize off the shelf systems so researchers can purchase the release mechanism that interfaces with their drone the best. The clamp chosen is the same design that the researchers currently use for the pole method. For the purposes of dropping tags, the clamp readily pops off the tag after impact with 100% repeatability during testing. Lastly the fin design is based on interfacing with the clamp and a wide array of release mechanisms, and has a geometry that maximizes stability based on fluid analysis.

Ocean Alliance uses the *PL1 Waterproof Fishing Rig* that will interface with an urban drones splash drone. This rig weighs 134 grams and can hold and release payloads up to 1kg and is shown in the figure below.

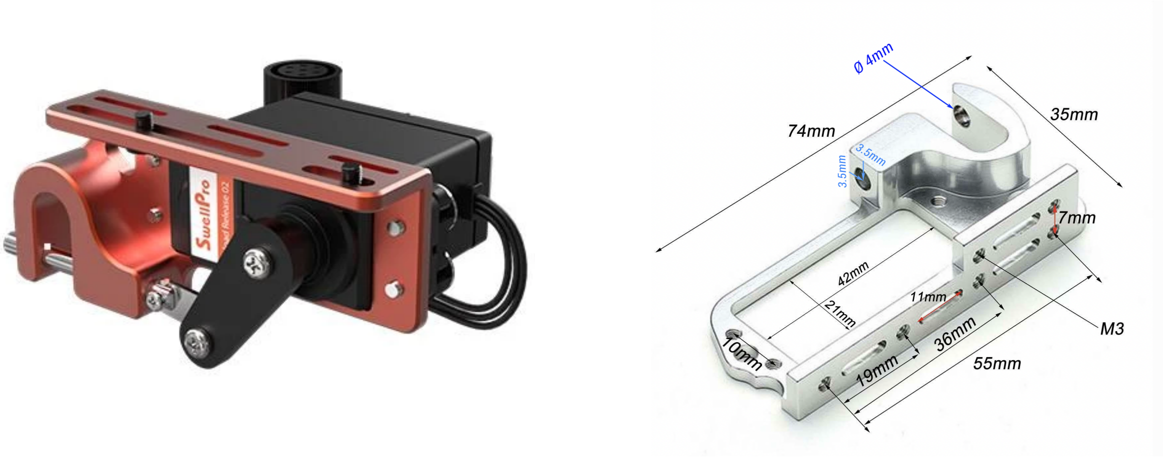


Figure 23. (Left) Image of PL1 waterproof fishing rig. (Right) Dimensions of the aluminum frame. Allow for extrapolation of fin dimensions.

The controls used to operate this system are *FrSky Taranis X9 Lite ACCESS 2.4G 24CH Radio Transmitter* and the *FrSky X8R 16ch Receiver, SBUS, Smart Port - Amplified PCB Antenna.* The transmitter, receiver, and release mechanism are components that Ocean Alliance had before this project started. Many other researchers with drones may either have these components already or can obtain similar components within their budgets and criteria.

The clamp design is identical to the pole method's clamp. The design is shown in Figure X

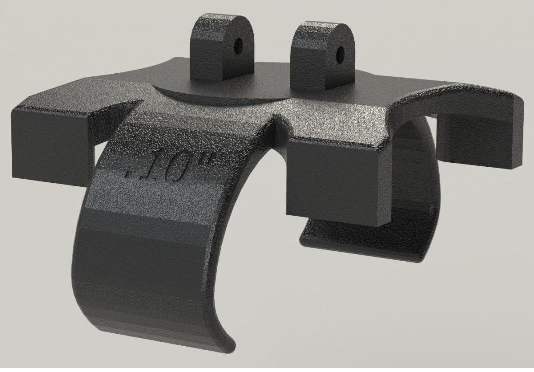


Figure 24. Rendering of the clamp used in both the pole method and the drop method of tagging whales.

Many researchers who currently use Professor Shorter's tags have these clamps from previous expeditions, or will have access to 3D print files to make these clamps. This increases ease and accessibility for researchers to test their own drones and release systems without having to purchase or have new parts shipped. This tag works by having two large protrusions that wrap around the body of the tag and hold on during flight. Four small feet help stabilize and maintain proper alignment on the tag. When dropped the force of the impact causes the entire fin/clamp/tag system's momentum to be reversed. Due to the suction cups, the tag will stick to the target while the now upward momentum of the fin and clamp assembly are launched upwards. The two large arms of the clamp that hold onto the tag have a small enough clamping force that the upward momentum overcomes the grip.

The final fin design has three key features; the compatibility, the buoyancy, and the stability. These can all be seen in the figures below.

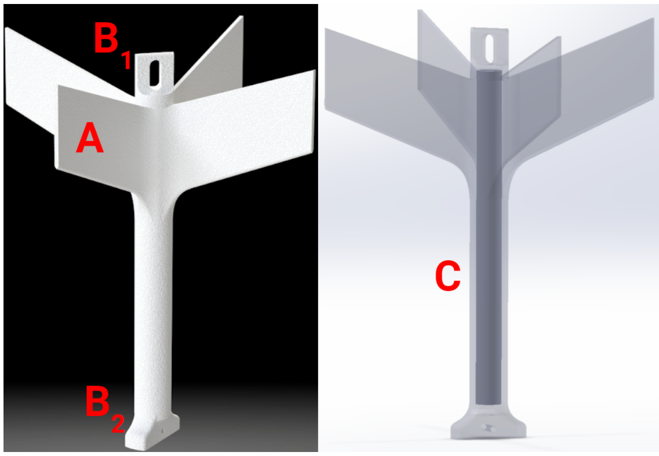


Figure 25. (A) The fin geometry based on fluid analysis gives maximum stability while having a low total footprint. (B_1 and B_2) The top portion of the fin is designed to be compatible with many consumer release systems. The bottom portion is compatible with current clamp designs. (C) The inside of the fin is hollow to increase buoyancy allowing the fin and clamp to be retrievable after tagging.

Making the fin compatible consists of the bottom section being able to slot into the clamp design. Both the width and length of this section are designed to interface with little to no play, creating a rigid system when coupled. The top portion of the fin design has a large opening that goes through a narrow slot. This large opening that is close to the top allows the fin to be slotted into various release systems. The team was able to have this slot into a small release system that would be smaller than most release systems compatible with drones. The buoyancy of this system allows for two different use cases. The first is that if the fin and clamp do not release properly from the tag, the buoyancy will allow the system to pop off after a whale dives. Second, the buoyancy allows the clamp and fin to float, allowing researchers to retrieve the assembly after tagging. Last, the geometry of the fin gives a static margin of 6 cm, ω_n of 1.844 rad/sec, and ξ of 0.922. The team had a target of ξ being as close to 1 as possible. This design is successful in this analysis, and during thorough testing, the tag is capable of correcting from both a 45 and 90 degree angle of attack.

Researchers have noted a few avenues to explore further with these designs. The main area of interest is the retrieval of the fin and clamp design. Eliminating the process of retrieval entirely could be done by using biodegradable materials such as PVA printed parts. Some considerations are that the parts would need to be sealed in airtight containers before being flown to minimize degradation of parts to humidity. The other way of helping with retrieval would be to add dye based markers. Having a compartment for dyes or an attachment would allow the water near the site of impact to be dyed in bright colors allowing researchers to easily find the fin and clamp. The 3d files for the clamp and fin are available for researchers to explore both of these options, and more.

Prototype Description

The team has made many low fidelity prototypes to verify the analysis along the way. The fin design has been made out of cardboard with many different fin shapes to test the position correction, as well as two different dropping mechanisms. A pin dropping mechanism and an electromagnetic dropping mechanism. All of these will be shown below in this section. However, the team plans to make the final design as the last prototype.

Initial Prototype

The initial prototype was given to the team by the sponsors. They deconstructed the attachment mechanism to the pole and taped fins on it, as shown in Figure 26.

Figure 26. Depicts the initial prototype given to the team from the sponsors.

Further Fin Prototypes

The next set of prototypes focused on the fin design and shape of the fins. It consisted of a long cylindrical tube of cardboard, and different fin shapes taped on to test the self correction of the position while dropping for fin shapes. These were used to verify that the results from the analysis on fin design was giving good results. These designs are shown below in Figure 27. The left image shows the fin design that is closest to what is shown in the final design above. This one had the best results for correcting position when dropped.

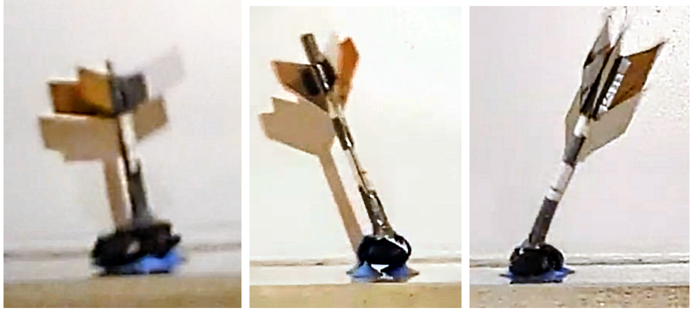


Figure 27. Shows the different prototype fin designs made out of cardboard at the moment of impact after being dropped horizontal to the ground. This angle of impact shows which are better than others.

Dropping Mechanism Prototypes

The two dropping mechanisms that came out of the pugh charts were the electromagnet and the pin dropping mechanism. The electromagnet was prototyped and turned out to be quite weak. A much larger magnet would be needed. Also the battery consumption was very high and would have needed lots of large batteries making the weight of the apparatus too heavy. The electromagnet is shown below in Figure 28.

Figure 28. Depicts the electromagnet dropping mechanism while it is holding onto the fin design. With a push of the button on the remote shown on the left the magnet will release dropping the fins and clamp.

For the pin method, a servo motor will be used to pull a pin out of a slot in the top of the fin design and the fin apparatus will drop. A similar set up is shown below in Figure 28.

Figure 29. Depicts the pin method. On the left of the picture there is a grey U shaped slot with a pin going through the top of the U. With a push of a button that pin will be retracted dropping the fin design.

Final Prototype

The final prototype that the group made was able to showcase many features discussed previously in the paper. Depicted below is a picture of the final prototype.

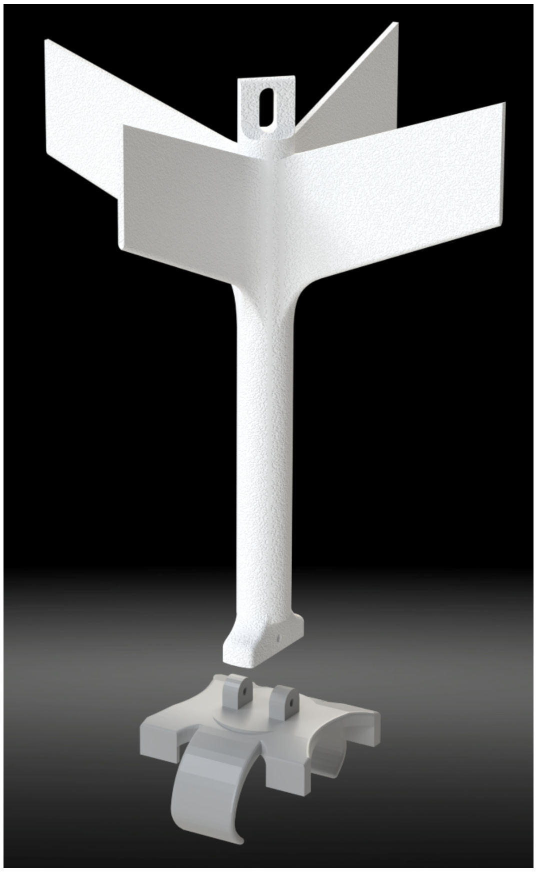


Figure 30. The final prototype of the fin and clamp, made from PLA with a 3D printer.

Figure 30 shows the final fin design in white, and the standard clamp in light grey. It features a long thin shaft that is hollow so that the fin will float once it is detached from the tag. It also has four fins for stability and correcting itself to the upright position when falling. The fin lastly has attachment points on both ends that are designed to fit into the already existing equipment. On the bottom it fits into the clamp that is currently used to attach the tag to the pole in the pole method. As well as on the top it has a slot so that it can be used with any generic servo horizontal pin dropper (example shown above in Figure 29). Most drones on the market have multiple options for a servo pin dropper and therefore maximizing usability of this design. In order to prototype the pin release mechanism, the team bought a simple version of the release system on Amazon.com. This system is manufactured by Top Race and is called the Top Race Drone Clip Remote Control Launcher. This release mechanism came with the servo motor pin system as well as a transmitter and receiver to actuate the dropping with a push of a button on the remote controller. The release system components as well as an image of the release system attached to the fin prototype are featured in Figure 31.

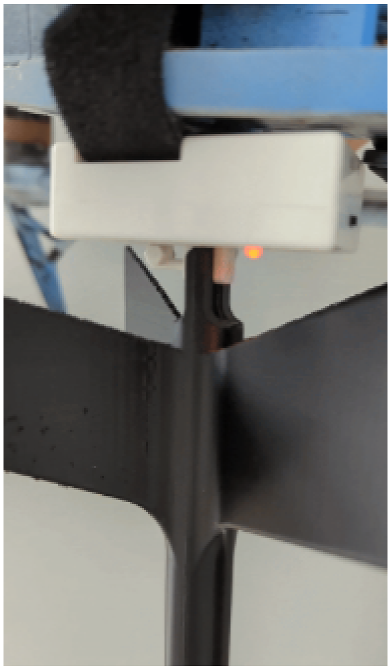


Figure 31. The components of the release mechanism used for the final prototype (left) and the final 3D printed prototype of the fin attached to the release mechanism (right).

The fin and clamp for the final prototype were 3D printed in Professor Shorter's laboratory. The fin is completely 3D printed so it is inexpensive and easy for any researcher with access to a 3D printer to make. This will bring the possibility of using drones to tag whales to all those that want to give it a try, and hopefully increase the world's knowledge of these creatures. The manufacturing plan and bill of materials for this final prototype can be found in Appendix A.

Verification and Validation

By definition verification is questioning if the solution works as we designed it to. More specifically we need to make sure that the design meets the engineering specifications and stakeholder requirements. Validation is confirming that the solution addresses the design problem that we set out to solve. To break these ideas down further the reasons for choosing a particular method are brought into question. We must also look at the pros and cons of faster and simpler methods to answer the same verification or validation questions.

Throughout the design process the team had multiple small scale validation tests such as early prototype drop tests, or visual suction cup tests. These smaller tests helped shape the validation and verification testing performed after the final design was created, and will shape the future tests conducted by Ocean Alliance. The most critical aspects of the design that need to be tested are the dimensions (including weight), the capabilities of the fin and clamp designs, and the ability for dropping to compete with the current pole method. Below are the results from these critical validation tests.

Table 11. Chart highlighting most critical verification tests performed and their results.

Requirement	Specification	Test	Results
Flight Time	Payload weight < 910 grams for DJI Inspire 2 Payload weight < 3000 grams for Urban Splash Drone 3	Weigh each component	Total system weight = 479 grams Release mechanism = 134 grams Fin = 77 grams Clamp = 26 grams Tag = 242 grams
Stability	Attachment angle is ≤ 15° from the vertical when dropped from 6 feet and drop angle of ≤ 30°	Drop test at 45° and 90° at 6 feet	Fin landed with an attachment angle ≤ 15° for 100% of tests with a drop angle of 45°
Tag attachment and detachment	3 out of 4 cups have sufficient force for >70% of attempts	Vertical Drop tests at various heights	4 out of 4 cups had sufficient force for >70% of drops with a height of 4 feet and sufficient force for 100% of drops at 6 feet
	Fin and Clamp assembly detach from tag for > 99% of attempts	Various drop tests	Fin and Clamp released for 100% of tests above 3 feet

Verification testing for weight consisted of weighing each part to the nearest gram on a scale when possible, and using manufacturing specifications for parts that we did not use such as the release mechanism. The release mechanism used for the table above is the one used by Ocean Alliance and is considerably heavier than the release mechanism the team used for testing. For dimensions the team measured the distance from the bottom of the drone body to the end of the tag and found the total distance to be just under 12” when using the test release mechanism. If this distance becomes an issue future engineers can adjust the dimensions of the fin or the placement of the release mechanism.

Tests for fin stability started with rudimentary drop tests and cardboard mockups. The validation testing with cardboard mockups were very successful even with suboptimal fin dimensions. The final verification testing consisted of dropping the assemblies 5 times for each drop angle at the minimum drop height of 6 feet. While the specification calls for a 30° release angle, the team wanted to test with 45° and 90° to account for the team testing in ideal conditions. All tests were recorded and reviewed in slow motion, and the landing angle never deviated above 15° for the 45° release angle. When dropping with a release angle of 90° the tag always landed within 30°, which is below the specification for landing angles, but did allow for all four suction cups to maintain a proper seal for every test.

The team did an early validation test and a later verification test for the suction of the tags when dropping. The validation test described in the "*Fin and Pressure Validation"* section allowed the team to visually compare a simulation of the pole method with a drop method. This validation showed that using our specified release angle the drop method matched or improved on the pole method. Later our team used a verification method with a 0° release angle at various heights to find where a pressure drop off occurred. The team found that at four feet the drop method was competitive with the pole method. After 6 feet the dropping method was consistently better than the pole method and could not achieve any greater suction.

During every drop test the team made note of whether or not the current clamp design was released on impact. The only time the clamp did not release was for drops under three feet. Because the recommended drop height is double the minimum for the clamp releasing the team is confident in this verifying the design. Ocean Alliance also commented that the drop height that will be utilized is closer to 10 feet for any research used by Ocean Alliance. The height of ten feet carries a great enough safety factor that during actual operation the clamp should meet specifications.

The team was not able to complete every validation/verification test that was wanted. However the team has worked with Ocean Alliance to set up future tests that the Ocean Alliance team is capable of performing. The current future tests are as follows: a buoyancy test to see if the buoyancy force is high enough to release the clamp from the tag underwater. A motorboat test to see if the speed of the water flowing over the fin when a whale dives is enough to force the clamp and fin off of the tag. Verification of the release mechanism and repeatability. And experimental validation tests with PVA (water soluble 3D print material) to test structural capabilities of the materials. Ocean Alliance will be going on an expedition in February and if water testing at the facilities in Massachusetts go well, the Ocean Alliance team will have the chance to verify the design with actual whales.

Problem Analysis

In order to create a solution for this problem an analysis must be done to determine what the goals are of the project, and the best way to reach those goals. To do a thorough analysis many factors must be considered, such as: the requirements and specifications, prior engineering knowledge, expected difficulties, and expected solutions.

The specifications that will drive this project are those that have a score of 12 or higher. With the specifications that earned a score of 15 being the critical specifications. The critical specifications are the specifications that if they are not met will cause the project to fail, while those between 12 and 10 points are the specifications that would be great to meet but if are not possible don't mean the total failure of the project.

The specifications of this project are measurable engineering ways of meeting the requirements of the stakeholders. Each specification has been quantified and has a measurable quantity assigned to it. The product will then be tested against the requirements to see if it is able to meet each of the specifications. To be able to analyze each specification the following past classes knowledge will be used.

ME 240, this class is on dynamics, and the product will be moving through space. Forces, moments, and the expected outcomes of them will be of high importance.

ME 382, material science will be integral to this project. For both finding a material to simulate whale skin, and choosing the correct material that will help meet the specifications, an in depth knowledge of how to choose materials will be needed.

ME 320, fluid mechanics is another extremely important class to utilize in this project. Since the drone will be interacting with many possible fluids, it will be essential to be able to measure and quantify the effects they will have on the final product.

ME 360 and 350, controls will need to be utilized for this project. Since our product will need to have some sort of release mechanism there will be some knowledge of controls that will be necessary to precisely time and aim the tag for it to be ultimately placed in the correct spot and position.

ME 250, 350, 450, and 499, the design process is extremely important in this course. Using the teachings from these courses will help keep the project on time and moving forward. It will also help to ensure the best possible outcome at the end of the term. Specific to ME 450, the team has continuously applied knowledge and tools from the Learning Blocks. The team used the learning blocks to formulate a stakeholder matrix, draft requirements and specifications according to the strategies outlined, contextualize the project within society and the environment, and utilized the concept generation tools recommended by the blocks.

There will also be some specialized equipment needed to do further analysis on both the specifications, and the product. An Instron will be used to measure the force needed to push down and fully depress a suction cup as well as pull it off of a material similar to whale skin. Also a pressure sensor will need to be used to measure the pressure differential in a suction cup at different levels of depression. These will then be used to quantify the force that the product needs to generate to depress the suction cups enough to stay on the whale. As there is a PhD student working extensively with suction cups and their effect on soft tissue in Professor Alex Shorter's lab there, her knowledge will be very important to helping setup and run these experiments. With these tests and technical assistance and correct utilization of the machines our specifications will be able to have correct numbers to aim for.

Anticipated Challenges

Even with this prior knowledge and having done the testing there are still a few expected challenges identified at the beginning of the process. This overall problem seems like a very simple problem with a very complicated outcome. For this reason, ideating will be a very hard part of this project, and may lead to going down the wrong path and not realizing it until it is too late. There are also the problems with ultimately getting the tag to stick. Since this will require a force to be applied, it is unknown how the drone will be able to handle said force. To cause the drone to crash or break due to the forces from the release mechanism would be a catastrophic failure of the system.

As the team further assesses and investigates the possibilities for this project some main challenges arise. These challenges will need to be addressed in the next two design review clumps in order to have a working prototype at the end of the semester which is a main goal of this project. The anticipated challenges include: control systems, repeatability issues, and drone flight stability.

For the control systems the design of this system is a large challenge for this project. The drones provided to us have an expected range of multiple miles. Our top stakeholders, Oceans Alliance, hope to be able to use the system a few miles out from the boat or shore. This means that any system we come up with or use needs to have an extremely large range. It also must be able to be repeatable in its function and expected actions. For the drone to be miles away and the dropping mechanism and control system does not act as anticipated this would be considered a critical failure. Since this control system will need to work extremely well and need to be very complex, it will be a large challenge for a team that is inexperienced in such disciplines to design and fabricate something that will work to meet the specifications.

The next issue will be repeatability. Since this system and solution will be used to drop a tag from a drone onto the back of a whale, repeatability is crucial. If the tag is to fall differently than expected, or the tag doesn’t drop at all, all would result in the tag not creating suction on the back of the whale and would be a critical failure. Since repeatability is very high possibility for failure the design against possible failure modes is crucial. The addition of fins that will guide the tag down in the correct orientation for suction is the expected way to mitigate all possible failure modes, however, all failure modes can not be thought of at this point and time, so we as a team must keep thinking and planning for every possible failure mode that could present itself.

Since someone will need to be flying the drone and using it to aim and drop the tag and tag guidance system, the drone will need to be predictable in its flight patterns. It must be stable in the air with the payload attached while it is flying. Since no one on the team has much experience with flying drones whatsoever, it is hard to judge how flight characteristics and stability will be affected by any systems that are added to it. Furthermore, while our stakeholders sent us two drones for reference, neither of them are flyable. This will make testing and validation difficult and close to impossible if there is no way to test our assumptions. Being unfamiliar with the modes of failure in this case, and what will affect drone flight it also makes it hard to problem solve possible ways to prevent failure modes. To get around this challenge as a team we are staying in contact with our sponsors and stakeholders to use their expertise on if our suggested solutions will cause any failure modes. Relying on their expertise is the best way to solve this issue.

The team has now moved on to the final stage of the design process, creating the final prototype and performing verification and validation testing. This will present its own set of challenges to overcome. The main challenge will be in manufacturing the components. While some parts will be bought some will need to be 3D printed. This will create issues on possible support structures that will need to be used and possible failures in printing capabilities. Since the fins will need to be 3D printed and are such an odd shape the challenges due to printing these will come into play. Furthermore with the 3D printing structure of this class, a team submits their design to the printing shop, and then comes and picks it up when it is done, there is not a lot of ability to find out where the printing process went wrong if it does go wrong. This will add complications to fixing the design if that will be necessary. The team plans to get around this by consulting the faculty that run the 3D printing shop if there are problems with the print to get expert help on making a design that will be possible to manufacture in this manner.

The next large challenges will be mounting the device to the drone in a way that will not negatively affect the way the drone works. Since the drone the top stakeholders sent is decommissioned there is an added layer of complication on whether or not the drone will be able to handle the attachment method chosen. There is also no way for the team to be able to test what attachments to the drone hurt its ability to fly or be controlled as expected. The plan to deal with this challenge is to send the design CAD and manufacturing plan to the top stakeholders and have them try the prototyped design on a working drone. This will allow for the final testing of if the design will work in the real world, and have the stakeholders see what the team has come up with for possible last minute feedback.

Discussion

Given more time and resources, the team would have explored certain areas of the problem in more depth. One question that the team would explore further is the effect of the turbulent air from a fully functioning drone on the system overall. As the team was not able to test the system with operating drones, the team would like to collect more data by testing with flying drones if the group had the appropriate time and resources. In that way, the team can analyze possible effects to the system while using the actual operating drone and perhaps alter the design to address any effects. Drop testing and correction tests can be done with actual flying drones, and turbulent effect analysis can be performed. These analyses will help to design the system further to meet the requirements of the purpose of the usage.

The true strength of the design is that it meets the requirements that sponsors expected, and the group was able to prototype and test the system to verify and validate. The process of verification and validation proved that the fin system works to reach the goal of the project. Another strength in the final product is its simplicity and adaptability; the final product is a fin with relatively simple geometry, and it is easy to adapt and make quick changes to its design. This is a strength because any user of the product can make simple changes to account for any problems they may run into when using the product. As previously discussed, one weakness of the design is the lack of testing done with actual flying drones. As the team were not provided with actual operating drones, the possible analysis of turbulent air caused by moving blades is missing. The team produced the design under the assumption that conditions would be ideal as the stationary drone that was used for validation testing. Designing for this assumption could potentially be a weakness if the design does not work the same way in nonideal conditions.

The group could have re-design the fin to include a spring-loaded system which scored the second on the pugh chart (Table 4 on page 15) after the rigid fin design, and prototyped it along with the testings to compare with current rigid fin design. During the prototyping stage of the design process, the group was not able to prototype this type of fin despite selecting it as a possible concept because of the time constraint. The spring-loaded fin has potential design features that could be beneficial to the final product, such as a fabric-attached spring can be compressed to absorb impact and has fins to assist the correction of the tag position while dropping. If the team were to redo a part of this project, this concept would be prototyped and tested with verification and validation rather than not being able to proceed to prototype after the concept selection phase.

The fin could also be redesigned to be more bouyant in ocean water. The present design relies on the hollowness of the shaft of the fin to keep the entire system afloat once the tag has been placed. The problem of buoyancy could have been explored more thoroughly throughout the design process. Different material elements, such as incorporating foam into the final design, would have been worth exploring to ensure that the product would never sink. Adding more buoyant materials could guarantee that the system floats on the surface of the water more easily compared to the current hollow PLA design. This improvement could only be beneficial to the end users, as creating the most buoyant system possible would result in the users being able to retrieve their system every time and minimize the risk of the fin sinking and thus being unrecoverable.

Recommendations

While the team was able to address and test many elements of the design throughout the semester, due to the timeline and resource constraints there are a few elements that remain untested and subsequently potential redesign opportunities in the future. Without a fully functioning drone at the team’s disposal, all testing was conducted using the drone as a stationary object and the prototype was never able to be tested with an actual operating drone with moving blades. The group would recommend that Ocean Alliance test the final prototype with one of their fully functional drones and test that the fin and tag are still stable and able to fall correctly when affected by the turbulent air and motion from the drone. The team expects the fin subsystem to be fairly stable during flight due to the tight fit of the fin inside of the pin release mechanism. However, if the motion of the drone greatly affects the stability of the fin/tag, then the group recommends a slight adjustment of redesigning to the system. The recommendation would include adding additional housing around the release mechanism that the fin could fit snugly into. This would add additional support for the fin subsystem as the drone is flying, and would keep the fin in the desired, stable position until the drone reaches to the desired spot above the whale and it is dropped.

Another design element that the team did not address during the design process is the retrieval of the system once the tag has been placed on the whale. After performing their functions, the fin and clamp subsystems are designed to float in the water. It is important that users retrieve these parts because it will save their money by reusing them and also will not be contributing to any pollution of the ocean ecosystem. The team did not specifically address this function of the system throughout the design process, aside from designing for buoyancy. One recommendation that the team has for users is to 3D print the fins and clamps using brightly colored PLA rather than neutral colors. This allows for the parts to be easier to spot from a distance in the water. If the parts are difficult to retrieve using a net, then we would recommend a slight modification to the fin that includes a loop that can serve as a place to hook the part. A hook can be placed through the loop on the fin, and then the part can be retrieved by reeling in the hook.

Conclusions

Professor Alex Shorter and the whale conservation group Ocean Alliance have begun collaborating in an effort to create a method of deploying biologging tags onto whales using drones. This method will replace the current system of getting close to the whales in small boats and tagging them using long poles. The motivation behind creating a new drone-based mechanism is to reduce any disturbance to whales associated with the current biologging process and to create a dependable method of tagging whales. Important stakeholders in this project include Professor Shorter and his biologging team, Ocean Alliance, and the whales themselves. Secondary stakeholders include the greater marine biology community and other groups that work in and around the ocean areas that whales inhabit.

The responsibility of ME 450 Team 28 is to design a mechanism for attaching suction-cup based biologging tags onto the whales using drones. The biologging tag to be used has been provided by Prof. Shorter and was developed in his lab. Ocean Alliance has provided two drones, and the mechanism can be developed for use on either or both of these drones. The team has weekly meetings with Professor Shorter and Ocean Alliance, during which we interview the stakeholders and gather information relevant to the development of the project. Relevant information that has informed the formation of our requirements and specifications have come from these meetings, academic journal articles, and the drone manuals for the drones that we are provided with. Benchmarks that we can use throughout this project include the traditional long-pole method of attaching tags, and developing technologies such as the Whale Rover. The team can also use technologies in other industries that involve deployment of a product or goods from a drone as a benchmark for our mechanism going forward.

Using the information gathered via research and conversations with stakeholders, the team was able to determine a list of requirements and corresponding specifications. In order to determine which requirements and specifications were most important, each requirement was ranked from 1-5 on a scale of importance and each specification on a scale of 1-3 on a scale of their importance to the requirement. The highest ranking requirements were whale impacts, flight time, and tag suction. To determine each specification's overall importance, the team multiplied the 1-5 requirement score by the 1-3 specification score. When comparing the specifications with a score of 15 (maximum) or 12 (second highest) to the project's likely success, it is reasonable to assume the scoring method is valid for analyzing proposed solutions.

For project analysis, the team applied key knowledge from past courses to evaluate the final design. Key concepts that were used were dynamic analysis to model how the mechanism will move, fluid mechanics to determine how the system will move through air and/or water, system controls for developing any electronics, and knowledge from our design courses on how to best conduct the design processes. The most important experiment at this phase of the process involves placing the suction cup under an instron that will provide adequate force measurement for full suction cup displacement. The team will use that measured force as a goal to get the best suction. Within that experiment the team will measure the pressure differential within the suction cup compared to the ambient pressure to calculate the maximum time the cup can be attached to a surface. The team will drop heights to evaluate the force generated and try to match that force to the maximum. We will prototype different fin arrangements and materials to maximize speed upon drop from the drone.

Three stages of concept generation allowed the team to move from a high level system ideation down to prototype ready sub components. The three stages used the methods such as functional decomposition and tools like TRIZ that the team learned from the 450 learning blocks.

In order to select final concepts, several rounds of Pugh chart analysis were conducted. The first round of these tests allowed the group to choose a long range solution and the next round allowed the group to decide upon using dropping as the method of long range. Once this method was selected, the system was broken into three subsystems: the fin, the clamp, and the release mechanism. Requirements were developed for each of these subsystems and all of the generated concepts were measured against each other according to these requirements. This analysis led the group to several selected concepts for each subsystem.

There were several tests that the team did on an acrylic plate and a silicon pad to look at the parameters of the suction cups themselves. These parameters were: the minimum force that is required to compress the cup fully, the pressure differential that is present in the suction cup when fully compressed. The specification of the force generated was reevaluated to be 184 Newtons per suction cup.

From the qualitative fin tests, the team was able to conclude that a fin would in fact be beneficial for self correction of position when dropping the tag from a long-range above the target. The qualitative pressure validation tests allowed the group to compare the suction generated in the dropping method versus the suction generated in the traditional pole-method. The team concluded that dropping generated just as much pressure, if not more pressure, than the pole-method. This conclusion was drawn from comparing the air bubbles in the suction cups for both methods.

Upon free body diagram analysis of the system, coupled with in-lab testing, the team was able to reach the conclusion that the tag must be dropped from at least 4 feet above the target to obtain the same amount of suction as the pole-method. In order to achieve maximum suction, the operator should drop the tag from at least 6 ft above the target. Ultimately, the team recommends dropping the tag from at least 5 ft above the whale.

In order to optimize the stability of the fin design, the team used OpenRocket software, prototyping, and ultimately an in-depth analysis of the aerodynamic properties of the system. When comparing different designs, the goal was to maximize the static margin, natural frequency, and damping ratio. After comparing different concepts, the final selection had a static margin of 6 cm, a natural frequency of 1.844 rad/s, and a damping ratio of 0.922.

In selecting a release mechanism, the team was motivated by repeatability and efficiency. After prototyping both an electromagnet system and a servo-motor pin system, the pin system was selected because it was more reliable at releasing the fin when desired and would drain less battery.

The final design includes an off the shelf pin-release mechanism, a fin with a total height of 8 inches, and a 3D printed clamp, which snugly holds the tag in place while on the drone and falling through the air. The fin is attached nested by a pin through 2 perturbed stables to the clamp, and together they form a subsystem that will be projected off of the tag upon impact. During flight, the fin will be held in place by the pin and the release system and when the pin is pulled out from a hole in the fin (actuated by the internal motor), the tag will drop.

The manufacturing plan is streamlined to a mix of off the shelf components that the team plans to purchase, parts the team will manufacture themselves and parts that were sent to the team from Ocean Alliance. Each of these acquisition methods are broken then into subcomponents that the pin release mechanism was purchased off the shelf.

In order to verify and validate the final design, several tests were performed using the final prototype. In order to test for the specification that payload weight is under 910 grams, all of the parts that make up the final prototype were weighed, which came to a total weight of 479 grams, thus satisfying the requirement. Several drop tests were performed to validate that the fin was able to correct the position of the tag when dropped from a 45 degree angle and that the tags were able to produce sufficient suction when dropped. Through these drop tests, the team was able to verify that the fin and clamp were able to detach upon impact 100% of the time.

Acknowledgements

During the semester there were quite a few extremely helpful participants in the project. Professor and sponsor Alex Shorter, lab technician Ethan McMillan, Ocean Alliance non-profit, and ME 450 section 7's instructor Randy Schwemmin. All of these people were integral in helping along the term and project trajectory.

First the team would like to thank professor Alex Shorter. He was the sponsor of this project and a huge mentor to the team. The guidance he provided was integral in streamlining the project and making it possible to have a finished product at the end of the term.

Next is Ethan McMillan. He is a lab technician in Professor Shorter's lab that works on designing and building of the biologging tags that are used to tag whales. Ethan was extremely helpful and a vast source of information on the tags themselves and the best ways of rapid prototyping and testing. His information and help sped up the testing processes and allowed the team to move more efficiently through obstacles.

Ocean Alliance organization was another huge influence on the team. They had the real world experience that the team needed to learn about. They are currently using drones to collect snot samples from whales as they exhale through their blowholes. They also tag whales using the current pole method that is discussed in the beginning of this paper. Listening to their rich experience and knowledge gave the team guidance and direction. Since no one on the team has ever worked or done anything remotely similar to collecting samples from or tagging whales it was extremely helpful to get to know and work with those who have.

Lastly the team would like to thank the section seven instructor, Randy Schwemmin. He was a great resource in guiding the team on how to attack design and build problems. He has a wealth of knowledge from being down a similar design and build path many times before in real world settings. He was able to pass along a lot of information in a very helpful and clear manner and the team feels that they learned a lot from him.

Overall the team had a lot of very influential people help them along the way. They are very thankful to each and every one of them that helped and shaped the way the project went. All of

the work and help has led to a final working prototype and hopefully will be able to be used in gathering more information about the whales that it is able to tag.

References

1. Szesciorka, A.R., Calambokidis, J. & Harvey, J.T. Testing tag attachments to increase the attachment duration of archival tags on baleen whales. *Anim Biotelemetry* 4, 18 (2016). https://doi.org/10.1186/s40317-016-0110-y

2. Börger, L., Bijleveld, A.I., Fayet, A.L., Machovsky-Capuska, G.E., Patrick, S.C., Street, G.M. and Vander Wal, E. (2020), Biologging Special Feature. J Anim Ecol, 89: 6-15. https://doi-org.proxy.lib.umich.edu/10.1111/1365-2656.13163

3. Mai Sakai, Leszek Karczmarski, Tadamichi Morisaka, and Meredith Thornton "Reactions of Heaviside's Dolphins to Tagging Attempts using Remotely-Deployed Suction-Cup Tags," *South African Journal of Wildlife Research* 41(1), 134-138, (1 April 2011). https://doi-org.proxy.lib.umich.edu/10.3957/056.041.0116

4. *Inspire 2: User Manual (Version 1.0),* DJI, 2016. Accessed 20 September 2021.

5. Kosuke Tsuchiya, Yuichi Tsumaki, Kyoichi Mori & Ryosuke Okamoto (2019) Whale rover moving along the surface of sperm whale, Advanced Robotics, 33:3-4, 195-206, DOI: 10.1080/01691864.2018.1555058

6. Meynecke J-O, Liebsch N. Asset Tracking Whales—First Deployment of a Custom-Made GPS/GSM Suction Cup Tag on Migrating Humpback Whales. *Journal of Marine Science and Engineering*. 2021; 9(6):597. https://doi-org.proxy.lib.umich.edu/10.3390/jmse9060597

7. Zak, Julia, Seonyoung Han, Max Lipari, Nate Laskinski, Luke Hausch. “Sponsor Interviews.” 16 Sept. 2021.

8. “Dog Tunnel 16.5ft Agility Pet Training Tunnel.” *Amazon*, https://www.amazon.com/Topmart-Playing-Agility-Training-Frisbees/dp/B07GWQ9HPT.

9. James, David, and Jonathan Potts. “Experimental Validation of Dynamic Stability Analysis Applied to Dart Flight.” *Sports Engineering*, vol. 21, no. 4, 2018, pp. 347–358., https://doi.org/10.1007/s12283-018-0279-9

10. Zak, Julia. “Analysis Discussion with Professor Noel Perkins.” 11 Nov. 2021.

Appendix

A. Final Manufacturing Plan

The final manufacturing plan was broken down into subcomponents and then split into 3 separate categories: Off the shelf parts, parts received from the sponsor, and parts that the team will manufacture. The off the shelf parts were purchased from Amazon. The part that the team bought from Amazon was a full pin release mechanism that came with all of the necessary components for the release, including a transmitter and receiver as well as a servo motor pin system. This product is called the Drone Clip Remote Control Object Launcher and is manufactured by the brand Top Race. The buoyancy was accounted for with the 3D printed tag so the team did not end up buying a floating boat keychain. This allows for a backup in case the fin does not release upon impact, the fin's added buoyancy will pull off the fin one the whale dives. The parts manufactured by the team were the fin system. The subcomponents of that system will be the fin itself, and the clamp. All of these components will be produced using 3D printing. Lastly, the team has received a few parts from their sponsor that have helped them through the design process. The sponsor provided the team with a decommissioned drone, which the final product was attached to. The sponsor also 3D printed a biologging tag that has similar weight to the tags that are used in the actual tagging process. A Bill of Materials can be seen in the following Table 12.

Table 12. The Bill of Materials. A summary of the manufacturing plan that lists out the internal part number, the name, the associated costs, what assembly needs to be made, and the material that is used for that part.The fin needed some rework after it was 3-D printed so additional filing tools will be necessary.

Part Number	Part Name	Cost	Source	Assembly Needs	Material
1	Fin	$25.00	3D Print	3D Print	Orange PLA
2	Pin Release Mechanism	$30.00	Amazon.com	Battery and remote setup	Electronics
3	Tag	$0.00	Sponsor	Clipped to Fin	Electronics and Foam
4	Clamp	$5.00	3D Print	Attachment to the fin	Orange PLA
		Total = $55.00			

The details of the assembly plan can be seen in the figure below.

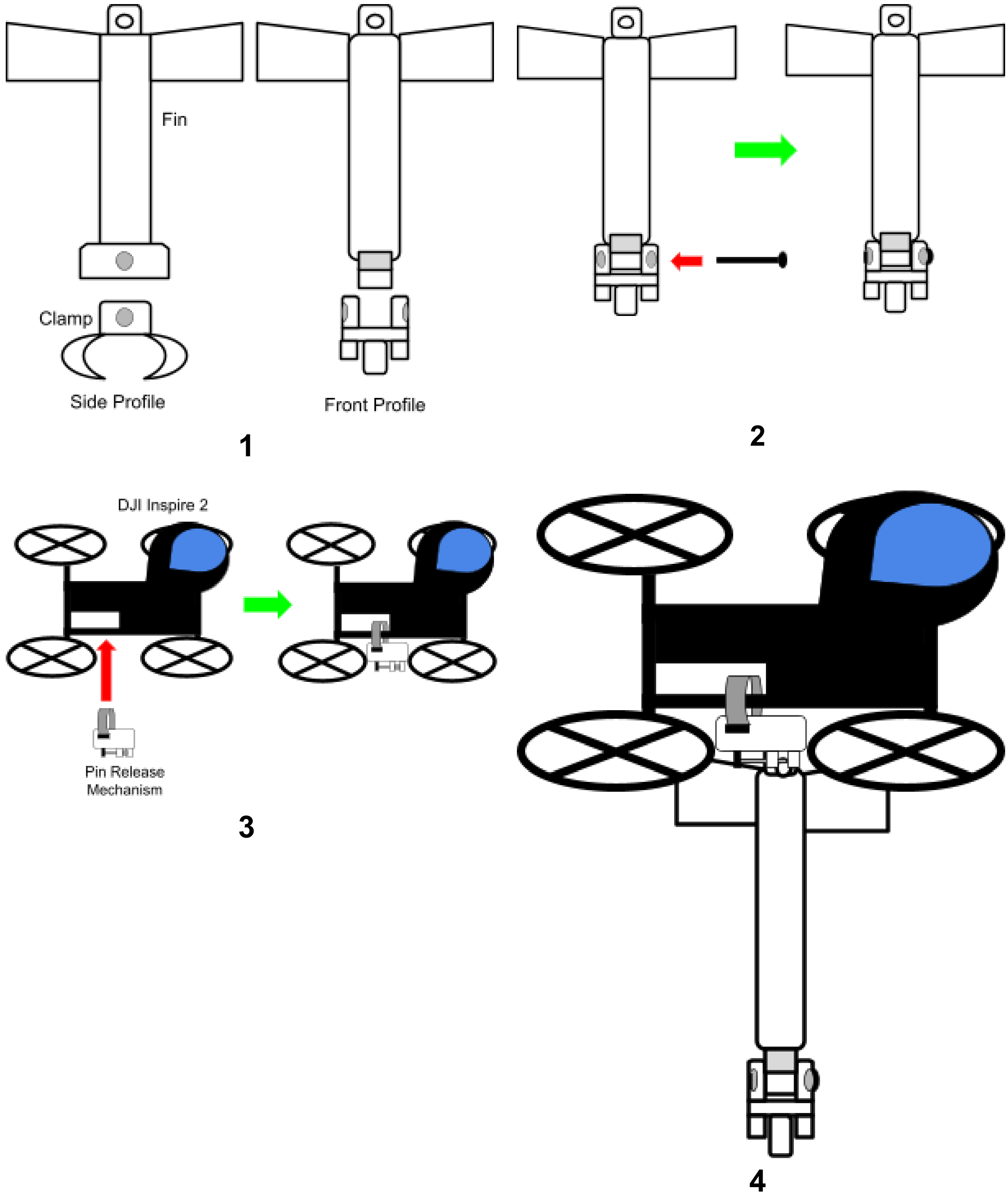
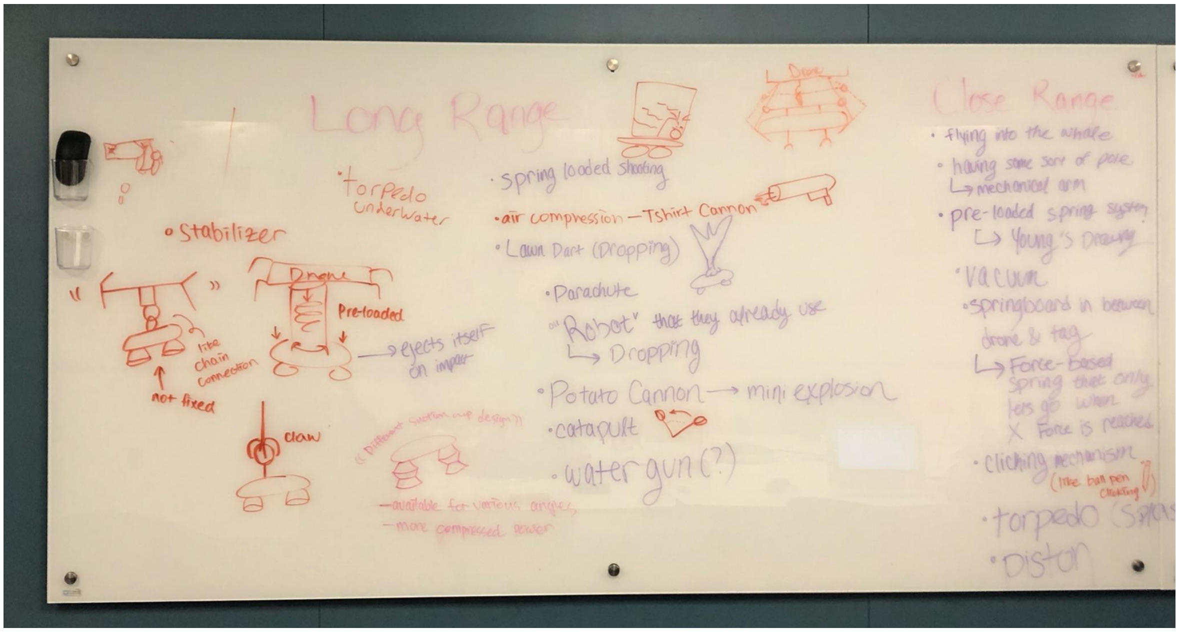
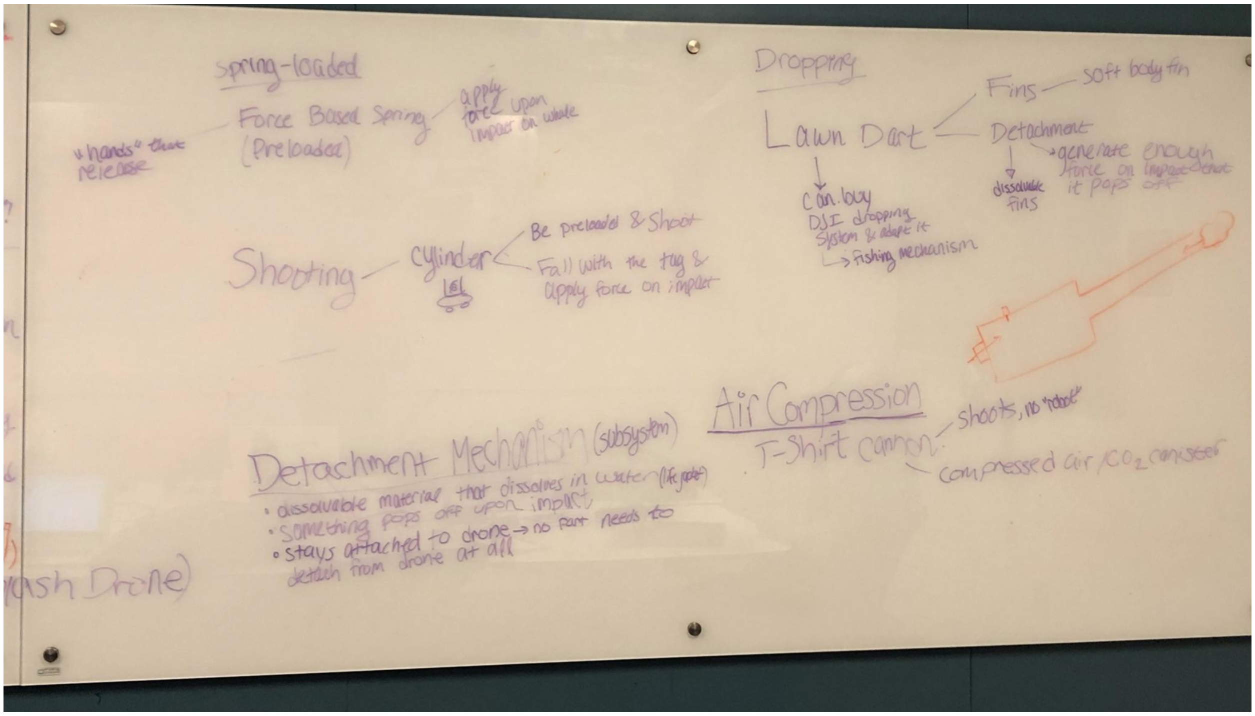


Figure 32. The team took the 3-D printed clamp and fin and nested them together. From there, a pin through fully inserted to nest along the edges(step 2) that held the 2 parts together. The pin release came with a strap that was then secured to the base of the drone (step 3). The finished prototyped can schematically be seen (step 4)

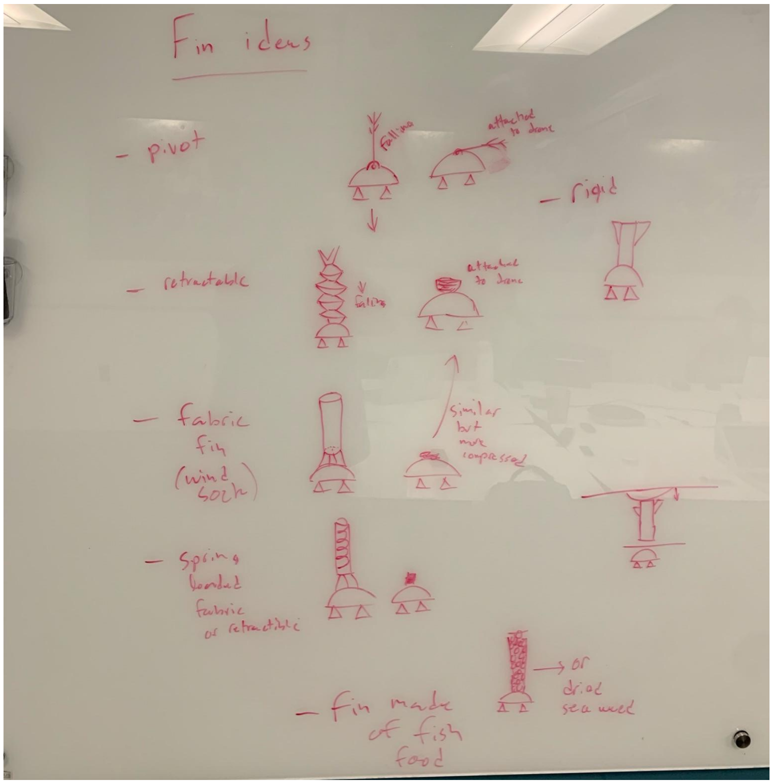
For mass manufacturing, it is relatively straightforward. In the context of this class we were limited to just producing one fully functional prototype. The manufacturing would be in a production line format that starts with an injection mold machine, Due to the simplicity of our fin design we estimate that this machine would cost about $100,000. The market for biologging tags is very niche so to increase margins the molding of the housing of the pin release mechanism and assembly would be done in house. After, a rework table would be inplace to debur any leftover material from the molding process. Next, onto both another work table that assembles the pin release mechanism. Lastly, onto a work table that the pin release mechanism would be attached to the fin. Approximately 5 operators would be needed to run this line, 1 for the loading and unloading of the injection molding machine, 1 for deburring the parts, 2 for assembly of the pin release mechanism and then 1 for attaching the pin release system to the fin. The cost analysis is mainly broken down from the setup of the machine, the material cost and the labor costs. As stated above, the cost of the injection molding machine the team estimates to be $100K. The cost of the material would be an operating cost approximately $3.00 per part. Lastly, if we have a single 8 hour shift, 4 days a week with an average hourly rate of $15 an hour per worker and 48 weeks. The total labor cost per year would be around $115,200. Due to the projected low volume of these parts, the ROI would be so low the team suggests to just 3-D print them for mass manufacturing.

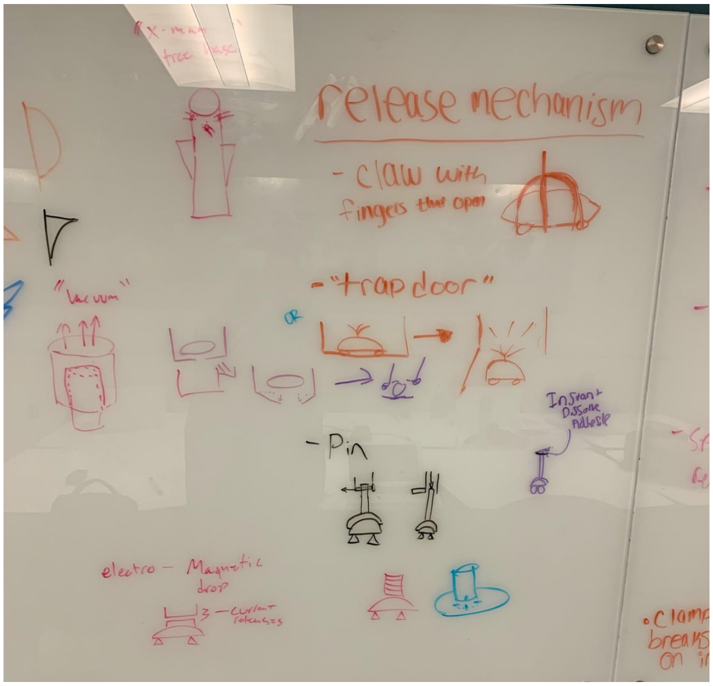
B. Initial Concept Generation Photos

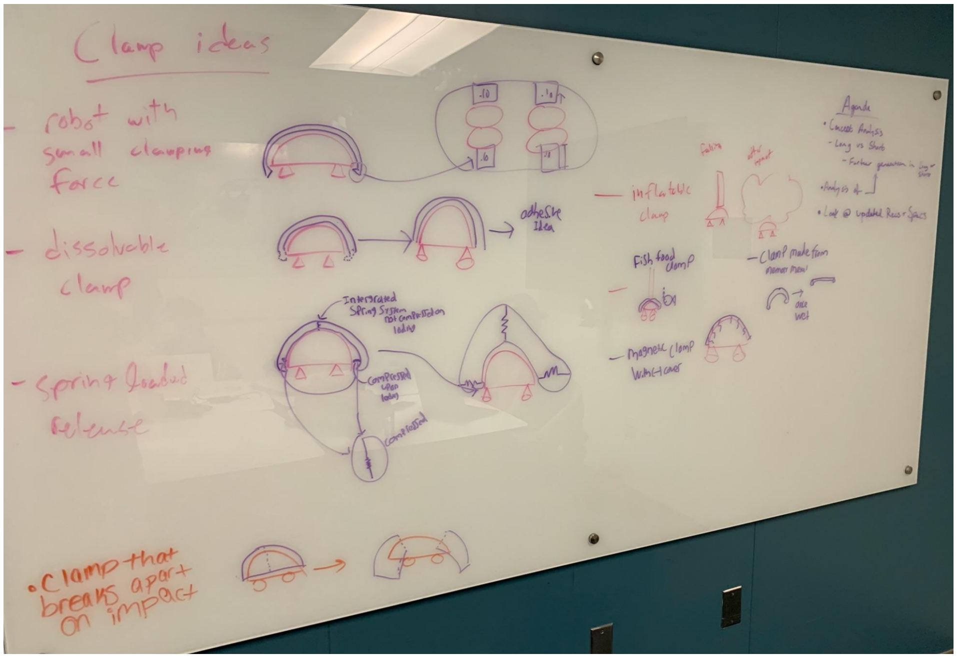




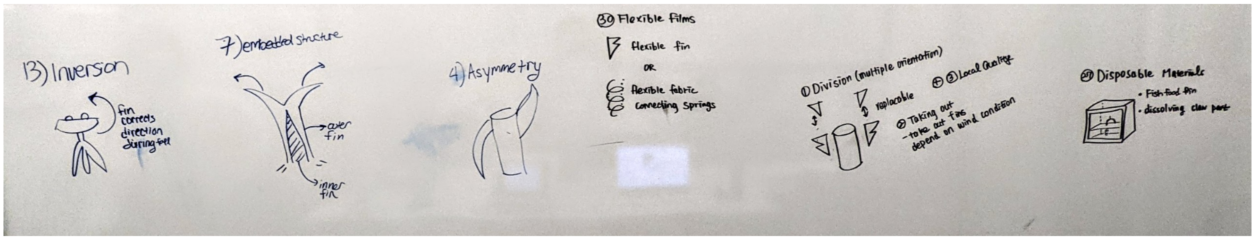
C. Photographs from functional decomposition concept generation session.

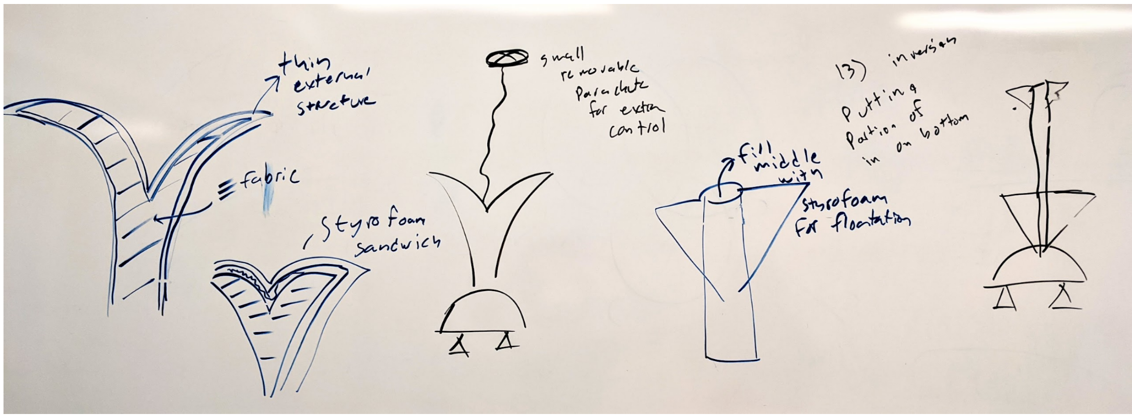


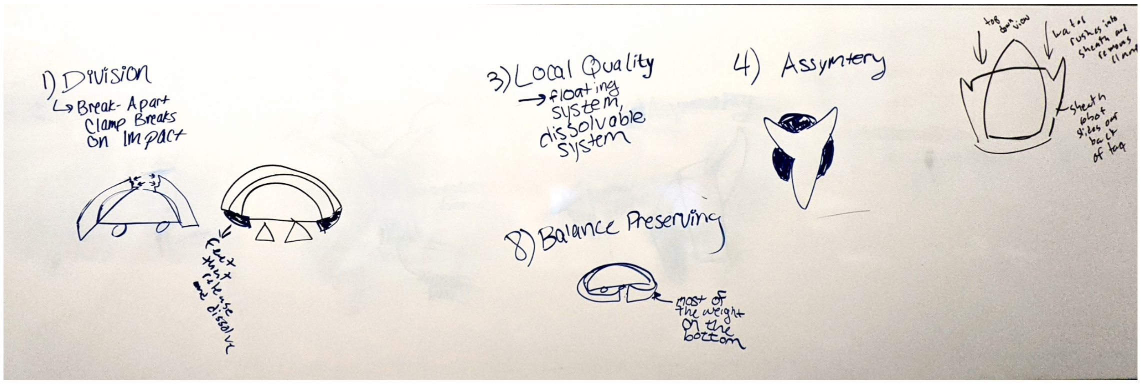



Clamp ideas
- robot with small clamping force
.10
.10
.10
.10
- dissolvable clamp
adhesive Idea
- spring loaded release
Intergrated Spring System not compressed on loading
compressed upon loading
compressed
• Clamp that breaks apart on impact
- inflatable clamp
falling
after impact
Fish food clamp
- Clamp made from memory metal
once wet
- magnetic clamp with cover
Agenda
• Concept Analysis
- Long vs Short
- Further generation in Long or Short
• Analysis of
• Look @ Updated Reqs + Specs

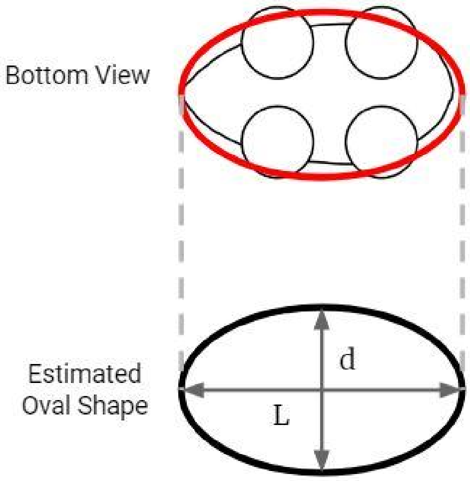
D. Photographs from TRIZ session.







E. Variables for Free Body Diagram Analysis



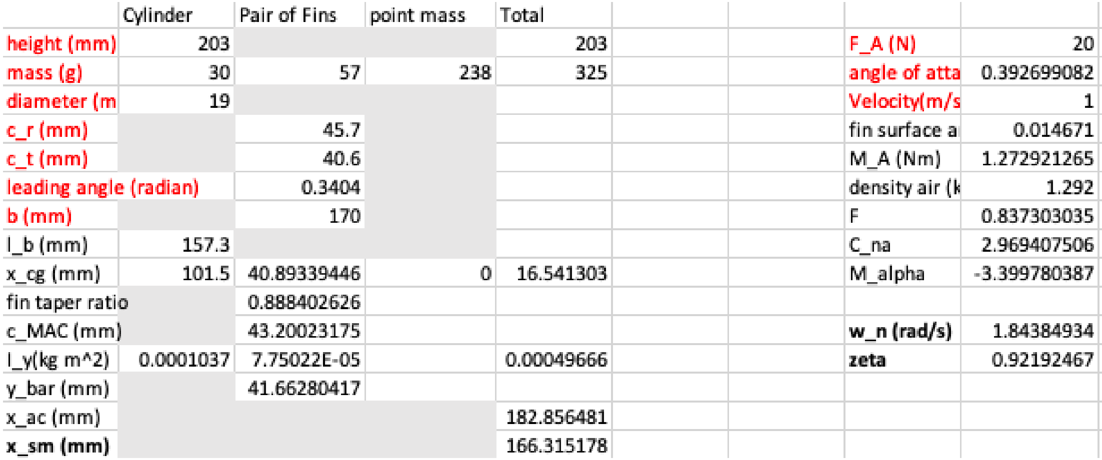
Estimated oval shape was used as the area of facing the drag force. The tag has the specification of $d = 3\ inch$ and $L = 4\ inch$, and by using below equation, the area facing the drag force resulted $0.00608m^2$.

$$A = \pi \times \frac{d}{2} \times \frac{L}{2}$$

Density of air used to calculate the drag force was $1.225kg/m^3$, following the International Standard Atmosphere (ISA) values, 15℃ at sea level.

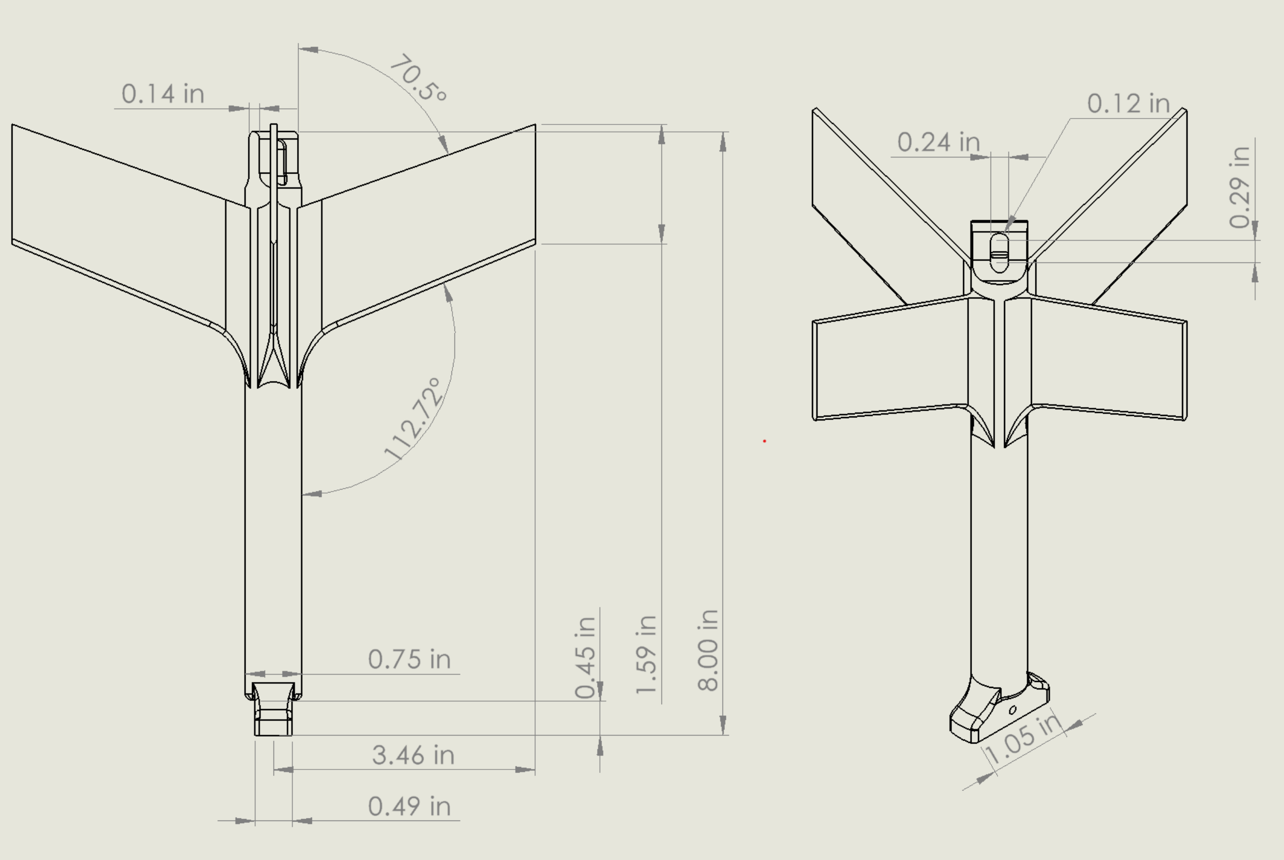
F. Screenshots of the Excel Spreadsheet Used to Aerodynamic Parameters

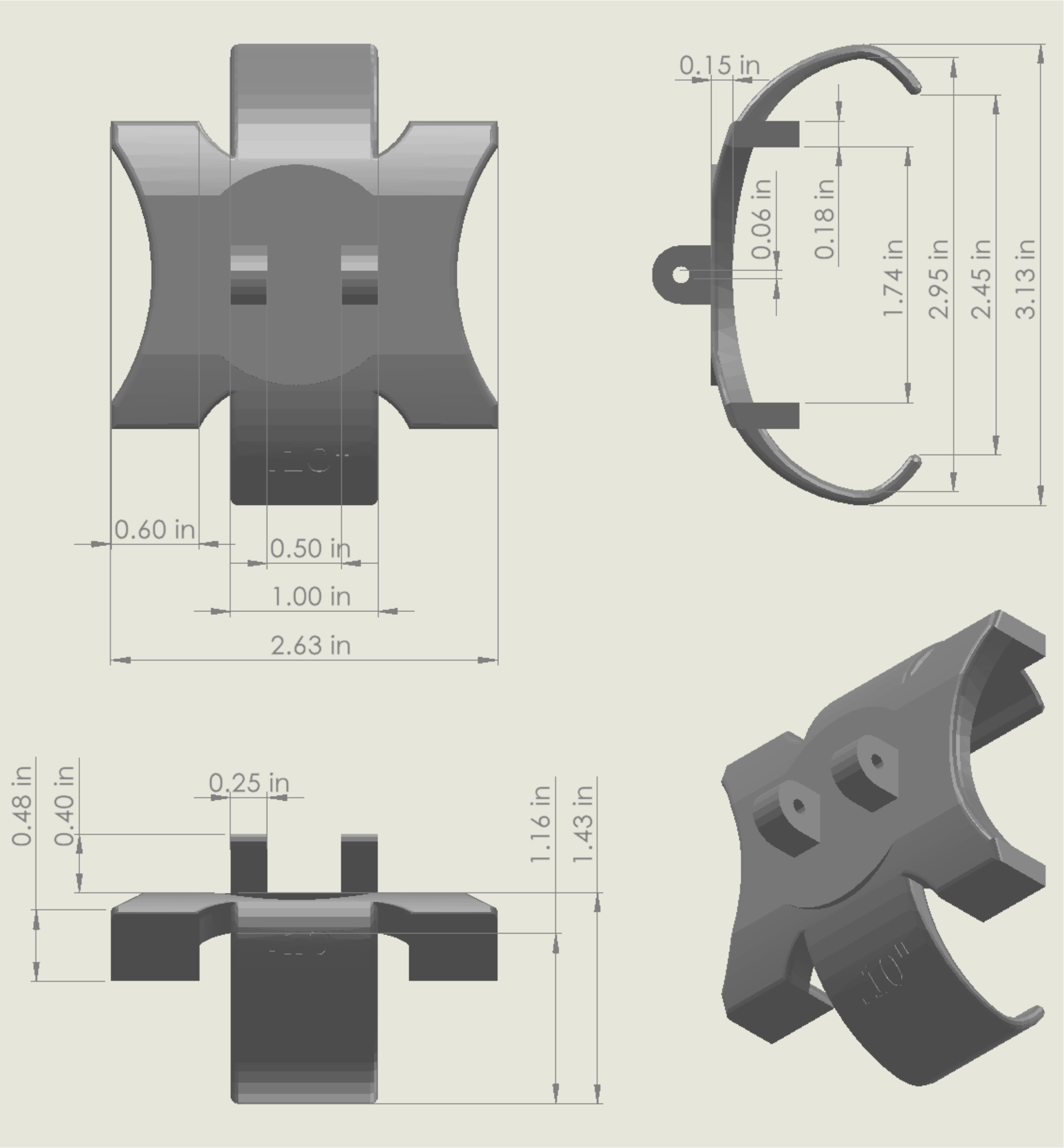
All values in red indicate design parameters to input. All of the values in black are calculated as a result of the input parameters. The bolded values are the calculated values that are ultimately trying to be optimized.



	Cylinder	Pair of Fins	point mass	Total				
height (mm)	203			203			F_A (N)	20
mass (g)	30	57	238	325			angle of atta	0.392699082
diameter (m	19						Velocity(m/s	1
c_r (mm)		45.7					fin surface a	0.014671
c_t (mm)		40.6					M_A (Nm)	1.272921265
leading angle (radian)		0.3404					density air (k	1.292
b (mm)		170					F	0.837303035
I_b (mm)	157.3						C_na	2.969407506
x_cg (mm)	101.5	40.89339446	0	16.541303			M_alpha	-3.399780387
fin taper ratio		0.888402626						
c_MAC (mm)		43.20023175					**w_n (rad/s)**	1.84384934
I_y(kg m^2)	0.0001037	7.75022E-05		0.00049666			**zeta**	0.92192467
y_bar (mm)		41.66280417						
x_ac (mm)				182.856481				
x_sm (mm)				166.315178				

G. Measurements for the fin and clamp designs




0.60 in
0.50 in
1.00 in
2.63 in
0.15 in
0.06 in
0.18 in
1.74 in
2.95 in
2.45 in
3.13 in
0.48 in
0.40 in
0.25 in
1.16 in
1.43 in
10"

Bios

Julia Zak is a senior studying Mechanical Engineering who will be graduating in April 2022. She is originally from Arlington, Massachusetts. Growing up just outside of Boston, she will always have a love of the Boston Red Sox and a passionate belief that the northeast is the best region in the country. In her schooling, she always had more of an aptitude for and interest in math in science, which naturally steered her towards a degree in the engineering field. Julia settled on mechanical engineering because she felt it was very broad and would provide a versatile range of skills that could be applied to any field or industry. After graduation, she hopes to enter the workforce, still unsure of exactly what industry she is looking to enter but has hopes to find a company that does meaningful work and provides interesting problems to solve. Outside of school, Julia loves to be outdoors and her favorite activities include going for runs, hiking, camping, and exploring new places with her friends and family.

Seonyoung Han is a senior majoring in mechanical engineering who is planning to graduate in December 2021. She is originally from Korea, studied in San Diego State University, and transferred to University of Michigan. She is really interested in airplanes as she saw her dad working as a commercial airline pilot, and is currently part of the student aero design team at the University of Michigan called M-fly worked as the manufacturing lead last year and currently business lead of the team. She is the person who wants to contribute to make this world a better place to live, and this is the reason why she chose to become a mechanical engineer as she thinks technology can affect human's life in the fastest way possible. After graduation, she wants to be a stress engineer who can work closely with airplanes and automotive vehicles. Other than school work, Young enjoys working out and running, driving and watching movies. During summer while staying with her parents, she watched the series movies and drama episodes with her mom all night until the morning and this is one of her best memories. She loves traveling to other countries or regions, and she is really good at researching and scheduling the travel plans beforehand.

Luke Hausch is a Senior in mechanical engineering who is graduating in December. He minored in manufacturing and works currently at an automotive/aerospace supplier as a Product Engineer intern. He works in the development of acoustical, thermal and electrical shields that go on cars, planes, commercial rockets, and trains. He hopes to one day start his own manufacturing company. Luke grew up in Westland, MI which is a suburb of Detroit. As far as he could remember he was tinkering with all sorts of mechanical systems: from working on legos to taking apart a refrigerator and putting it back together. His first taste of any sort of engineering was in a 7th grade automotive shop class where he prototyped a new drive system for a model car. Luke has always had an interest in model rockets building them from as long as he can remember. The last one that Luke built before adventuring to the University of Michigan has a C8-5 engine which is a pretty big size. Luke started his Engineering academic career at a local community college called Schoolcraft. Doing really well there after applying and getting into the University of Michigan he was torn between Mechanical and Aerospace engineering. He chose Mechanical engineering over Aerospace due to the fact that a lot of Mechanical Engineers work in the Aerospace industry and the degree as a whole is extremely versatile. In his free time Luke enjoys playing the violin and saxophone and doing a lot of volunteer work. One of Luke's favorite things to do on the weekends is to go "Up North" as Michiganders would say to the woods that my family has a cabin at. Luke loves any outdoor activities that range from golfing and beach volleyball to hunting and fishing. Luke has a goal to play in an amateur golf tournament and bow hunt the mountains of Montana for Elk.

Nate Lasinski is a 5th year Senior in mechanical engineering and will be graduating in April 2022. He is from Ann Arbor, and has grown up being a Michigan Wolverine fan. He became a mechanical engineer because he enjoyed tinkering with toys, and dirt bikes growing up. Often tearing them apart and then taking them to a mechanic to put back together. When learning this adults would often say "You would be a great mechanical engineer." Once being accepted to the University of Michigan school of engineering there was only one clear choice. Nate's goals for the future are simple. He hopes to use what he has learned in the past years at Michigan and prior schooling to obtain a job in manufacturing. Nate will then work for three to five years before going back to school for a masters in business. This will then be used to start a small business or climb the corporate ladder in an existing company. Outside of school Nate enjoys building up his Jeep Wrangler and turning it into an off roading monster. While he doesn't have Jeep projects, Nate likes to be outdoors, cook, and do photography. He is currently taking a photography class, and the first class related to a hobby he has ever taken.

Max Lipari: I am a sixth year Mechanical engineering major with minors in Art and Design and Music Performance. I originally studied as a Music Performance major and transitioned to engineering midway through my third year. I grew up in the Dallas, Texas area but after being in Ann Arbor for so long I call this my home. When I was really young I always wanted to do creative work, either being a chef, or a car designer, or fashion designer. However I never developed enough of an artistic background to pursue the more creative fields. Later in highschool, my physics teacher showed me the world of engineering through experiments in his course. The way I process information seemed to click when it came to thinking about mechanical physics. This and my interest in renewable energies led me to the field of engineering. When applying to colleges I really wanted to pursue a dual degree in Music Performance (classically trained double bass) and engineering, but due to time constraints opted for just engineering in the end. As my time at Michigan has progressed and my art minor has progressed, I have started to realize my passion for art and music still impacts where I want to work. I really love working with people and creating wonderful experiences, so I have been focusing on finding careers in human centered design. My end goal is to merge the worlds of design and engineering. The engineering school has given me the technical skills and background to understand design constraints and how to work with engineers, while my artistic backgrounds have given me critiquing skills and the language to work with artists. My art classes have also given me incredible experiences, such as using science fiction as a tool for critiquing the ethics of emerging technologies. I don’t know where I will end up but I hope it is working with both of these fields one day. For now I will try to graduate as soon as possible and hopefully stay sane in my down time through casual gaming, cooking, playing dungeons and dragons, longboarding, snowboarding, building custom keyboards, finding new inks for my fountain pen collection, and relaxing to LoFi music.