Testing Environment for Deployment of Whale Biologging Tags

ME 450 Team 23

Sponsor: Alex Shorter, Associate Professor, UMich Mechanical Engineering

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Alex Aldighieri

Patrick Burke

Daniel Calvache

Jacob Rochell-Share

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Executive Summary

Researchers are tracking whales' behavior and biomechanics using biologging tags designed and built by Professor Shorter's research team at the University of Michigan. Dropping tags from a drone onto the whale is the preferred method of delivery, but this method is currently inconsistent due to issues with drone height, orientation, drone downwash, and more. Our team is designing experiments and a testing environment to quantify what makes a good drop and test future changes to the system.

To generate design concepts, the team first had to come up with a list of requirements and specifications. We had three main categories of requirements: measuring critical physical characteristics, simulating real-world conditions, and budgets, timeline, and safety. Using these requirements, we used functional decomposition and multiple ideation rounds to select a final list of concepts. Putting these concepts together we created our initial alpha design: a testing structure with fans to simulate downwash and a dropping mechanism that can be set to a variable initial angle. The flight dynamics and attachment quality are measured using a camera tracking system and the suite of sensors (accelerometer, gyroscope, pressure) in the test tag. To manufacture the design we mainly used readily available materials and tools in the x50 shop and employed 3D printing for some of the more specialized components, such as the dropping mechanism.

To test the system after it had been built, we designed experimental procedures to both verify our requirements and describe how a typical test should be set up, performed, and analyzed. Some of our physical requirements can be easily verified, like height and angle variability. For the camera tracking system, multiple group members performed repeated analysis on the same set of drops in order to determine the accuracy and inherent uncertainty of the camera tracking system, which ended up being within our specification of 1 degree of uncertainty. Other requirements are awaiting verification due to issues accessing the data of the smart tag. However, we have been able to use the camera system to show differences in fin performance, which is an important part of the validation of our design. There are also steps that can be taken to improve the system in the future, such as improving the fans to replicate drone downwash and altering the landing plate to prevent damage to the fins and test tag. In conclusion, many important aspects of our design have been verified and the team believes that it can be a great starting point to further develop fin testing and iteration.

Revised Abstract

Researchers are tracking whales' behavior and biomechanics using biologging tags designed and built by Professor Shorter's research team at the University of Michigan. The data collected is used to support conservation efforts and inform our understanding of whales and their ecosystem. Tags are attached to the whale with suction cups and are placed with a long pole or dropped from a drone. The drone method disturbs the whale less but is currently inconsistent and unreliable. The goal of this project is to create an approach to systematically test and evaluate drops in order to quantify what makes a "good drop."

Information Sources

Our project is sponsored by Professor Alex Shorter, Professor in the Mechanical Engineering Department at the University of Michigan. The following information was provided by Ocean Alliance and Professor Shorter.

Driving Problem

Harmful human-whale interactions have occurred due to a lack of understanding of the natural behavior of these animals. Excessive noise and collisions with large vessels could be reduced by gaining a better understanding of the movement patterns of the whales [1]. Specifically, understanding the depth at which the whales travel during different periods of the year and feeding habits can help to revise vessel routes to avoid whale mortality [16].

Initial Solution

Biologging tags that attach on the whale via suction cups were created with sensors that track all relevant conservation data. This data can be used to reduce the disturbance of whales from human interaction while simultaneously gaining a better understanding of the whales' breaching mechanics and ecosystem function. These tags were initially deployed by researchers manually using a 20 foot pole while the user stands on the boat. However, the goal of these tags is to collect purely natural behavioral data and the presence of researchers and the methods being used are causing disturbance to the whales. Consequently, the tags are collecting less accurate data.

Revised Solution

Professor Shorter's research team introduced and tested the idea of using DJI Matrice drones to deploy biologging tags from above to replace the pole attachment method. The drone can be piloted far from the research vessel and drop the tag while flying above the whale. This method allows less disturbance to the natural behavior of the whale. A set of self-detaching fins help the biologging tag to fall more predictably and can be seen in Figure 1 below. However, turbulence induced by the drone propellers is causing inconsistency in the drops and further research is needed to develop the system of delivery for the biologging tag.

The Scope of Our Project

Our team worked closely with our sponsor to create well-defined parameters that describe a “good drop” in a way that can be quantified. Our team is tasked with creating a set of experiments and methods that can be used to evaluate different release mechanisms as they release from the drone and transverse through the air and contact the whale. The most notable variables that influence the quality of the drop are the orientation of the tag (which is heavily influenced by drone downwash), impact velocity, impact force, and pressure differential of the suction cups [1][7]. Also, due to the novelty of the project, it is necessary to provide a platform that can be easily adapted in order to facilitate changes in what data needs to be collected. Our project must also follow the CoE Student Safety Policy [9].

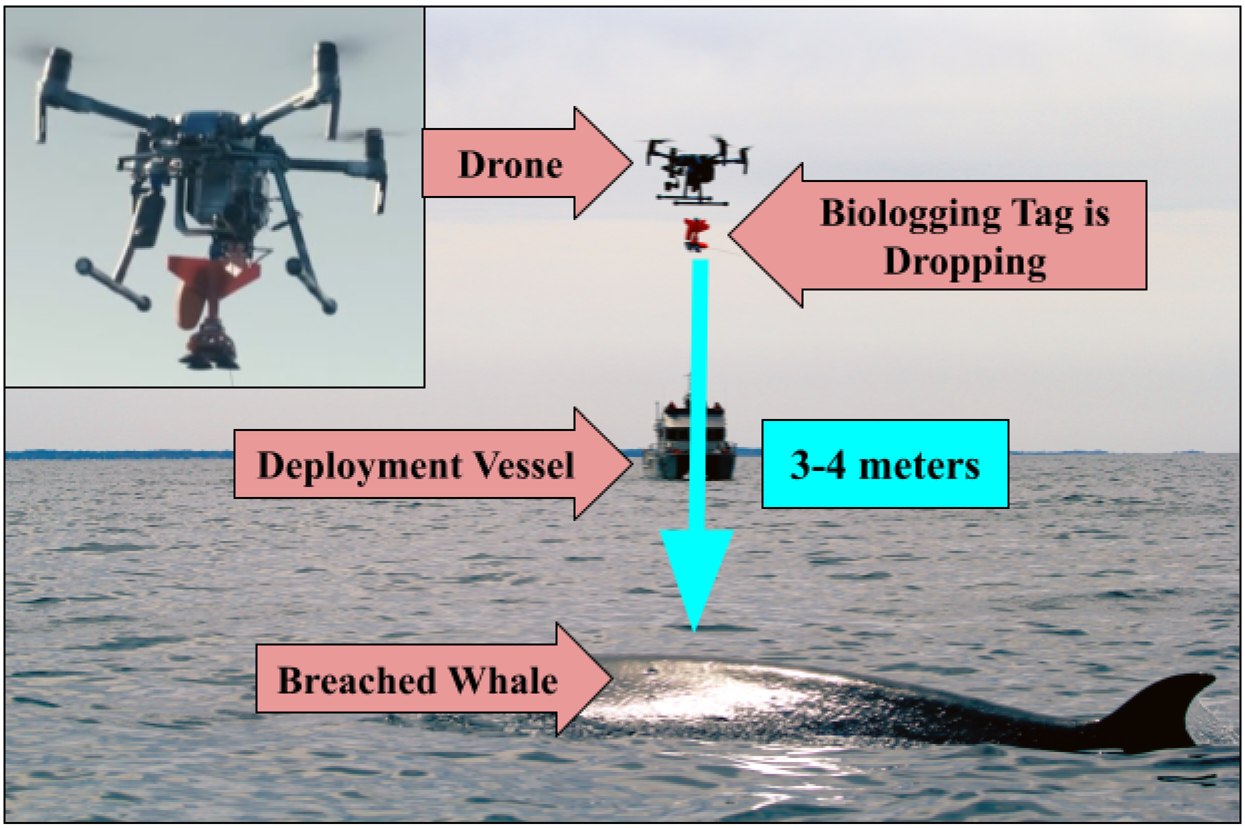


Figure 1. The biologging tag is shown an instant after dropping the biologging tag attachment mechanism. The drone was deployed from the deployment vessel shortly after spotting a surfaced whale.

Design Process

The team is generally following the ME Capstone Design Process Framework for this project, shown below in Figure 2. This framework is split into five stages: need identification, problem definition, concept exploration, solution development & verification, and realization. This framework includes recursive elements as well, encouraging designers to go back to previous stages throughout the whole design process.

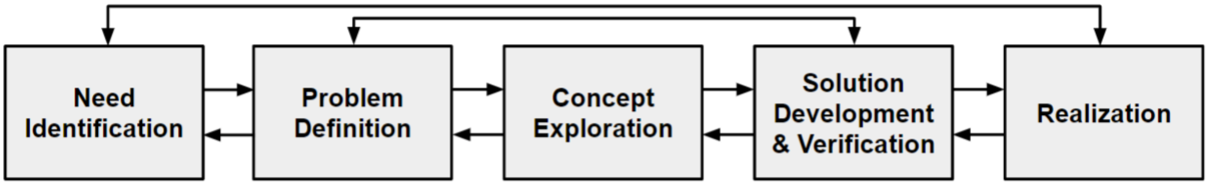


Figure. 2 Design Process Model

However, our process differs slightly from the basic framework because we are placing more emphasis on the later stages. Since we came onto the project after work has already been done, the need for problem identification and problem definition are mostly set and fully explored. For the first design review, our work was focused on understanding the problem space and creating requirements and specifications. In the past few weeks, we have been focused on the concept exploration phase, following a functional decomposition process similar to the one shown below in Figure 3.

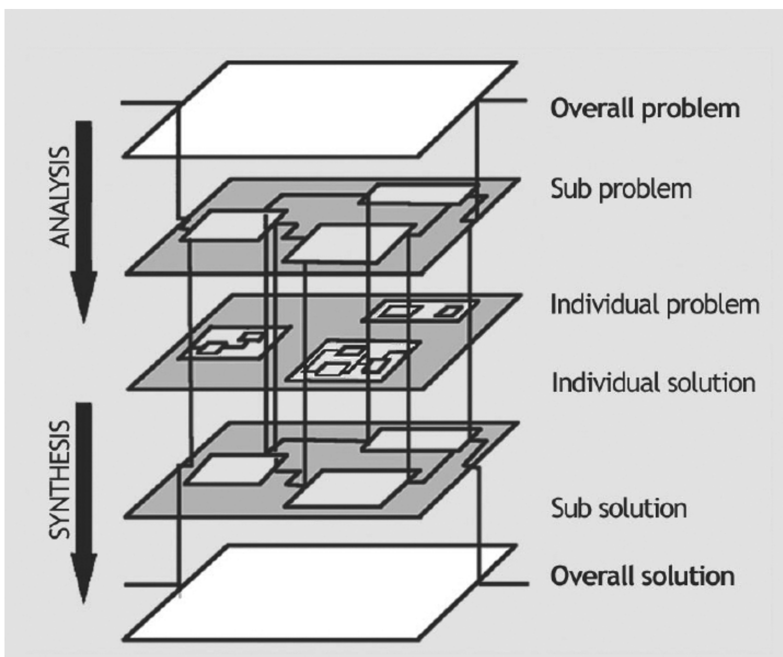


Figure 3. Functional Decomposition Design Process [15]

First, we split up our problem into subfunctions – for this project, each subfunction is essentially a metric of the drop that must be tracked (velocity, orientation, impact force, etc). Utilizing group ideation techniques, we generated many possible concepts that fulfill all the subfunctions of our design and performed multiple down-selection phases to narrow the list of concepts down into a preliminary set that comprises our Alpha Design. The concept exploration activities and Alpha

Design are detailed later in this report in their respective sections. Our next project stage is solution development, which we have already begun. This involves an iterative building, testing, and learning cycle in which we construct the concepts we have selected and start testing and improving the various functions. Solution development also includes the development of experimental procedures for using the test rig. Experimental design can only be completed after we fully understand how all the subfunctions of our design work.

Design Context

To examine what design contexts are important to consider when designing for our project, we first had to identify and organize all of the stakeholders. Stakeholders were placed into three tiers: Primary, Secondary, and Tertiary. Primary stakeholders deal directly with our project and its outcome, secondary stakeholders are indirectly affected by our work, and tertiary stakeholders will be impacted the least by our project. Stakeholders were also placed into 6 categories to better illustrate their relationship with the project. These categories and the full stakeholder map are shown below in Figure 4.

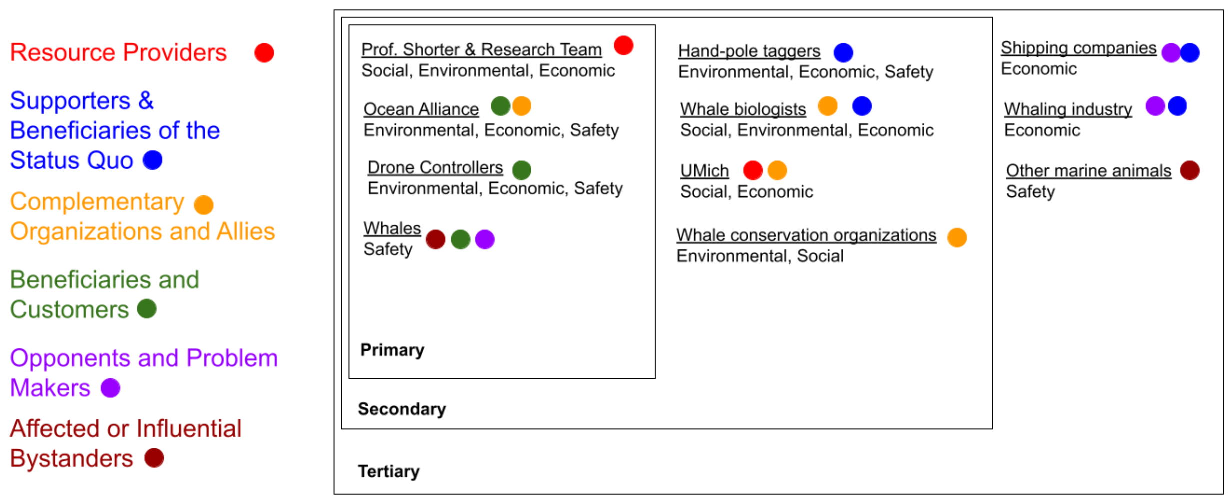


Figure 4. Stakeholder Map

Design Report 2 will only examine the design contexts of the Primary Stakeholders since they are the primary users and their design contexts are the most crucial to consider while making design decisions. In future design reports the design contexts of all stakeholders will be examined in depth.

Primary Stakeholder Design Context

Important social, environmental, and economic contexts are relevant to Prof. Shorter and his research team. In terms of social contexts, it looks good if they are progressing in their research.

Also, understanding these animals can lead to taking better care of these animals, as well as increased awareness and conservation/research funding. For the environmental context, they are concerned with helping whale conservation efforts. Finally, their economic considerations include staying within a reasonable budget while developing tags and creating deployment systems that work on the first try.

The most relevant context for Ocean Alliance and drone controllers are environmental, economic, and safety. First of all, OA's mission statement is to protect whales and their environment. Secondly, they want efficient drops that work on the first try, which is important for their economics and time considerations. Finally, using drones eliminates the need to go super close to the whales, making the whole process safer for both humans and whales.

The primary design context for whales (or any other animal the tag might be used on) is safety. Data can inform conservation efforts, improving conditions for whales. Additionally, the drone tagging system is much less invasive to the whales than the hand-pole system.

Most stakeholders will be positively affected by the project. Prof. Shorter, the research team, and anyone using tags will be helped by the data from our testing platform and the better quality drops that will result from the project. Additionally, biologists, conservationists, and whales will benefit from more data from better-quality drops. More successful drops lead to more data that can be used to inform conservation efforts and protect/help whales. The only stakeholders that might be affected negatively are the whaling industry and shipping companies. If the data from the tags actually inspires and informs conservation efforts that have a material effect, whales would be better protected, impacting the whaling and shipping companies.

The primary social aspects of this problem are closely tied to the environmental aspects. As human activities affect the planet through climate change and other impacts, collecting data on ecosystems, biodiversity, and animal behavior is more important than ever. This data can inform conservation efforts and raise social awareness about how we are impacting the planet and our fellow species. Because of this, Professor Shorter ranks social impact highly when viewing the project in the big picture. However, our main focus of the project is to set up a testing environment and a process to systematically evaluate drops. There will be little immediate social impact from the use of the testing environment since the end users of our design will likely only consist of the project team, Professor Shorter, and his research team. Another important context for the sponsor is the economic context. By setting up a testing environment to evaluate drops, tag deployment will be more efficient and work on the first try, saving costs and speeding up research and data collection.

Intellectual Property

Intellectual property considerations have not played a significant role in a project so far. There are not really any competitors using similar tags and deployment systems, and our testing rig does not have any competitors or will not be sold on the market or anything that requires legal rights.

Sustainability

Our project, as it exists right now, is already fairly sustainable. First of all, tags must be physically collected in order to extract data, so as an added bonus they do not pollute the ocean. Additionally, our testing rig will likely only be made once for use at the University of Michigan, so there will not be great environmental impacts during manufacturing or disposal. One thing we will keep in mind and consider throughout our design process is the energy use of the system. Another way we could make the system even more sustainable is by recovering the fins of the deployment mechanism.

Ethics

One possible ethical dilemma we might face in the future is making a design decision that would make the system work better but increase the impact on the whale. For example, a higher impact force would lead to better tag attachment, but also disturb the whale in the process. Because the overall goal of tagging the whales is to study their natural behaviors, we plan to prioritize the whales and minimize impacts on them if any similar decisions arise.

Power Dynamics

Since the team is coming into this project as it is already up and running, there are definitely power dynamics affecting us. Our project sponsor and the people who deploy the tags know so much more than we do about everything in this problem space. Additionally, there are aspects of the system we do not have the power to change, such as the actual tag, the type of drone, etc. Between team members, there are no big power dynamics at play. No one on the team had experience working in this field or doing this type of work before, so we are all starting out in a similar place in regard to power and knowledge.

Inclusivity

It is important to be inclusive when exploring the problem space and making design decisions. Because the whole team is new to this field, it will be really important to communicate with all our stakeholders who will be using our project and the tags to find out what they value and want to see. Additionally, it is also important to include the whales in our decision-making. Although we can't communicate with them, we can still make decisions with their needs and experiences in mind. Creating a system that is non-invasive and works well will be the most inclusive thing we can do for the whales.

Requirements and Specifications

Table 2. *A list of all of the requirements we would like our project to meet and the testable values needed to meet the specifications. The list is ordered by priority of the requirements.*

Requirement	Specification	Reference
Track Flight Path	Measure tag angle deviation from original orientation with a resolution of 1 degree Measure lateral displacement from original position for ranges of 0 to 2 m with a resolution of 10 cm	[5]
Track Flight Velocity	Measure flight velocities ranging from 0 m/s to 13 m/s with a resolution of 0.5 m/s	[1]
Measure impact force	Measure impact forces ranging from 0 to 6 N with a resolution of 0.3 N	[1]
Measure quality of suction	Measure unloaded vacuum pressure from 0 to 15 kpa	[6]
Test a variety of designs	1 or less tools needed to set up any design	[7]
Simulate wind + turbulence conditions from drone	Generate wind speeds of 4-5 m/s	[8]
Durability	Must be able to withstand 100 tests a week with no maintenance required	[7]
Fit Within ME 450 Budget	< $500	[7]
Easy to Use	It takes 1 person less than 5 min to set up a test	[7]
Safety/Stability	Stay grounded when a 200N force is applied // look for safety standards for research equipment safety	N/A
Minimum Height	2-6 m	[1]

In order to come up with the engineering targets listed above in Table 2, we had to consider what physical quantities could be measured that could give us insight into drop quality, what aspects of the real-life scenario were crucial to simulate the drop most accurately, stakeholder needs, and end user safety. The first four requirements in the table are about the physical quantities that we will measure from the drops in order to determine the performance. We are tasked with observing the behavior of the tag drop system from the moment it detaches from the drone to the moment it makes an impact on the animal. We know that in order for a successful tag the suction cups must be oriented parallel to the body of the whale at the moment of impact, therefore it is important firstly to track the flight path which will inform us of the orientation that the tag system will be during different times of the fall and the deviation from aiming point. We are also trying to measure how well the tag sticks onto the whales based on the velocity at which the system makes contact with the animal, the amount of force during the impact, and what the final pressure difference is between the air in the suction cups and the surrounding air. As we continue through this project we will be able to attribute weights to each one of these performance metrics in order to give a tag drop system an overall score and be able to compare it to other designs.

The next couple of requirements are targets to simulate some of the important aspects of the real-life scenario. These are simulating the turbulent winds created by the drone propellers and being able to test the drop systems from a minimum height of 2-6 meters from the landing zone. We believe that these are the conditions that are most critical to simulate because the winds created by the drone affect the orientation of the tag drop system and it is important for us to learn exactly how. Using the minimum height range from the specification will allow us to test the tag drop systems from similar heights to those in the real scenario.

We considered the end user of our testing system to come up with the rest of the requirements. The two main motivations for these requirements were providing a quality product and creating a safe testing system for a lab environment. The requirements regarding creating a quality product are being able to test a variety of designs, durability, and be easy to use. Being able to test a variety of designs is fundamental to our project because our end goal is to be able to compare the performance of those different designs. Durability is not an explicit requirement placed by the stakeholders but it would be nice to be able to perform hundreds of tests with minimal maintenance. The easy-to-use requirement is also more of a suggestion than a hard requirement, it would be fine if went over the 5-minute mark by a couple of minutes. However, the overall idea is to be able to test multiple designs more efficiently. For our safety requirement, we are going to be doing research into what specific protocols our testing system would have to follow in a lab environment. These specifications may also change depending on what sort of equipment we decide to use for our final design.

The final requirement that didn't fit under the categories previously listed is the project budget which is determined by our sponsor. This is also more of a suggestion rather than a hard requirement because our sponsor is open to purchasing technology that might be outside of our budget if we make a compelling argument for it.

There are not any extra requirements that have not been stated in our table or that have been stated in the preceding paragraphs. The only codes that we might have to follow would be covered by the safety requirement because we are commercializing our product therefore we don't have to worry about any other laws or standards regarding intellectual property. There are no specifications we have that seem outrageous to us at the moment.

Concept Generation

As an entire group we came up with ideas and built upon our individual ideas generated in DR2 that tackled different aspects of the overall problem. This process is seen in Figure 7, in the appendix. We grouped ideas that could fulfill our different functional requirements and crossed out ideas that were too outrageous or did not fall under any of our functional requirements. This method of idea generation is known as morphological analysis. This method generates a variety of ideas by combining the different individual ideas from each of the subcategories [12]. The functional requirements we chose to break up into subcategories are outlined below in Table 3 with their respective specifications.

Table 3. *Functional Requirements for Concept Generation*

Functional Requirement	Specification
Track tag drop system orientation	Measure tag angle deviation from original orientation with a resolution of 1 degree Measure lateral displacement from original position for ranges of 0 to 2 m with a resolution of 10 cm
Simulate drone downwash	Generate wind speeds of 4-5 m/s
Track impact force for suction quality	Measure impact forces ranging from 0 to 6 N with a resolution of 0.3 N Measure unloaded vacuum pressure from 0 to 15 kPa
Allow testing for different impact angles	Allow to test impact angles from 0 to 15 degrees
Track velocity of tag drop system	Measure flight velocities ranging from 0 m/s to 13 m/s with a resolution of 0.5 m/s

The requirements listed above are listed in order of importance with the top two being of highest priority. These two requirements are the most important because the inconsistency of successful tags using the drone method is currently attributed to the turbulent wind affecting the orientation and flight path of the tag drop system. For that reason, the first two subcategories are meant to tackle this aspect of the drop.

The following categories are used to determine different aspects regarding the impact of the tag on the surface. The most crucial component of the impact is the quality of suction made by the suction cups. The three categories that affect the quality of suction are the force at which the tag makes impact, the velocity of the tag before impact, and the angle at which the suction cups make contact with the surface.

Function	Concept 1	Concept 2	Concept 3	Concept 4
Track Tag Drop System orientation	Camera from the top view	Camera underneath clear plate	Side view Camera	Accelerometers on top and bottom of drop device
Track force of impact (for suction quality)	Use a force plate on the landing plate	Tie tag drop system with a rope and use a force meter to measure tension of taught rope	Solve with F=ma using accelerometer on drop device	Measure force required to pull cups off
Allow testing for different impact angles	Have different impact blocks with different impact angles	Hold plates by hand	Hinge on one side, adjustable height on the other	3d print bed style leveling
Track velocity of system	Solve theoretically with conservation of energy	Highspeed camera to track position at different times	Accelerometer on tag	Time the flight over a known distance
Simulate drone downwash	Handheld Fans	Computer Simulation	Wind tunnel	Multiple mounted fans

Figure 5a. *First Round of Ideation*

The ideas that we came up with for each category are shown in Figure 5a above. The leftmost column includes the subcategories that we first initialized and each row only contains the ideas we came up with for that particular subcategory. With this format of idea generation, a complete idea would be made up of one of the ideas from each of the subcategories. Therefore, this table is capable of producing 1024 or 4^5 complete ideas. Many of these ideas don't make a lot of sense or are not compatible with some of our other requirements. The following section demonstrates how we were able to downselect in order to get an Alpha Design.

Concept Selection Process

We used a number of different downselection strategies to select individual concepts to fulfill each subfunction of our design. The first down-selection strategy was eliminating ideas based on feasibility. The Concept Exploration Learning Block advocated out-of-the-box thinking, which is extremely helpful for brainstorming but also ends up producing some ideas that have no practical chance of working or do not make sense for the purposes of this class.Next, the remaining ideas were grouped by what requirement they fulfilled and placed into a table (see Figure 5a). From here, we used our other requirements to score each idea on a gradient. As a team, we evaluated each idea based on safety, budget, whether or not it could be accomplished before the end of the semester, and technical feasibility. Each concept was given a score from 0 to 3 and points were added up. See Appendix B for an example of how a concept was rated for each category. Any idea with a 0 in any of the categories was immediately eliminated. Figure 5b shows the morphological table after all concepts have been graded.

Track Tag Drop System orientation	Camera from the top view	3 3 3 3	Camera underneath clear plate	3 3 3 3	Side view Camera	3 3 3 3	Accelerometers on top and bottom of drop device	3 3 3 2
Track force of impact (for suction quality)	Use a force plate on the landing plate	3 2 3 2	~~Tie tag drop system with a rope and use a force meter to measure tension of taught rope~~	2 3 3 0	~~Solve with F=ma using accelerometer on drop device~~	0 3 3 2	Measure force required to pull cups off	2 3 3 3
Allow testing for different impact angles	Have different impact blocks with different impact angles	3 3 3 3	~~Hold plates by hand~~	0 3 3 1	Hinge on one side, adjustable height on the other	3 3 3 3	~~3d print bed style leveling~~	3 0 0 0
Track velocity of system	Solve theoretically with conservation of energy	3 3 3 2	Highspeed camera to track position at different times	3 1 3 3	Accelerometer on tag	3 3 3 2	Time the flight over a known distance	3 3 3 3
Simulate drone downwash	Handheld Fans	0 3 3 1	Computer Simulation	3 3 0 0	~~Wind tunnel~~	3 0 2 1	Multiple mounted fans	3 3 3 2

Legend	
Safety Rating	(green)
Budget	(blue)
Can be accomplished within the semester	(yellow)
Confidence in skills required to make the project succeed	(pink)

Figure 5b. First Round of Down-selection

For our second round of ideation, we combined, modified, and refined the remaining concepts to create another morphological table, shown below in Figure 5c.

Track Tag Drop System orientation	Camera from the top view	Camera underneath clear plate	Side view camera	Accelerometers on top and bottom of drop device
Track force of impact (for suction quality)	Use a force plate on the landing plate	Measure force required to pull cups off		
Allow testing for different impact angles	Have a different impact blocks with different impact angles	Hinge on one side, adjustable height on the other		
Track velocity of system	Solve theoretically with conservation of energy	Accelerometer on tag	Time flight time over a known distance	
Simulate drone downwash	Multiple mounted fans			

→

Track Tag Drop System orientation	Track roll with camera underneath clear plate Track pitch and yaw with 3-axis accelerometer	Track roll with camera underneath clear plate Track pitch and yaw with side camera
Track force of impact (for suction quality)	Use a force plate on the landing plate	Make drop force vs pull off force calibration curve using scale in lab. Then measure force required to pull cup of after running experiment.
Allow testing for different impact angles	Have a different impact blocks with different impact angles	Hinge on one side, adjustable height on the other
Track velocity of system	Accelerometer on tag	Time flight over known distance
Simulate drone downwash	4 fans in 2 x 2 pattern mimicking drone	

Figure 5c. Second Round of Ideation

We used the same gradient process to score each concept on a gradient from 0 to 3, but we changed our categories to make sure we were taking all aspects of our project into account during our ideation and down-selection processes. For this round of ideation, concepts were scored on safety rating, predicted performance, ease of use, and the team's confidence in our ability to successfully build and/or implement the concept. Figure 5d shows the morphological table after all concepts have been graded.

Track Tag Drop System orientation	(9) Track roll with camera underneath clear plate Track pitch and yaw with 3-axis accelerometer	3	3	2	1	(9) Track roll with camera underneath clear plate Track pitch and yaw with side camera	3	2	1	3
Track force of impact (for suction quality)	(11) Use a force plate on the landing plate	3	3	3	2	(9) Make drop force vs pull off force calibration curve using scale in lab. Then measure force required to pull cup of after running experiment.	2	2	2	3
Allow testing for different impact angles	(9) Have a different impact blocks with different impact angles	3	1	2	3	(11) Hinge on one side, adjustable height on the other	3	2	3	3
Track velocity of system	(10) Accelerometer on tag	3	3	3	1	(9) Time flight over known distance with video footage	3	2	1	3
Simulate drone downwash	(10) 4 fans in 2 x 2 pattern mimicking drone	2	2	3	3					

Legend *(rating 0-3)*	
Safety rating	(green)
Predicted performance	(blue)
Ease of use	(yellow)
Confident in skills required to make project succeed	(red)

Figure 5d. Final Round of Down-selection

Once we had evaluated each idea, we added up the scores and compared concepts that fell under each function. In general, we were able to select the highest-scoring concept for each function. However, the different functions of our design should also be compatible with each other so we also had to consider how selecting one concept might influence our other functions. For example, the concepts under "Track Tag Drop System Orientation" received the same score so it was necessary to find another way to select a final concept. The team realized that using an accelerometer on the tag to track the velocity of the system had clearly scored higher. Since we had already decided to put an accelerometer on the tag, it made the most sense to also track the tag orientation with the accelerometer method, so that concept was ultimately selected.

Selected Concept Description: The Alpha Design

After selecting concepts to fulfill each subfunction/requirement of the design, we began visualizing how a prototype model would look using SolidWorks. We decided to split up our building process into three phases. Phase 1 is the upper stage, Phase 2 is the landing zone, and Phase 3 connects the first two phases together. To start, Phase 1 is shown below in Figure 6a.

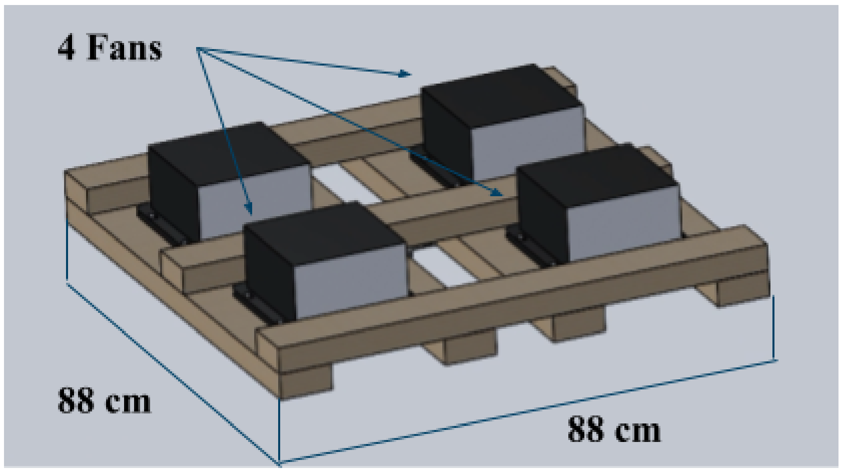


Figure 6a Prototype Plan, Phase 1

Phase 1 is the most important and complex part of our design, so the team decided to start working on it first. This phase contains the fans that will simulate drone downwash, the dropping mechanism, and sensors to track flight orientation, all of which are key parts of the design and important parts of accurately simulating a drop. Phase 2, the landing zone, is shown below in Figure 6b.

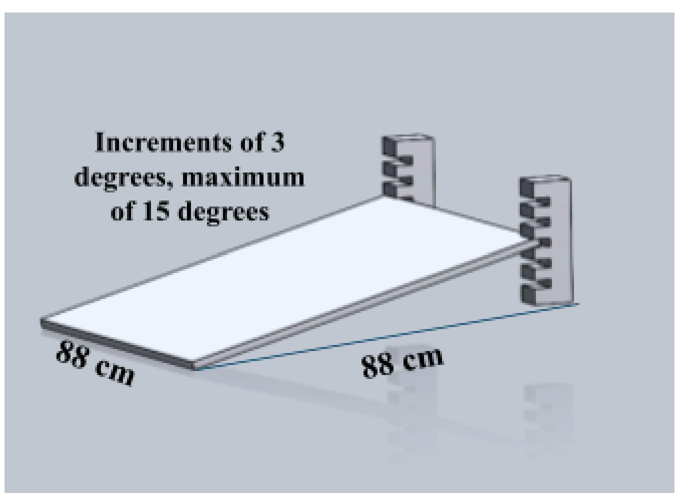


Figure 6b Prototype Plan, Phase 2

Although Phase 2 should be easier to construct, it still fulfills several important requirements for our design. Having an adjustable landing angle allows us to simulate changes in both the tag orientation and how the tag lands on the whale. Additionally, the modular aspect of our design allows for this phase to be swapped out for a simple force plate or any other landing surface the tag may be tested on in the future. Phase 3 combines Phases 1 and 2 and is shown below in Figure 6c.

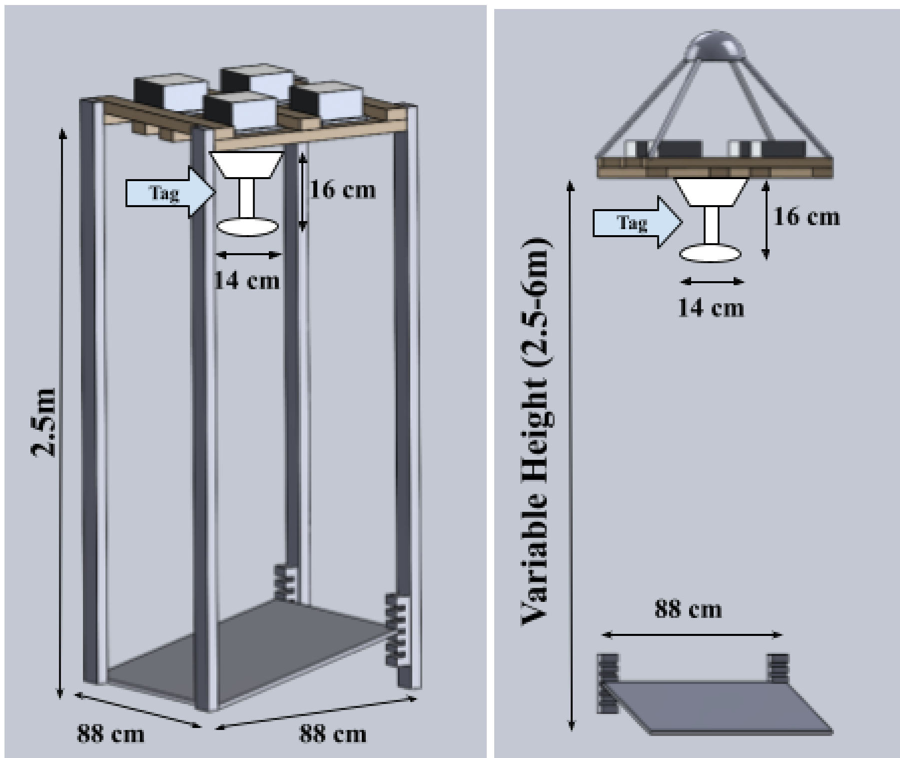


Figure 6c. Prototype Plan, Phase 3

One benefit of building the first two phases separately is that we have a flexible, modular design that can be assembled in multiple ways. Phase 3 involves the construction/exploration of two possible ways to combine the upper stage and the landing zone: a tower method or a suspension method. The tower method has a fixed height of 2.5 meters, while the suspension method is designed to be hung from any tall structure, simulating drops at many different heights. An initial bill of materials is included in Appendix C.

Our sponsor is looking for a specific product so there is undoubtedly a lot of sponsor influence in this design. Our sponsor also provided us with some materials like fans and tags for testing that also factored into some of our budgetary and time decisions. However, we tried to be very objective throughout the whole concept generation and down-selection process to arrive at this alpha design. For the time and budget constraints we have as an ME 450 project team, this design makes the most sense while still satisfying all of our functional requirements. We expect this project to be difficult to achieve, because of both the ME 450 constraints and the team's limited experience with some of the technologies we plan on using.

Engineering Analysis

Dimensions and Materials

One of the first design parameters we had to decide was the dimensions of the testing rig. Important factors that went into this decision were the real-world conditions the tag is used in and the physical constraints associated with working in the x50 room of the GGBL. In the field, drones typically drop tags from heights ranging from 2-6m, and the ceiling of the x50 room is around 3m tall. We chose a structure with a height of 2.5m and a drop height of 2.13m so we could perform drops greater than the minimum height seen in the field while still being able to fit inside the x50 room and easily fix and iterate on the upper stage of the structure. We chose a depth and width of 88cm, which is around the size of the drone Ocean Alliance used. While we are currently using fans, this design choice was made with future iterations in mind. In the future, we have considered replacing the fans with more powerful ones or drone propellers.

For the materials of the structure, we had to balance ease of manufacture with strength and stability. When it came to unique pieces and mechanisms we designed ourselves, it made the most sense to use 3D-printing to manufacture them. For example, we redesigned the dropping mechanism multiple times throughout the course of the project in order to increase reliability and performance, and using 3D printed parts helped us iterate quickly on our design.

When looking at the fans to simulate drone downwash, the team had to make a decision on how in-depth we wanted our analysis to be. We considered performing a CFD simulation of the system to see how the turbulence from our fans compared to the turbulence of the actual drone used in the field. Ultimately, we decided against this since no one on the team had extensive experience with CFD simulations, and because of our limited project work time. The fans can always be updated and iterated upon later. Instead, we decided to measure the downward wind speed generated from our fans and compare it to downward wind speeds from the drone used in the field.

Another important requirement for our project is to have a variable initial drop angle. In the field, the drones/tags are not always perfectly level over the whale. After analyzing multiple drop videos from Ocean Alliance, the team determined that having the ability to angle the initial angle up to 40 degrees from the horizontal was more than enough to simulate all the situations we observed.

Sensors

To ensure we had a comprehensive suite of sensors that are capable of tracking flight dynamics and impact forces, we researched similar projects and consulted with our sponsor. We discovered it was important to track flight velocity and tag orientation. The type of orientation we are primarily concerned with is the angular displacement of the tag from the vertical axis. Thanks to the research team, the test tag already had an accelerometer, gyroscope, and pressure sensors in the cups. The accelerometer and gyroscope will track position, speed, and orientation. The pressure sensors will report the pressures in each cup. Using these pressures, we can use the formula for relating pressure and force to determine the suction quality of each drop. Using the clear landing plate, cup area can be easily measured from the bottom after the tag lands.

$$Pressure = Force/Area \Rightarrow Force = Area * Pressure$$

However, we did not have access to this tag for much of the project timeline and wanted to create a camera system that could also track some of these important flight dynamics. We can use one data stream to calibrate the other and synthesize their data in order to have a clearer idea of flight stability and impact forces. Using a camera tracking system influenced many of our design decisions. First, we had to include calibration points on the structure in order to accurately measure distances. We also had to place markers on the tag and fins to ensure that the system would measure each component from the same point at each frame. These calibration points and markers work together to increase the repeatability and accuracy of the system. To extract the angular displacement from the raw positional data, we took the inverse tangent of the x and y positions. Below, Figure 7 illustrates the angle and measurements taken to derive it.

$$\theta = tan^{-1}(\frac{\Delta Y}{\Delta X})$$

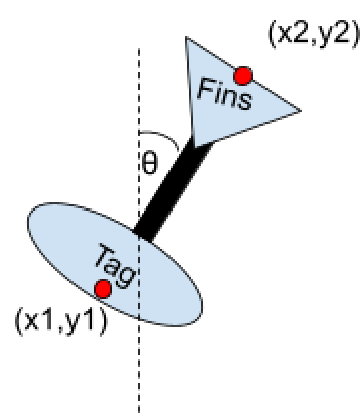


Figure 7. Measuring Angle Displacement

Build Design/Final Design Description

The final embodiment of our project consists of three different components which include the physical build, procedures in order to run tests, and guidelines to understand the information from the experiments and compare different tag drop system designs. Our final structure is seen below in Figure 8 and is capable of releasing tag drop systems at angles ranging from 0 to 40 degrees from a height of 2 meters from the landing surface. The components of our testing rig are the overall frame, the four fans, the dropping mechanism, and landing surface.

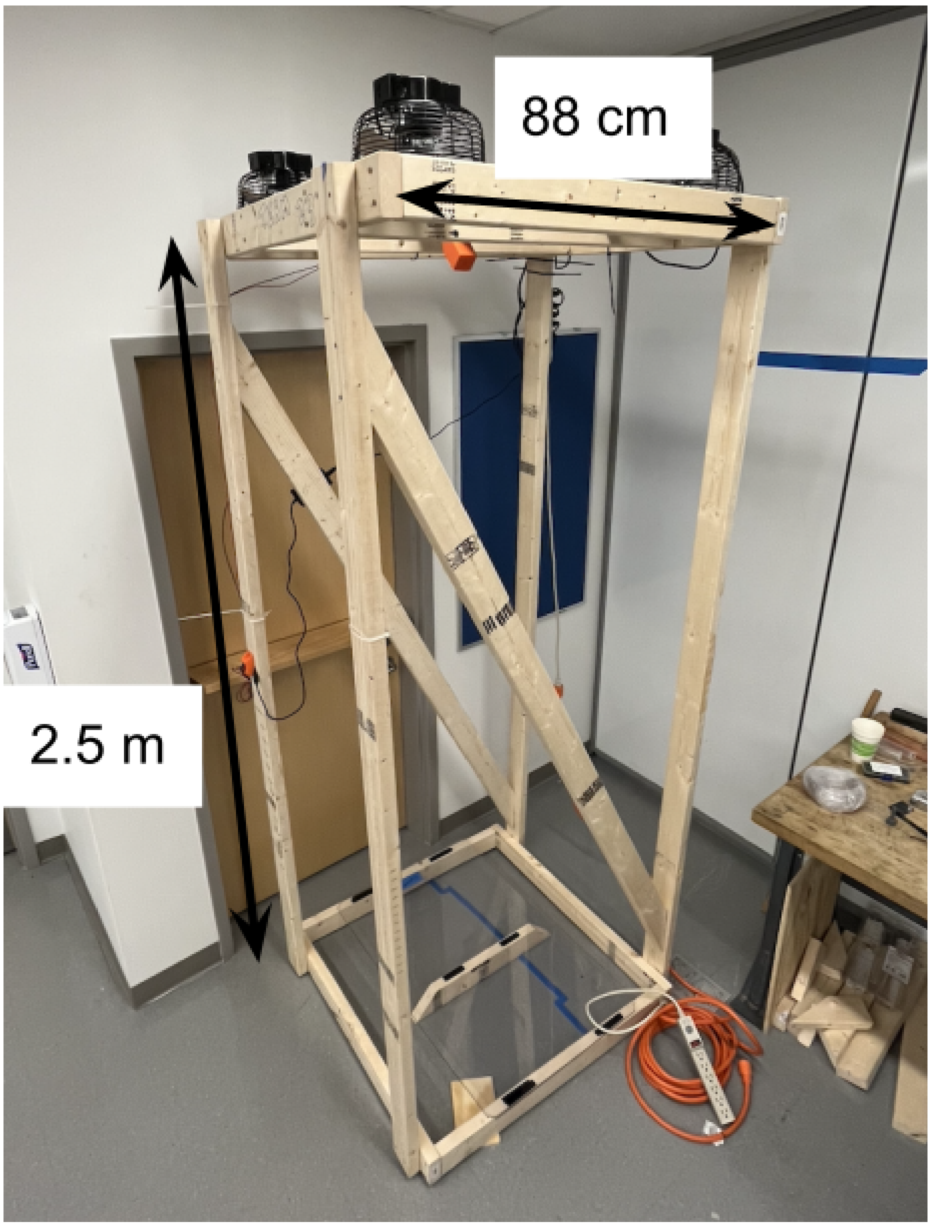
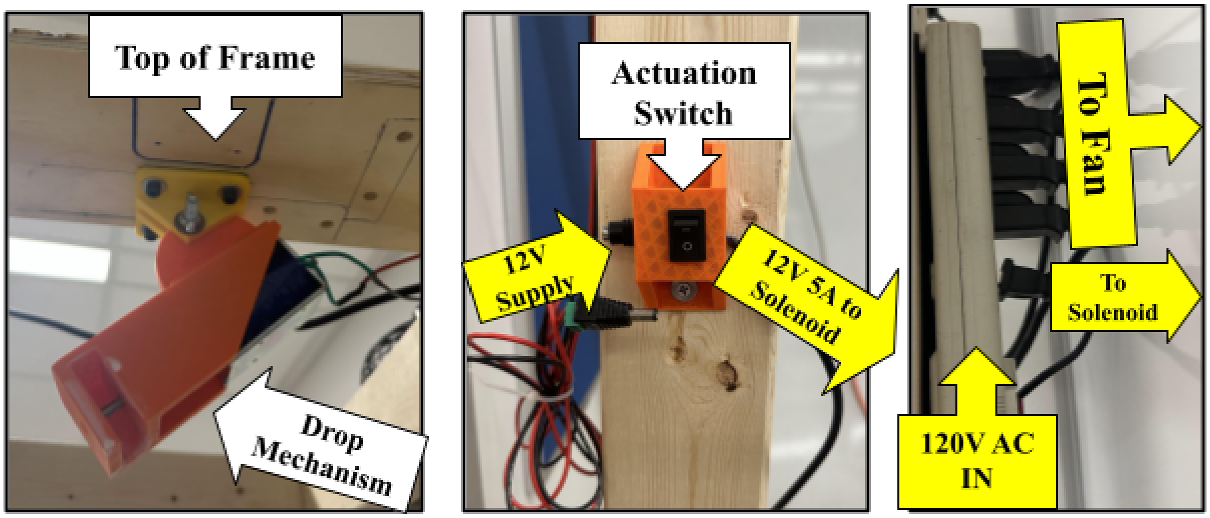


Figure 8: Testing Rig



(A) Dropping mechanism mounted to frame **(B) Solenoid-actuating switch** **(C) Power strip setup**

Figure 8 (A)(B)(C): Close-up photos of electrical and actuation subsystems for the final design

As seen in Figure 8 above, the overall frame is made of wooden 2x4's. The reasons for this are that wood is more cost effective than any metal, easier to manufacture and assemble, and is still strong enough for our application. We used the price for wooden vs. aluminum fences as reference, and found that wood is cheaper initially but has a higher maintenance cost over a long period of time [17]. Taking this into consideration for our use we believed that wood was still more cost effective than aluminum. The tools required to manufacture the frame were a tape measure, sharpie, wood saw, hand drill, hammer, and wood screws. The process was to first use the tape measurer and sharpie to make marks at locations where nails would be inserted and cuts needed to be made based off of the Solidworks model. Next the marked pieces of 2x4 were taken to the wood to perform the cuts. Lastly the final assembly was made by hammering the wood screws into the specified locations and using the hand drill to tighten the screws into place. The purpose of the diagonal wooden beams placed on two sides is to provide support and increase stability of structure while in use. A lesson learned during this process is that wood is easily warped which caused the bottom of our structure to be uneven. In the future we recommend verifying that the wood being used is not warped and possibly using jigs during the manufacturing process to align the pieces more accurately when assembling. Another improvement could be to have made the testing rig taller. We were limited to the height in which we assembled the testing rig, but a taller structure would allow us to study the tag drop system's behavior over a longer period of time.

As previously discussed, the purpose of the fans is to mimic the disturbing turbulent winds created by the drone dropping the biologging tag. The verification test that will be discussed further in a later section demonstrated how our fans compare to the DJI Matrice propeller.

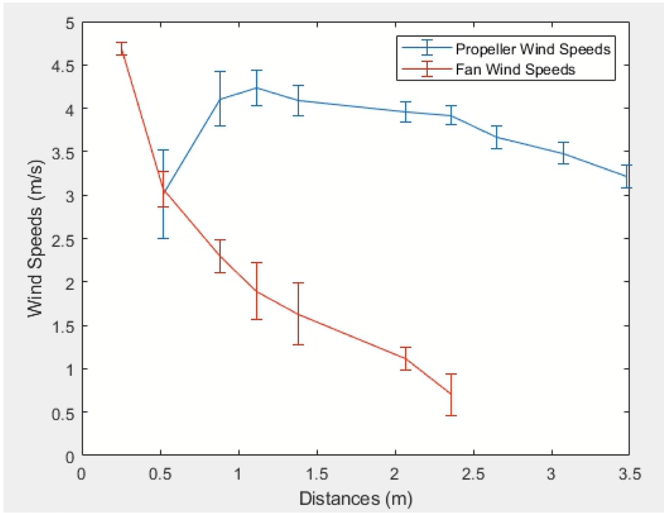


Figure 10: Wind Speed test results

The graph shown in Figure 10 above demonstrates the wind speeds of the fans being used in our testing rig compared to those generated by the DJI Matrice. Although the fans meet our specification of generating wind speeds of 4-5 m/s the graph clearly shows that the wind speeds created by the drone stay consistently higher over a longer distance. Compared to our fans which produce high wind speeds at close distances but sharply drop when distance is increased. A future change that could be made is replacing the four small fans with the propellers used on the drone or replacing the current fans with more powerful ones.

Dropping Mechanism

The dropping mechanism shown below in Figure 11 consists of various 3-D printed mounting parts, a solenoid, and a circuit to control the solenoid.

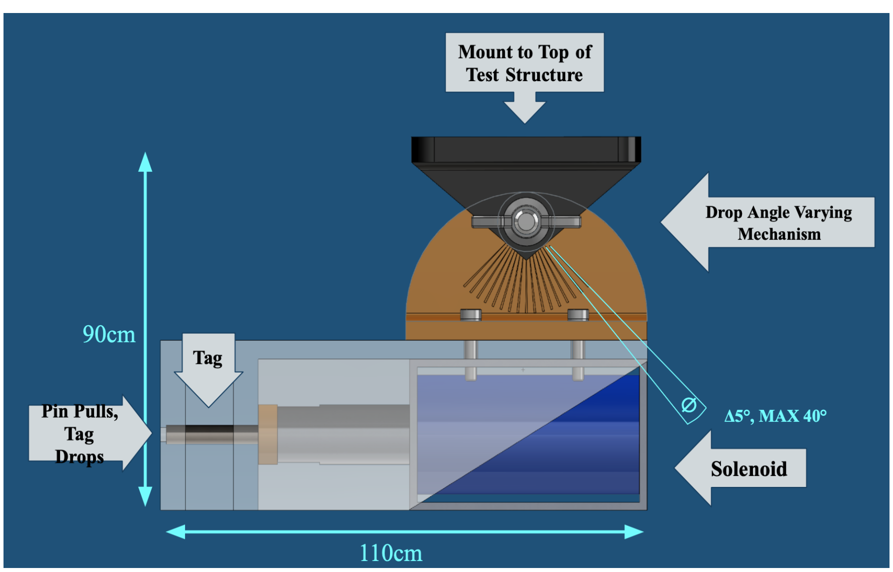


Figure 11: Dropping Mechanism

The dropping mechanism works by placing the fin toppers, shown in Figure 12 below, where the tag arrow points to in Figure 11 above. The dowel pin attached to the solenoid inserts into the fin topper's hole. The walls on either side of the 3-D printed solenoid mount keep the fin topper from slipping off of the dowel pin at any angle.

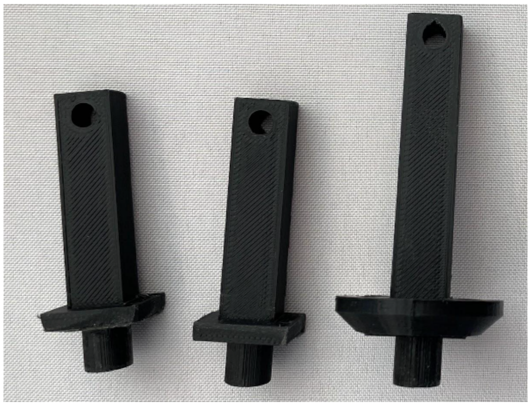


Figure 12: Fin Toppers

When the user is ready to drop they can flip the switch which activates the solenoid and pulls the pin, allowing the tag drop system to free fall. The drop angle varying mechanism allows the user to adjust the drop angle up to 40 degrees. The plastic mounts are held in place by tightening the wingnut at the desired angle.

The landing surface is simply a clear polycarbonate plate attached to the wooden frame by velcro. This setup is ideal because the material is a smooth surface which allows the suction cups on the tag to stick well. The fact that it is attached via velcro is an advantage because after performing a drop we are able to analyze the quality of suction from beneath the plate as seen in Figure 13 below.

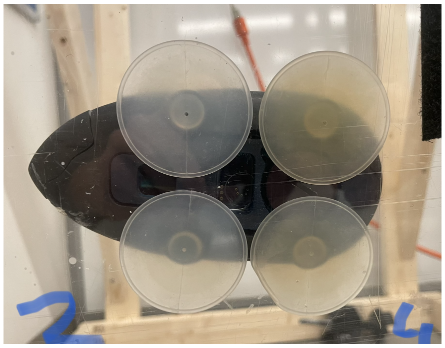


Figure 13: Bottom view of Suction Cups

A result of using velcro is that it is more convenient for any future adjustments to replace the polycarbonate plate for a material which more closely resembles the skin of a whale.

The second major component of our final design is the procedures to collect the data from the drops. The complete set of instructions can be found in section D of the appendix. The necessary equipment to collect the data is a camera that can record video at 60 FPS, a tripod that is at least four feet tall, Tracker software, Matlab, Python, Arduino, and a biologging tag with accelerometers and pressure sensors. The testing procedure document splits up the steps into set up, execution, and data extraction sections. Within the Set Up section there are instructions to prepare the video tracking, the smart tag tracking, and how to mount the tag drop system onto the dropping mechanism. The Execution section covers the steps to take while performing the drop as well as the number of times that the experiment should be repeated. The Data Extraction section covers how to use the video taken to measure data using the Tracker software as well as how to extract the data measured by the Arduino in the Smart Tag.

The final major component of the design is the analysis of the information and how to use it to compare different tag drop system designs. The two characteristics that will be used for comparison are stabilization time and quality of suction. The stabilization time will be interpreted using an Angle Deviation vs Time graph, shown below in Figure 14.

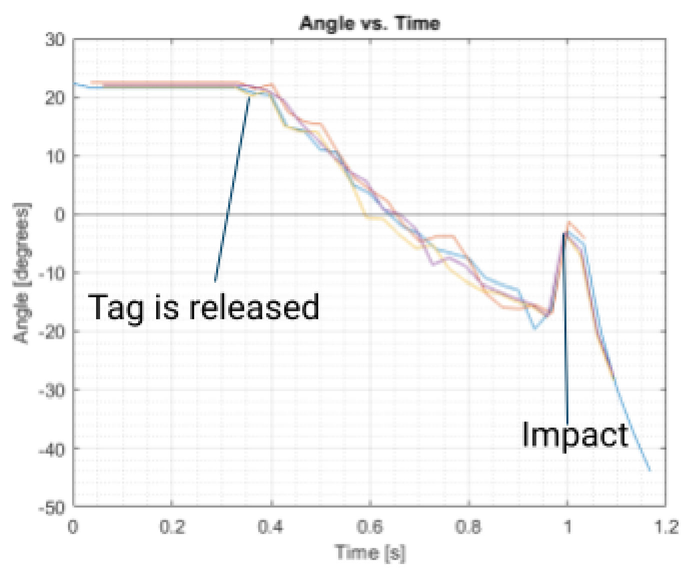


Figure 14: Angle Deviation vs Time graph

This graph represents the how the angle Θ of a tag drop system, previously discussed in the Sensor's section, reacts to an input initial angle. The graph ideally takes the shape of a sinusoidal wave decreasing exponentially towards the zero. Because we were limited to a drop height of about 7 feet, depending on drop angle, the average flight time was about 0.6 seconds. This meant we were not able to see the tag drop systems fully stabilize during the drop. Ideally the angle deviation would be zero at impact so the tag could be parallel to the surface of the whale when the suction cups are sticking. There are two approaches to accomplish this task. The first is to create a tag drop system that is capable of stabilizing itself within the time of the fall. If the system is able to stabilize itself for the most critical angle then any lesser angle input would also stabilize in time. The second approach would be to predict what the initial angle deviation of the drop would be and knowing the time of free fall try to design a tag drop system whose angle deviation graph is crossing the zero degree axis during the impact. This method is more complex due to the angle deviation curve being a product of the input angle which is a characteristic that is almost impossible to keep a constant in the real scenario. We plan to use the accelerometer data measured by the Arduino in the Smart Tag to verify and support the information found from the video. The quality of suction will be determined by using the pressure sensors in the smart tag. We expect the Smart Tag to produce a graph similar to Figure 15 below.

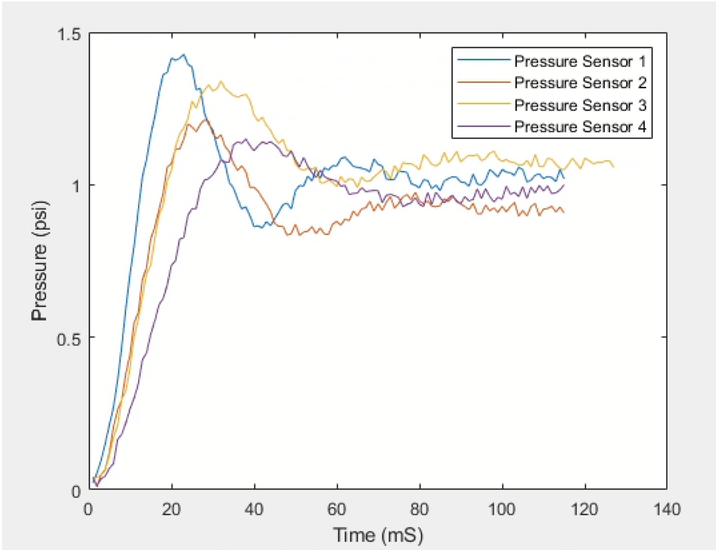


Figure 15: ΔPressure vs Time graph

Each curve on the graph shown above represents the pressure differential between the pressure within the suction cup compared to that of the atmosphere. As seen in the graph the pressure differentials will peak during impact and then settle to a stable pressure. An ideal outcome would be for the four curves to be as close as possible to one another as well as have a high pressure differential. Factors that have an effect on the pressure differentials of the suction cups are the angle at which the tag makes contact with the surface and the force during impact. We will also be measuring the diameters of the suction cup once attached to the landing surface. We expect to see a direct relationship between the diameter of the attached suction cup and the pressure differential measured by the smart tag. The goal is for end users to design tag drop systems with the intention of minimizing the stabilization time and improving the pressure differentials within the suction cups by using the testing rig, following the given procedures, and analyzing the data collected.

Verification Plans

Individual verification plans were created to verify that our design addresses and meets each of our requirements and specifications. These are shown below in Table 4, and the most crucial ones will be explained in depth later in this section.

Table 4. *Requirements, Specifications, Design, and Verification Plans*

Requirement	Specification	Design	Verification Plan
Track Flight Path	Measure tag angle deviation from original orientation with a resolution of 1 degree	Camera and video analysis tool	Tested Experimentally - repeated analysis of drops by multiple team members
Variable Initial Drop Angle	Drop angle can be offset up to 30 degrees from vertical	CAD	3D model will provide estimate of angular variability
Track Flight Velocity	Measure flight velocities ranging from 0 m/s to 13 m/s with a resolution of 0.5 m/s	Camera System + Accelerometers	Use position footage over a period of time to calculate velocity and calibrate accelerometers
Measure impact force	Measure impact forces ranging from 0 to 6 N with a resolution of 0.3 N	Camera System + Accelerometers	Compare calculations of force impact between change in velocity (taken from camera tracking) and maximum acceleration due to impact (from accelerometers)
Measure quality of suction	Measure unloaded vacuum pressure from 0 to 15 kpa	Pressure sensors in cups	Identify pressure sensor in tag, compare specification of sensor to required specification for suction quality
Simulate wind + turbulence conditions from drone	Generate wind speeds of 4-5 m/s	4 fans pointed down at flight column	Tested Experimentally - measuring wind speed at a variety of distances below each fan
Drop Height	Minimum 2-6 m	CAD + measurement	Drop height estimates from CAD design will be compared to measurements taken after the structure is built

Variable Drop Angle and Drop Height

The dropping mechanism seen in Figure 11, pg 21 shows angular markings in increments of 5 degrees, up to a maximum of 40 degrees. These lines are printed into the rotating mechanism, which allows the user to set the initial drop angle within the required specifications. The preliminary design of the structure, seen in Figure 6c, pg 16, was used to determine cut lengths for the 2x4 frame of the testing structure. We can assume that the model accurately represents the actual drop height which is 2.14 meters. To further verify this, we used a measuring tape to find the actual drop height which was found to be 2.13 meters.

Flight Velocity, Flight Path, and Impact Force

To verify the camera tracking system, we designed and performed an experiment to verify that our system fit our specification of measuring the tag angle deviation from original orientation with a resolution of 1 degree. First, repeated trials of drops at different angles were performed using the following test procedure:

1. Set the deployment mechanism desired initial angle
2. Attach tag/fin system to deployment mechanism.
3. Turn on power to the fans and deployment mechanism
4. Set up the camera 2m away and 1.22m off the ground, perpendicular to the testing rig
5. Start recording at 60 fps
6. Release tag
7. End recording

All four group members analyzed the same drops using the following analysis procedure:

1. Upload video to Tracker as a .mp4 file
2. Calibrate video using markings on calibration stick
3. Track the tag through each frame by clicking the red dots, labeled as tag mass
4. Track the fins through each frame by clicking the yellow dots, labeled as fin mass
5. Add a center of mass, using the two sets of tracking data for the tags and fins
6. Export tag and fin mass x and y positions as a .txt file
7. Import data to angle_analysis.m and run code to generate displacement angle vs. time plot

Multiple people performing analysis on the same drop videos will help determine how accurate our system is, as well as the inherent variation and uncertainty associated with our cameras and video tracking software.

After analysis, Figure 14 (pg. 23) was generated to exemplify our results. Each color represents a different trial and the respective angle from vertical with respect to time from when the tag was released to when it hit the landing plate. While there are small variations between analyses, each trial has a similar magnitude and shape. Once we had our data, it was time to do error analysis to determine how accurate our system was. Resolution error was found by measuring the number of pixels per inch, 18. This means that each pixel has a length of 1.41mm, which translates to a resolution error of 0.71mm. Our precision error calculation was based on the average standard deviation between analysis of the same drops. This resulted in a precision error of 3.2mm. Combining our precision and resolution errors, this results in an uncertainty of 3.3mm for the video tracking system. Using the length of our tag/fin system used in the trials, an uncertainty of 3.3mm would translate to an uncertainty of 0.93 degrees in our angle analysis. Since our specification was to have a resolution of 1 degree, our camera tracking system meets the specification. However, we will continue to revisit the accuracy of our system and perform more analysis of variations and errors as we collect more data from different angles and fin designs.

Simulating Wind Turbulence

Wind turbulence is generated from the 4 overhead fans in each corner of our final design. In order to verify that these fans meet our requirements and specifications, we designed and conducted an experiment to gather information on wind speeds. In the experiment, 7 different distances from the fans were chosen and 10 different measurements of the wind speed at each distance were recorded. The following test procedure was followed:

1. Randomize the order in which the 7 distances will be tested
2. For each distance measure the distance from the outermost part of the fan fin to the anemometer
3. Record the wind speed output by the anemometer
4. Then repeat step 1 and 2 for each of the distances in the order they were randomly generated
5. Repeat steps 1-4 until you have 10 wind speed measurements for each distance

Then, the following analysis procedure was performed:

1. Calculate the mean and standard deviation of the measurements at each of the distances
2. Confirm that the recorded wind speeds for the DJI Matrice propeller falls within two standard deviations of the fan mean.

The main source of error for this experiment came from the precision error between the different trials. Using the standard deviation for the 10 trials at each distance, the average precision error between each distance was calculated to be about .18 m/s. The results for this experiment were presented earlier in this report in Figure 10, pg 21.

Suction Quality

To verify that the onboard pressure sensors can meet our specifications, first we will identify the exact sensor type that is being used. We assume that the suction quality is only a function of the pressure differential. We will then find the specifications for this sensor and verify that it meets the maximum pressure specification for our project.

Validation Plans

While we have not completely verified and validated all aspects of the design, we have started to validate some crucial parts of the system. The whole point of this project was to show that our design is capable of showing differences in performance, so our main validation plans focus on showing that we can point out differences in performance based on flight path, impact force, attachment quality, and more. After the camera tracking system was verified, we used it to compare different fin designs. The fins and data from these tests is shown below in Figure 16.

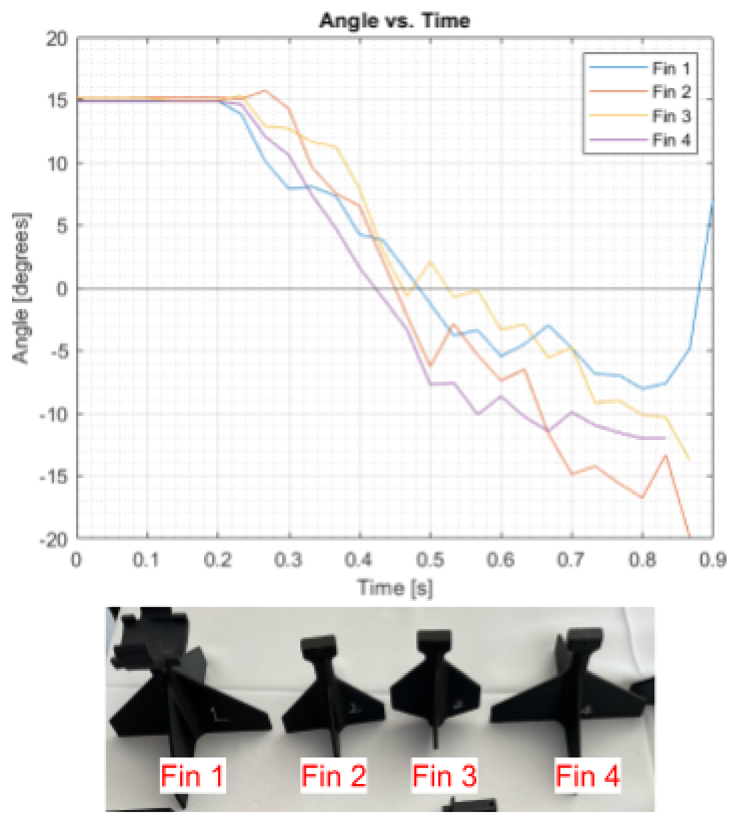


Fig. 16. Flight Tracking Data Comparison Amongst Fin Designs

This figure shows the vertical offset of four different fin designs, dropped from an initial 15-degree offset with the fans on. While the flight paths of the four designs start roughly the same, they begin to diverge as they rotate over the vertical axis. Impact takes place around 0.8 seconds. For the best attachment quality, we want the tags to be perpendicular to the landing area, so as close to a 0-degree angle as possible. Based on this test, we can rank the fins in order of performance: Fin 1, Fin 3, Fin 4, and Fin 2. More importantly, this test shows that our design and experiments are capable of quantifiably highlighting differences in fin performance and paves the way for future fin iteration. Future validation plans would look very similar to this and look and impact force, attachment quality, and more. As this data is recorded and analyzed, fin designs can be iterated upon and improved based on the information gained in these tests.

Discussion

Problem Definition
At the beginning of our project, it was difficult for our team to wrap our heads around the scope of the project because we came into the project thinking we would be doing iteration work on the fin design instead of making a testing environment for them. Our situation was especially challenging in the verification phase because we were verifying that our design could measure other designs, which was confusing at first. Also, after seeing that we built our prototype so fast after the design phase, we think that we could have spent much more time researching every aspect of our project. While our design fulfilled or had plans to fulfill all of its requirements, hindsight has made us aware that dedicating more time early-on to gain more confidence would have helped make a better product.

Our team would have liked to have spent more time completely understanding what resources were already available to us at the beginning of the project and prioritized developing areas that needed our work the most. Also, we should have considered that these resources may not have been the best solutions and that other routes were available. We didn’t get to learn to use the smart tag (it had the capabilities to capture all of our flight dynamic requirements) until about a month before our time frame was over. We could have budgeted much more of our money and time to better simulate the wind column and drop conditions, which would have been more productive for the project.

Design Weaknesses and Recommendations

Impact Force Measurement - Add Force Plate
One of our requirements was to measure impact force when the tag dropped. Our method of predicting impact force with acceleration data taken from the video tracking system as well as the onboard accelerometers is less accurate than what is needed to properly assess tag performance. The correct piece of equipment to record this data would be a force plate with a sampling rate of at least 1000 Hz such as the FP4060-05-PT-1000 from *Bertec.* This would allow for a more resolute calculation of maximum force than our current sampling rate of 60 Hz.

Impact Surface - Decrease Rigidity
We selected clear polycarbonate early on in the design process so that we would have the ability to record video from underneath if needed. It turns out that we don't need to record from underneath and that the hard polycarbonate was actually a detriment to our testing process. Since the sheet was stiff, the impacts for our tests were aggressive and caused 3 out of the 4 fin designs to fracture as well as one of the tags. We would recommend choosing a material that more closely resembles the surface of a whale and placing this on top of the force plate.

Structure Design - Decrease Warping, Make easier to Assemble
The main frame of our structure is made of standard 2 x 4 pine. This was very convenient for getting the structure built fast and cheap, but it resulted in some unforeseen problems. The most notable was the warping. This got worse over time and caused the structure to wobble and needed adjustments throughout the semester. The second inconvenience arrived when adding on modules to the structure later on. Every time we wanted to add a new component to the structure we had to measure and hand drill holes, which is a permanent and potentially inaccurate change. The last issue with having a wooden frame is that it is hard to disassemble and reassemble due to the uniqueness of each piece. Since this design takes up lots of space and the project may continue past our semester, optimizing the frame for assembly could be beneficial.

We recommend that the 2 x 4 frame is replaced by 3" x 3" 80 20 aluminum extrusion and the joints are replaced by sturdy 3d printed gussets or aluminum ones (Mc-Mastercarr #5537T194). Also, additional cross bracing may need to be added depending on stability. This would solve the above issues while also adding the benefit of variable height. If the top structure, seen in Figure 6a, pg 15, mounted onto the frame via vertical rails, the drop height could be adjusted.

Smart Tag - Prioritize for Flight Dynamics
Our group didn't realize the full range of capabilities of the smart tag we were given by Professor Shorter until we had already mostly decided upon our data collection methods for tag tracking. Since we were late to this, we never got the onboard data collection working properly.
Given another chance, we would focus on familiarizing ourselves with the capabilities of this piece of equipment and how to use it before deciding what supplementary data collection devices are needed in the testing setup. Had we found that all the sensing from the smart take was sufficient to meet our tag-tracking requirements, our focus could have been more concentrated on more accurately simulating the test environment.

Fans - Upgrade to More Closely Simulate Downwash
In order to more closely mimic the drone downwash winds we would like to replace the current fan set up with one which has a wind speed to distance relation seen by the DJI drone propellers in Figure 10, pg 21. Some alternatives would be to purchase an industrial fan with a speed controller or buy the same propellers used by the DJI drone. With either of those options we would most likely also need to improve on the safety of the fans. An option for safety would be to create guards that would prevent the user from accidentally touching the fan fins while turned on. Another would be to only have the fans running when the user is a minimum distance from them to prevent any hazardous incidents.

Another aspect of the tagging process we would like to simulate is the cross winds that the tag has to deal with. We would need to research at what horizontal speeds the drone travels during the tagging procedure as well as under what environmental conditions the researchers perform the tagging. Taking these factors into consideration we would find a fan or set of fans that we can place on a side of our structure and recreate those cross winds similar to how we use fans to mimic the drone propeller winds.

Reflection

When designing, it is always crucial to examine what societal contexts are relevant to the project. Since our project is pretty focused and will likely only be used by Professor Shorter, his research team, and future ME 450 groups, many of these factors are not immediately relevant to our project. Since our project aims to design a testing rig along with procedures to be used by a very limited number of people, factors like public health, safety, and welfare do not clearly fall under the scope of the problem. Of course, the safety of anyone using the design is incredibly important, but it will not affect public safety as a whole. Similarly, our design will not benefit a global marketplace. However, conservation efforts informed by biologging data could impact the global marketplace by affecting areas like shipping routes. Like the other public and global factors, there will be few social impacts associated with the manufacture, use, and disposal of the design since, to our knowledge, only one instance will be created. Positive social impacts could be gained from conservation efforts assisted by increased tag effectiveness. Economic impacts associated with manufacture, use, and disposal consist mainly of the price of the raw materials used. If the design is successful in improving the fin designs, Ocean Alliance and other tag users could save money and time while using tags. To analyze the stakeholders and their design contexts, we used a stakeholder map (Fig 4. Page 6).

Inclusion and Equity

All the team members had a similar background when it came to the classes and experiences they had encountered during their time at the University of Michigan. We were able to collaborate smoothly together throughout the project. Some of our individual differences outside of the classroom helped us to excel. We each had unique strengths such as communication through speech and writing, knowledge of manufacturing, and knowledge of current technology which we brought to the table in order to create our final product. We were able to identify each other's strengths and weaknesses in order to better work with each other and get the most out of each team member.

Within the team members there were no major power dynamics. All major decisions made by the team on the design were made democratically where any team member would share their idea or perspective on a matter then we would discuss as a group and unanimously decide how to move forward. We aimed to create an environment that allowed all team members to confidently share ideas or constructive criticism about any topics regarding the project. Our project was unique in the fact that our sponsor, Professor Shorter, was also our end user and the only stakeholder who we met with for an opinion about the project. This allowed us to only have to focus on what his needs were for the outcome of the final product. The dynamic between him and our team was one of collaboration with his expert knowledge on the subject matter. Professor Shorter provided us with many design characteristics that we ended up using throughout our design process and in our final product. His background in whale tagging helped immensely in pointing out what some of the weaknesses of the current tagging process are and how our design could simulate those in order to create better fin designs for researchers to use.

Ethics

One of the only ethical dilemmas we were faced with was on safety vs. performance when it came to the fans we used. They originally came with guards meant to minimize any potential hazard with fingers getting caught in the fan. With the fans being as weak as they already are we decided to take the guards off in order to achieve the necessary performance that we required from them. The fans also specified that if they were to be used without the guards on, they should be a minimum of two meters away from anyone while turned on. If this product were to enter the marketplace this aspect of the design might get some backlash. If we had more time to continue this project we would have liked to create guards that meet any safety standards for a lab environment while not interfering with the performance of the fans.

The University of Michigan or a future group will always ensure that any product or procedures required to create a product meet all necessary safety standards. We believe the same for ourselves. Apart from those standards we also use common sense when it comes to our designs and the manufacturing process. If there seems like there could be a potential risk we approach it with a high level of carefulness.

Conclusions

We made a lot of progress on our project throughout the semester. Starting with the initial problem statement and our meeting with Professor Shorter, our sponsor, we first explored the problem scope and did background research to inform ourselves and determine stakeholders and relevant design contexts. Biologgings tags that are designed and built by Professor Shorter's research team at the University of Michigan are being deployed onto whales to study their behaviors and inform researchers of their movements and ecosystems. The current method of using drones to drop these tags from above is inconsistent and unreliable. Our project aimed to create a testing environment that can measure and quantify important factors in these drops to ultimately determine what makes a "good" drop. We planned to use a highly iterative design process to develop a consistent testing system that can be used by Professor Shorter and his research team. Our primary stakeholders included Professor Shorter, Ocean Alliance, and the whales themselves. Each of these stakeholders would positively benefit from our project through more data from better quality drops that will be used to inform conservation efforts and improve the whales' well-being. After research, we were able to create our requirements and specifications, which are mainly focused on measuring flight dynamics and suction quality, simulating real-world conditions, and safety. From here, we used functional decomposition and multiple ideation rounds to come to an initial set of concepts that made up our alpha design. Important concepts here included a camera tracking system to track flight path and velocity, sensors in the tag to track flight dynamics and attachment quality, fans to simulate drone downwash, and the ability to alter the initial drop angle. Next, we began constructing and implementing all of these concepts together. After construction was completed, we focused on verifying and validating as many requirements and specifications as possible through repeated testing and development of experimental procedures. We were able to verify many of our requirements, including physical aspects like height and angle variability. We were also able to verify and start to validate our camera tracking system by first determining the uncertainty and resolution in the system and then using it to compare different fin designs. The team believes that our design is a good starting point and can provide a good platform for future iteration and improvement of both the testing rig and fin design. While we have been able to show differences in some aspects of fin performance, there is still potential for more work to be done. Smart tag data must be implemented in order to analyze fin performance through the lens of other important variables like attachment quality. Additionally, our design would benefit from more powerful fans to accurately simulate drone downwash and a different landing plate to account for the durability of the test tag.

Acknowledgements

Thank you to Professor Barton and Professor Shorter for all their help and advice on this project. Their feedback, advice, and information were crucial to our successes and helped guide us along the way. Also, the x50 shop employees were incredibly helpful during our manufacturing phase, advising us on how to construct the rig and providing key safety recommendations to improve our design. Finally, thank you to the other groups in our ME 450 section (Teams 21, 22, 24, and 25) for their feedback and questions on our project updates and Design Review presentations.

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Appendices

A. Initial Concepts

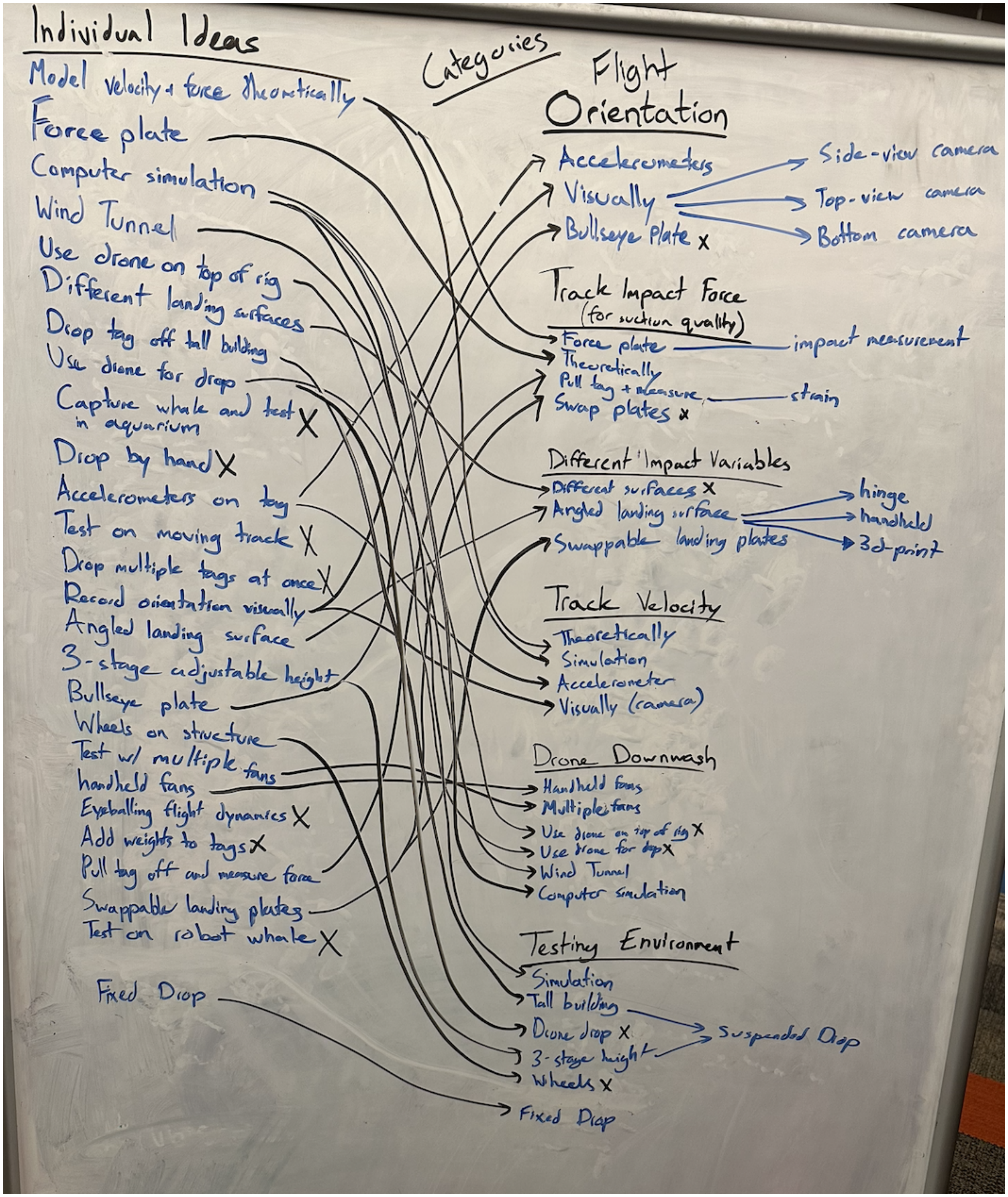

Figure 7: Brainstorming and categorizing ideas into functional requirements

B. Downselection Gradient Example

First Round Downselection

When evaluating the concept of using an accelerometer on the tag to track the orientation, we used four categories to score the idea on a range from 0 to 3: safety, budget, timeliness, and technical feasibility. For safety, using an accelerometer on the tag system does not introduce any hazards into the system, so it receives a safety score of 3. For budget, accelerometers range from $10 to $45, well within the ME 450 budget. This concept receives a budget score of 3. Attaching the sensor on the tag should not take a lot of time, so this concept also receives a timeliness score of 3. Finally, no one on the team has much experience with accelerometers and analyzing the positional data, so the concept receives a technical feasibility score of 2.

Second Round Ideation

Since the accelerometer does not interfere with any camera system, we decided to combine the concepts. Using the techniques in tandem will provide us with more information and help us know if both are working correctly.

Final Round of Downselection

For this round, concepts were scored on safety, predicted performance, ease of use, and technical feasibility. Again, this concept does not introduce hazards to the system, so it gets a safety score of 3. Using an accelerometer correctly should provide more precise data than any other method we could think of, so the concept receives a predicted performance score of 3. Since the concept now includes a camera, this will likely place more of a burden on the user. The accelerometer will track pitch and yaw, but the user will have to track roll with the camera. For ease of use, the concept received a 2. Finally, the team has little experience tracking orientation with both cameras and accelerometers, so we will have to absorb a lot of information in a short amount of time to correctly implement this concept. Because of this, we gave the concept a 1 for technical feasibility.

C. Bill Of Materials

Table 6.Bill of Materials

Material	Quantity	Manufacturer	Price
Fans	4	N/A	$199.96 (Given)
Solenoid XRN-1564T	1	Uxcell	$18.75
Rocker Switch 7395K11	1	McMaster-Carr	$5.80 (Given)
3D Printed Solenoid Mounts	3	x50	Machine Shop (Free)
Polycarbonate Plate 8707K114	1	McMaster-Carr	$79.67 (Given)
Test Tag	1	Prof. Shorter	N/A
Cameras	1	Personal Phone	N/A
8ft wood 2x4s	8	Home Depot	$26.80
Wood Screws	32	McMaster-Carr	$6.37 (Given)
Wingnut 90866A007	1	McMaster-Carr	$17.74 (Given)
Dowel Pin 98381A542	1	McMaster-Carr	$8.57 (Given)
⅜" Non-metallic Twin-screw Cable Clamp connectors 20511	1	Home Depot	$2.98

D. Experiment Procedures Document

This document covers how to set up, execute, and extract data from the tag drop experiments.

Set Up

- *Video Tracking*
  - Place tripod at 65 in from testing rig
  - Mount camera on tripod and raise it so the center of the lens is 4 ft off of the ground
  - Ensure that the entire testing rig is in the frame and the camera is set to record to at least 60 FPS
- *Smart Tag Data*
  - For best practice charge the tag until the led turns green
  - Connect to the Arduino Nano inside of the tag
  - Upload the TowingTankExp_ver3.ino file onto the Arduino
    - Change the filename on line 230 to match the trial number
    - The trial time in seconds for which the Arduino records could be edited on line 17 (shorter times are recommended)
    - Once the code is sent to the Arduino the trial time begins
- *Dropping Mechanism*
  - Adjust the dropping mechanism to the desired angle
    - Each line on the Angle Varying Mount is 5 degree increment
    - Use the wingnut to lock in the desired angle
  - Plug in the connection which give power to the fans and solenoid
  - Use the switch to pull back the solenoid pin
  - Place tag drop system within walls of the dropping mechanism and align the hole on the fin topper with the solenoid's dowel pin
  - Use the switch to push the pin though the fin topper and lock the tag drop system in place

Execution

- *Drop*
  - Once the camera is in place, the code has been uploaded to the Arduino, and the tag drop system is fixed on the dropping mechanism begin the record the video
  - Hold the calibration stick on the same vertical plane as the tag, perpendicular to the camera, and as close the same height of the lens as possible for a couple of seconds
  - Press the switch to active the solenoid and drop the tag drop system
  - Once tag has settled stop recording the video

- ➢ Detach the polycarbonate plate from wooden frame to measure and record the diameter of the suction cups with a ruler
- ➢ Detach the tag from the landing surface and attach the plate back in place aligning the velcro strips

❖ *Repetitions*

- ➢ For each angle that will be tested we recommend to repeat the drop 3-5 times
  - ■ Once you have finished the trials for the first angle do the same number of drop trials for the remaining angles
- ➢ We recommend completing drop trials for 0, 10, 20, 30, and 40 degrees

Data Extraction

❖ *Video Tracker*

- ➢ Upload video to Tracker as a .mp4 file
- ➢ Calibrate video using markings on calibration stick
- ➢ Track the tag through each frame by clicking the red dots, labeled as tag mass
- ➢ Track the fins through each frame by clicking the yellow dots, labeled as fin mass
- ➢ Add a center of mass, using the two sets of tracking data for the tags and fins
- ➢ Export tag and fin mass x and y positions as a .txt file
- ➢ Import data to angle_analysis.m and run code to generate displacement angle vs. time plot

❖ *Smart Tag Data*

- ➢ tag.connect() to start the Serial communication
- ➢ tag.update_files() to get all the files on the SD card
- ➢ tag.download_file(*file_index* -> corresponding to the index from tag.update_files(), *wanted_filename* -> what the local file name is for saving the data to)
- ➢ tag.disconnect() stop the Serial communication, without which Arduino sketch upload can fail since it cannot assert control over the Serial line

Team Bios

Alex Aldighieri I grew up about 25 minutes from Ann Arbor in the small town of Chelsea, Michigan. I come from a family of engineers, so I had plenty of resources to experiment and tinker as I grew up. Coming to UofM was a no-brainer for me because of the reputability, in-state affordability, and proximity to home. When I graduate this semester, I hope to find a job in R&D somewhere local. Aside from academics, I'm the team captain of the club pickleball team, I love cooking, and I occasionally write and perform music with an acoustic guitar.	
Patrick Burke I am originally from Centennial, Colorado, but have spent every summer of my life living in Cape Cod, Massachusetts. I have five older siblings and am the youngest in my family. Math has always been my strong suit and I always had that gut feeling that I was going to be an engineer. Mechanical engineering was especially interesting to me because I love how it covers the fundamental principles that can be applied to any other engineering discipline. I also enjoy living an active lifestyle and doing hands-on work. Studying mechanical engineering at the University of Michigan brought all of my interests together as it is one of the premier engineering programs in the country and a top-tier school all around. Outside of school I play on the club hockey team and enjoy spending time with friends. Upon graduating in the spring I hope to get a job in automation engineering and use my skills that I've learned here at Michigan.	

Daniel Calvache I was born and raised in Miami, Florida. I was introduced to engineering as a high school elective where I first got to use a CAD software to create a 3D model. This experience and having a supportive teacher in that class instantly made me want to do engineering. Once I got to Michigan I learned more about designing, manufacturing and mechatronics through courses such as ME 250 and ME 350. With these class experiences as well as some internships I realized that the field I want to go into is automation because I can combine the skills I have learned about design, mechatronics, and controls. It is a growing field with many interesting challenges and I cannot wait to dive deep into it.	
Jacob Rochell-Share I am originally from Minneapolis, Minnesota. I'm majoring in mechanical engineering, and participating in a program in sustainable engineering (PISE). From a young age, I've always been really interested in math and science and how they interact with the world around us so mechanical engineering seemed like a great way for me to explore all my interests. I'm also very passionate about the environment so I'm especially interested in how I can use mechanical engineering to help fight climate change and develop sustainable and renewable energy. Last summer, I had an internship working on electric cars and the experience got me excited for the future of sustainable engineering.