Acoustic Sensor and Harness for Sea Lions

Final Report
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EXECUTIVE SUMMARY

Emissions from anthropogenic noises can have negative impacts on marine mammals. Our sponsor, Dr. Ron Kastelein is working to identify the sound pressure levels that have behavioral and physical impacts on sea lions in particular. We are working with him to develop and improve upon an existing solution to this problem in the form of a harness equipped with an electronic tag used to take in audio data for evaluation. The tag takes this data using hydrophones, then stores and processes it. The current model has issues with accuracy due to sensor positioning and attenuation from the housing material and the actual body of the sea lion.

The main stakeholders in our project are Dr. Kastelein, our section professor Dr. Alex Shorter, and the sea lion we are working with. We have identified various critical requirements and specifications for our design, the primary ones being accurate sound pressure level (SPL) representation, wearability, and ease of use for our sponsor. We elected to focus our efforts on the packaging of the design process. We worked together using many concept generation strategies, and using our requirements filtered down to the best options to select our alpha design; a waterproof collar housing the electronics so that hydrophones are close to the sea lion's ears. This alpha design was meticulously workshopped through analysis and testing, where it eventually became our final design.

Our final design we are working with encapsulates all our necessary requirements and specifications, and allows our sponsor to have a more user-friendly experience while theoretically increasing the acoustic reading accuracy due to hydrophone relocation (this remains to be fully tested due to unavailability of electronics). Instead of exclusively using a harness, our design focuses on getting accurate readings by using a collar, which is much closer to the sea lion's ears. This design is currently under rigorous engineering analysis and verification, where we are ensuring our requirements are met and making any necessary adjustments along the way. This engineering analysis includes a hydrodynamic drag analysis on the packaging surrounding the electronics of our design, a test procedure to identify noise levels in clip options using a method involving Fourier transforms, and a stretch test to determine the strongest and most effective attachment method for the collar material.

With the semester and our project coming to an end, we have a few recommendations for next steps pertaining to the full completion of this project. Firstly, we would like to send Dr. Kastelein the various final designs we have fabricated for further validation purposes. His feedback will be incredibly valuable to optimizing the current design, as it was difficult for us to exactly know how it will work on an actual sea lion. Additionally, once the electronics are available to us, we would like to create a full final design in which the electronics are working and encased within our housing. This would allow us to complete our final verification test of an accurate SPL representation, and could then be sent over to our sponsor to be used in his research.

ABSTRACT
Our team is tasked with creating a solution to the challenges faced by Dr. RA Kastelein with the current digital acoustic-recording device ‘D-Tag’ (Shorter et al. 2017). Having compared the D-Tag sound pressure level sensitivity against the grid design, Dr. Kastelein has concluded that the tagging presents a real solution to measuring acoustic data in the wild, but does not provide accurate results in the current form (i.e. the D-Tag on the harness). Our motivation for this project is to improve the sound pressure level sensitivity while working within the existing framework for biotagging.

INTRODUCTION
With the further development of offshore technologies and vessel traffic in the oceans, marine wildlife is exposed to man-made audio disruptions that may be damaging to their hearing. These disruptions have many possible sources, including offshore wind turbine installation and operation, oil drilling, military activity, and recreational boating. California sea lions (*Zalophus californianus*) are a prime example of a species affected by these frequencies due to their proximity to these noise sources.

Our sponsor, Dr. Ron Kastelein, studies how these frequencies affect marine mammals in particular. He has a testing facility located in the Netherlands where he can conduct experiments on how certain frequency ranges affect these animals’ behavior and hearing, both permanently and temporarily. To obtain this data, he utilizes a harness with an attached sensor that can take in acoustic data to be examined as shown in **Figure 1**. The sensor is equipped with hydrophones for audio data collection, and the sea lion has been properly trained to wear the harness effectively. This sensor mechanism is referred to as a “D-Tag” throughout this report.

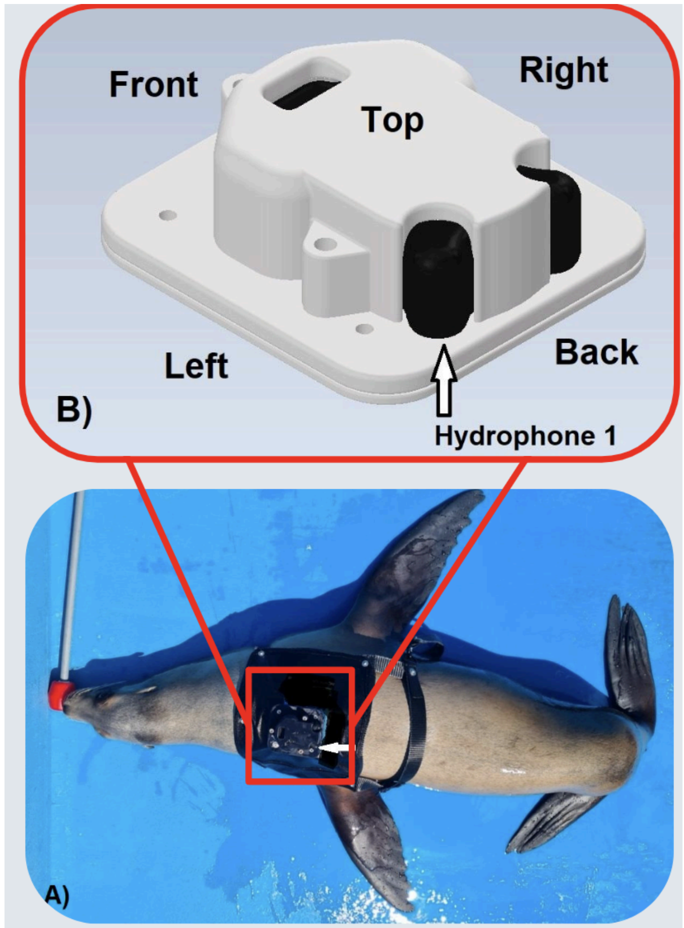


Figure 1. The integration of the D-Tag into the current harness.

This semester, we will be working with Dr. Kastelein and Dr. Alex Shorter, our other sponsor and mentor for this course, to improve the acoustic data intake of the existing sensor. If time permits, we will also be looking into designing a new harness for the D-Tag to be mounted on, as the current harness has many issues with it. Our main focus will be on upgrading the current sensor, and this report will outline important background information, benchmarking on previous designs, design requirements and specifications, stakeholders, and various other important aspects of the design process.

BACKGROUND INFORMATION

Marine mammals including California sea lions (*Zalophus californianus*) utilize sound for communication, predator detection, and orientation [10]. These animals have specific sensitivities to different frequencies of sound and therefore can be negatively impacted by disturbing noises created by shipping, offshore wind turbines, sonar, and other acoustic systems.

A temporary threshold shift (TTS) is a temporary hearing loss or presence of sound perceived without an external source. Exposure to a fatiguing sound is the cause for these shifts to occur, and current research is being performed to determine the effects of specific sound pressure levels (SPL) and which are the cause for such shifts.

Previous research has been published in which audiograms are used to show that hearing sensitivity in California sea lions ranges from 0.1 to 50 kHz, and Dr. Kastelein performed projects on temporary hearing threshold shift (TTS) testing both frequencies between 0.6 and 80 kHz and low-frequency levels as far as 0.031 kHz. These low-frequency tests were performed to cover the entire range of sea lion hearing.

Dr. Kastelein exposed two California sea lions (named F01 and M02 for research purposes) to fatiguing sounds followed by hearing tests during two to three-month trials per frequency, between January 2019 and April 2022. During these trials, signals were played after a short duration of time once the sea lion was positioned at a designated listening station. The sea lions are trained to move away from the listening station once they detect hearing the sound. They do not leave the station without hearing a sound unless called back by their trainers. During these tests, trainers were out of sight, there were no movements within 15 meters of the pool, the water circulation system was turned off, and weather conditions were set within a certain wind speed range all to maintain constant low ambient noise.

Each of these test sessions lasted up to 12 minutes per sea lion and consisted of around 25 trials. One-third of these tests were “catch” trials in which no signal was played, and these were kept in a random order so no patterns arose to affect the sea lion's behavior. One important finding was that the hearing thresholds needed to adapt to new hearing test frequencies, which took two or three, sometimes even 5, sessions to stabilize. This data was omitted and testing of these frequencies continued once both sea lion thresholds were stable.

Figure 2 (on page six below) shows the audiograms recorded for both sea lions (F01 and M02) at both ranges of frequencies. Following is **Figure 3** which is a collection of audiograms for each of the seven California sea lions’ TTS hearing thresholds that have been published. Throughout this study, F01 aged from seven to 11 years old and M02 from one to five years. The wide range of ages observed among the sea lions in various tests raises speculation, largely due to the small sample size. Dr. Kastelein's goal was to increase that sample size to reduce any worry that hearing sensitivity was due to the individual differences between the animals and/or the measurement methods. **Figure 4** shows audiograms for the two sea lions in this study alongside Ronan’s, the equation for “other marine carnivores” and the proposed generic audiogram equation. Ronan was used in comparison specifically due to having the lowest audiogram published so far, as well as similarities in hearing thresholds with F01 and M02. The behavioral measurement technique in the study with Ronan, as well as low ambient noise levels, made these data good comparisons.

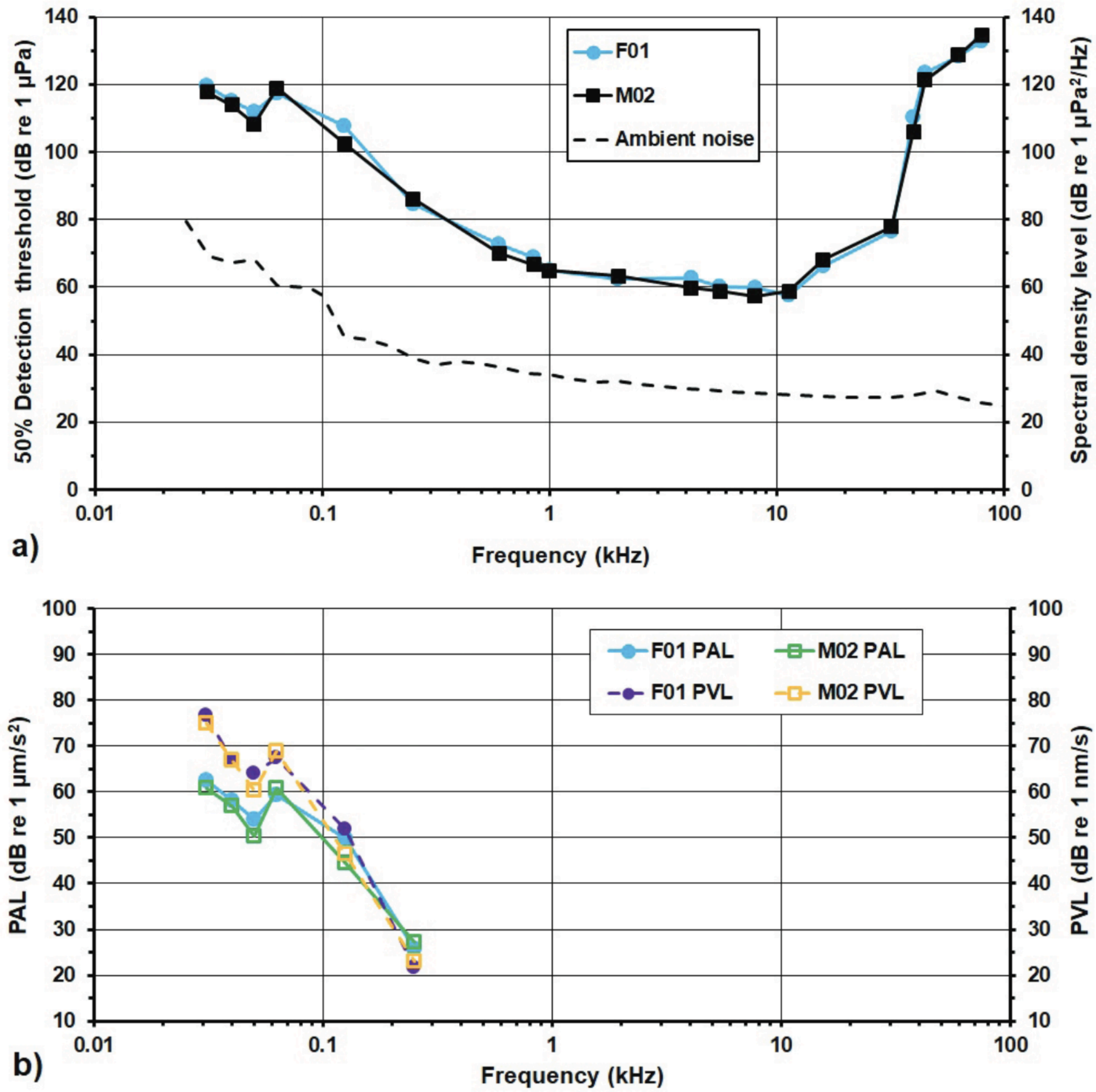


Figure 2. Underwater sound detection in California sea lions. These audiograms for sea lions F01 and M02 are shown during the presence of (a) sound pressure levels from 0.031 to 80 kHz and (b) particle acceleration level (PAL) from 0.031 to 0.25 kHz. The dashed line in (a) represents the ambient noise in the pool between .025 and 80 kHz. [10]

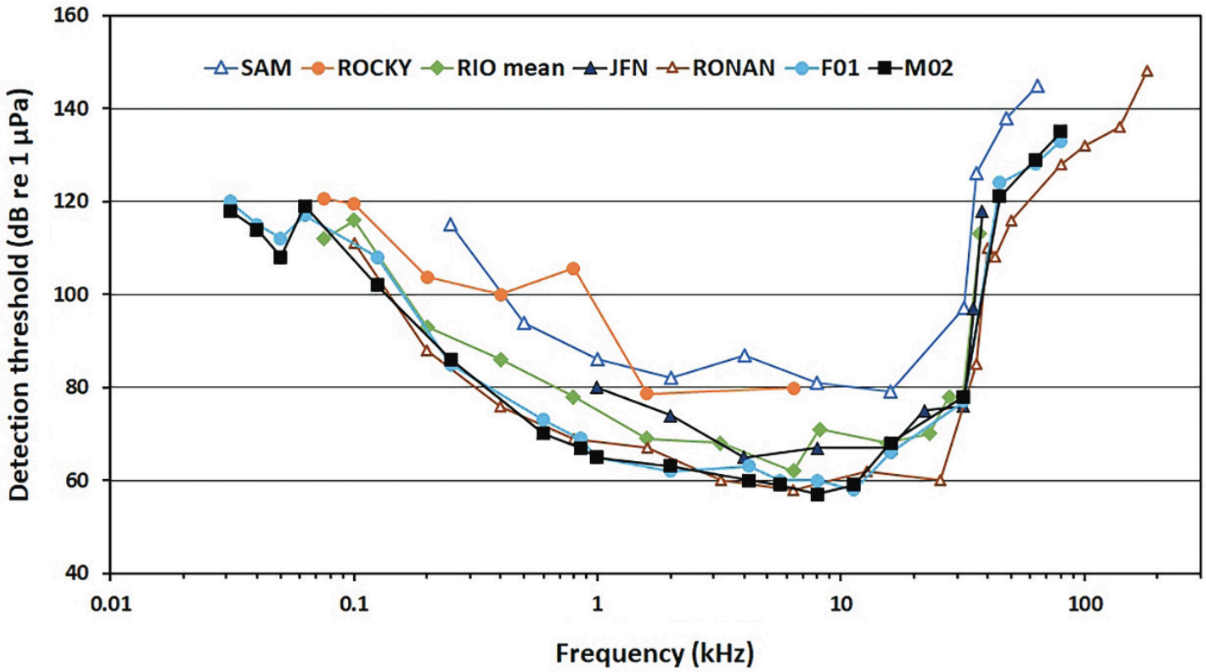


Figure 3. Underwater audiograms of 7 California sea lions throughout published studies recording this specific species. Each is outlined by Dr. Kastelein. [10]

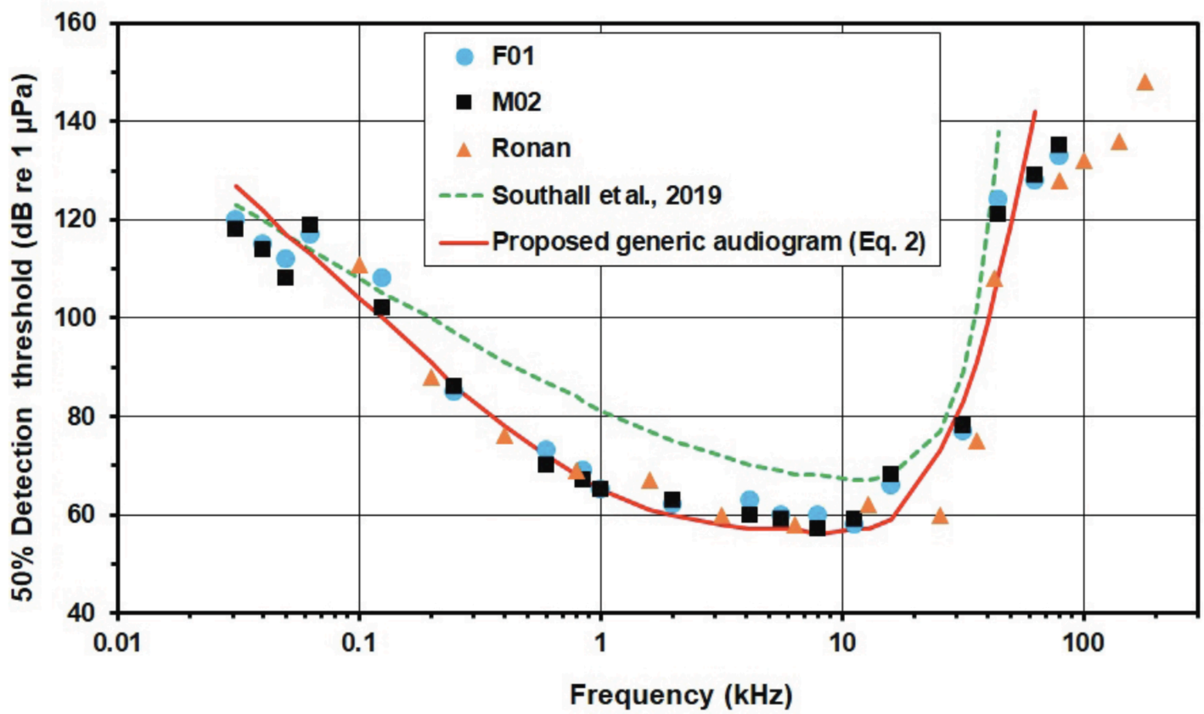


Figure 4. Proposed equations to fit underwater detection threshold of California sea lions. The dashed green line represents the equation for "other marine carnivores in water" and the solid red line depicts the proposed genetic audiogram equation for California sea lions. [10]

PREVIOUS SOLUTIONS

Hydrophones

Hydrophones which can be seen in **Figure 5** are piezoelectric ceramic passive elements that when exposed to changes in pressures create small electrical currents. When these signals are amplified they can be used to measure the frequency and sound pressure level of the phenomena underwater. These provide a way for scientists to characterize underwater systems that are most easily understood through acoustics.

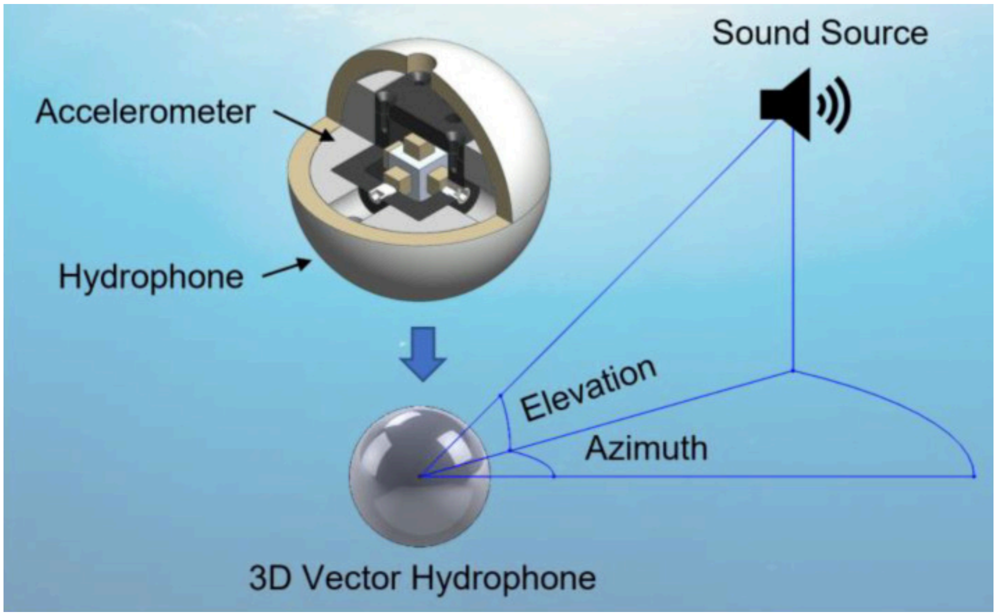


Figure 5. This image shows a Ceramic Piezoelectric Hydrophone, which is made up of an accelerometer sensor that detects the acoustic pressure variations in the water.

Long-Term Passive Measuring Systems

One solution that exists for measuring underwater acoustic effects is long-term (> 1 year), passive acoustic collection. An example of this strategy is the WaveGlider HARP System shown in **Figure 6** developed by Liquid Robotics in collaboration with the Scripps Institution of Oceanography (SIO). This system samples acoustic signals at 200 kHz continuously. This system then stores the data samples into 2 TB hard drives that are offloaded by the WaveGlider making landfall and a voyage.

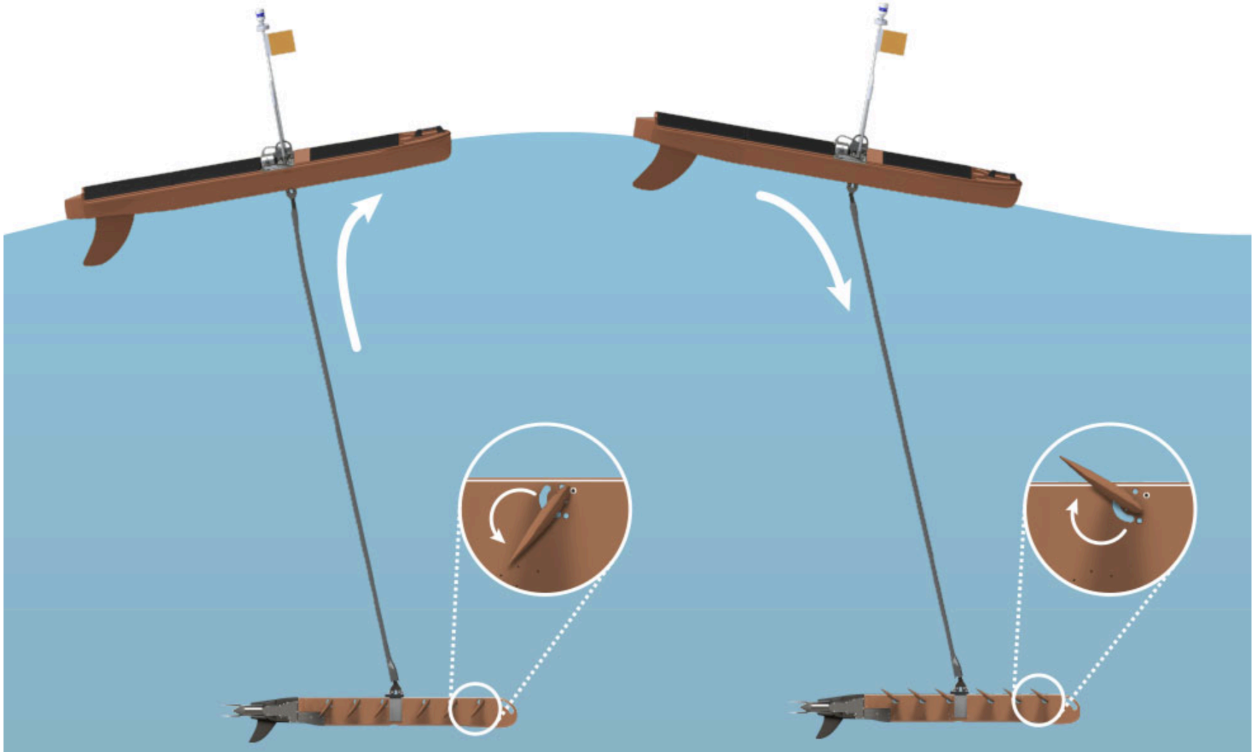


Figure 6. Image shows two WaveGlider HARP Systems developed by Liquid Robotics in action. The WaveGlider HARP Systems are shown riding the waves using a two-part architecture that exploits wave energy which provides the energy for forward propulsion.

Advantages: Systems like this help gather large amounts of data around a certain region when animal-specific information is not necessarily the main focus. The ability to collect large amounts of data can provide a basis for more studies in the future if interesting behavioral patterns aren't understood on a more microscopic level.

Disadvantages: Systems with such a macroscopic focus make it hard to judge individual effects on a specific population and animal-specific effects. They also lose the ability to investigate a specific pattern in an animal population such as anthropogenic noises in an animal species.

Sonobuoy

Sonobuoys are air-deployed acoustic sensors primarily manufactured to detect submarines. Its compacted package is formed into a small buoy that is dropped from the aircraft as shown in **Figure 7**. The data is collected and then relayed to an aircraft. The acoustic data is received and then used to detect underwater machinery.

Figure 7. This image shows a sonobuoy being deployed out of an aircraft.

Advantages: Systems like this are helpful because they relay real-time data and provide data without having to retrieve the device.

Disadvantages: Systems are designed only to be used once. Another disadvantage is that the Sonobuoys cannot move with the subject that is trying to be measured and cannot be relocated either if misplaced.

Hydrophone Grid

The setting for Dr. Kastelein's research is the SEAMARCO Research Institute where there are two tanks of dimensions (7 × 4 m, 2 m deep) for the outer pool and (6 × 4 m, 2 m deep) for the indoor pool connected via two channels (each 2 × 2 m, 1 m deep) (shown in **Figure 8**).

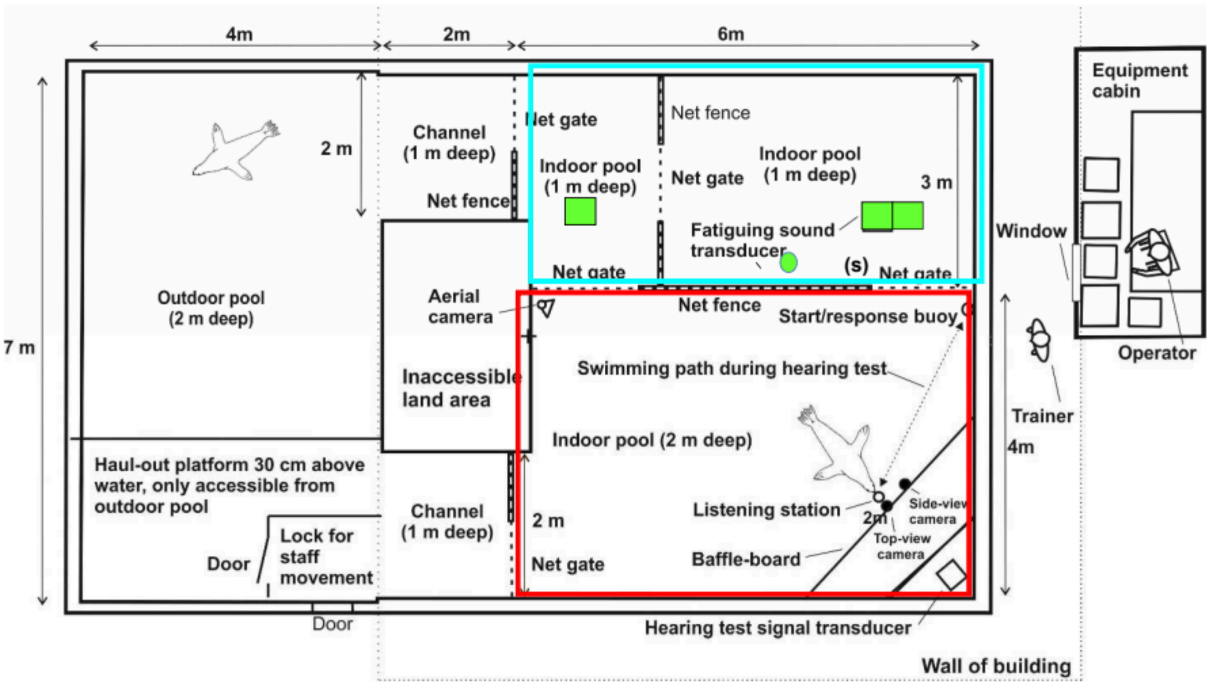


Figure 8. Diagram of the SEAMARCO Research Institute (Image courtesy of Dr. Kastelein).

The original method for sound pressure level measurement is a grid of hydrophones placed every square meter at 0.1m and 1.0 meters of depth. The sound measurement equipment consisted of three omnidirectional hydrophones (B&K, model 8106, sensitivity -173 dB re 1 V/μPa; all 3 were used at the same time) with a multichannel high-frequency analyzer (B&K PULSE, model Lan-XI type 3160) (Kastelein et al., 2024).

Advantages: The advantages of this solution are the high accuracy and low attenuation of the sound recorded by the devices. This allows Dr. Kastelein to get a clear image of how the sea lions interact with the fatiguing sound in a controlled environment. This also can serve as a basis to benchmark future solutions since Dr. Kastelein has a lot of confidence in this method.

Disadvantages: The disadvantages to the solution is the static nature of the measuring scheme. This grid of hydrophones is hardly possible in the wild when wanting to measure actual sound exposure. Dr. Kastelein has stated that although this is a good solution for a lab setting, it is not feasible when taking measurements in the natural habitat of the sea lion (Kastelein et al., 2024).

Previous D-Tag:

The other solution that Dr. Kastelein has explored is using an animal-fixed method for measuring sound exposure level. For this method he has employed the use of a digital acoustic recording device or 'D-Tag' (Shorter et al. 2017). This solution involves attaching a D-Tag to a custom-made harness that the sea-lion has been trained to wear. With the current form of the solution, the D-Tag is oriented backwards to be more hydrodynamic. An example of the harness and the D-Tag is shown in **Figure 9.**

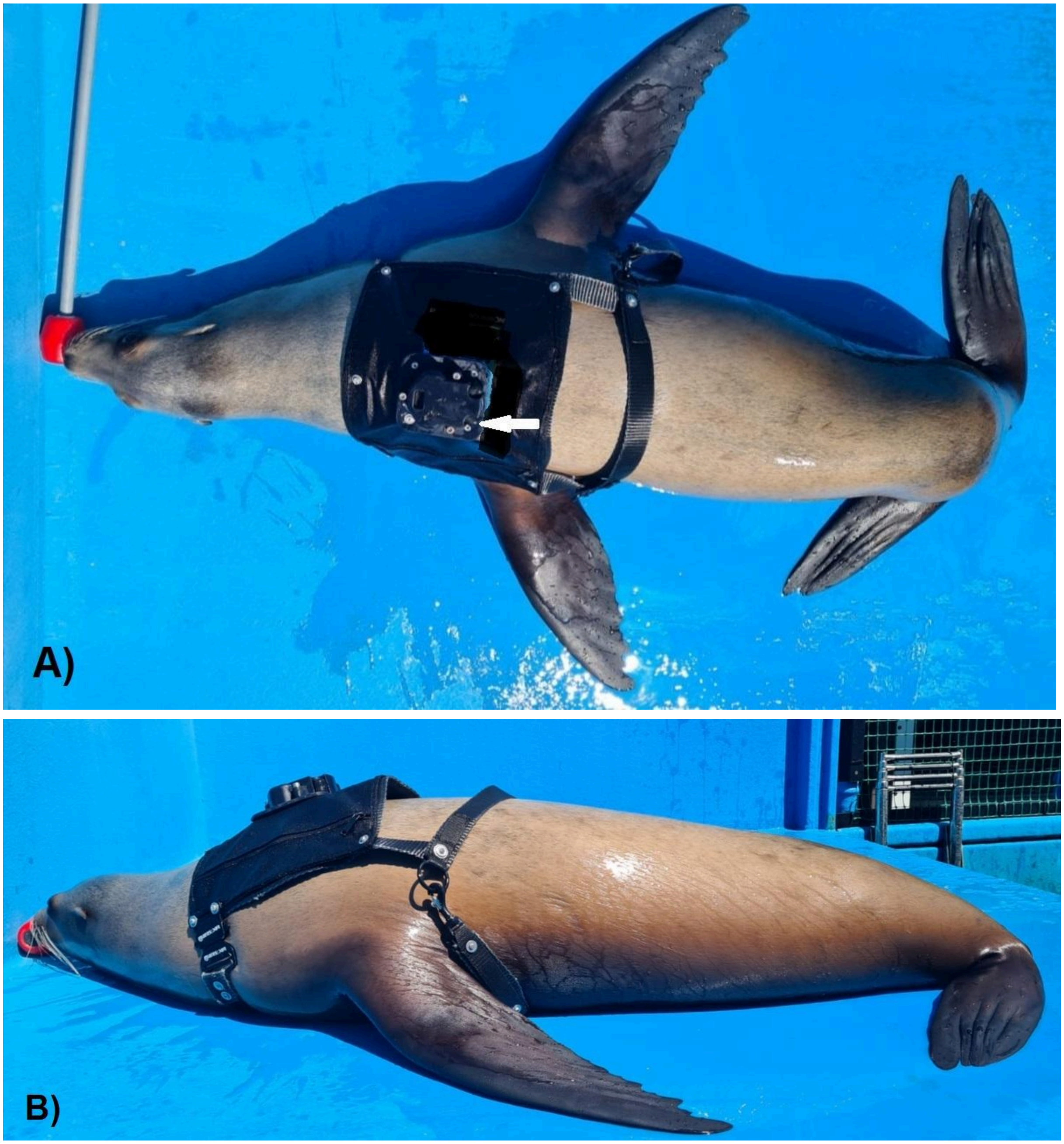


Figure 9. The D-Tag and harness on the back of the sea lion. This harness was custom built by Dr. Kastelein when a previous harness solution failed. The sea lion has been trained with this harness solution. (Images from (Kastelein et al., 2024)).

Advantages: One advantage to a mobile setup is the environment neutral state of the solution. That is to say, the tag can be deployed in any novel environment (e.g. the wild or natural habitat of the sea lions) and theoretically record accurate data. In addition, the maintenance on this tag solution is very minimal when compared to the grid of hydrophones presented earlier. The post processing data can also be interpreted more easily as the user is guaranteed that results from the acoustic measuring are relevant only the animal is wah attached to instead of having to extrapolate the sound exposure level (SEL) of the animal based on localization methods from a grid of hydrophones.

Disadvantages: The issues that Dr. Kastelein has with the current D-Tag setup is the loss in sensitivity of the hydrophones when the animal is oriented with its body in between the D-Tag and the point source. This results in significant SPL sensitivity that Dr. Kastelein cannot accept as valid measurements (**Figure 10**).

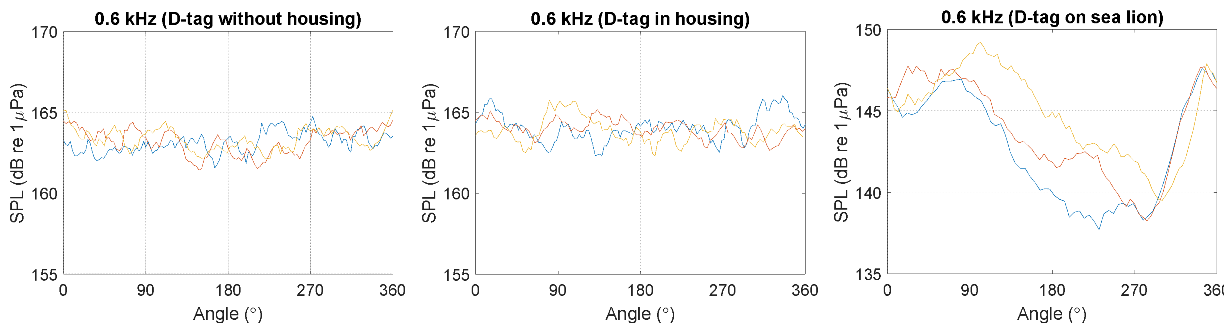


Figure 10. Sound pressure level sensitivity loss with D-Tag in three different test setups. This is an example of the results from (Kastelein et al., 2024).

Here it can be seen that the losses seen by the housing of the D-Tag are very small compared to simply the D-Tag without the housing. However, when the D-Tag is mounted on the sea lion and the sea lion is spun around a perpendicular axis to the sound path of travel to the D-Tag, The losses are significant and measurable compared to the other two tests. This is a prime example of the current issue with mobile bio-tagging that Dr. Kastelein has asked us to improve.

DESIGN PROCESS

In developing an acoustic solution to Dr. RA Kastelein's problem, our team has chosen to take a structured design approach. Our team has chosen to follow the *ME Capstone Design Process Framework*. We opted for this framework because it offered comprehensive guidance for each stage of the process. When choosing a design process framework our team thought of four necessities which the framework would compose of. The first necessity was that the framework needs to have clear objectives at every step. We found that the *ME Capstone Design Process Framework* encompassed that as it divided every main step that is necessary in coming to a result. The ME framework demonstrates what needs to be done at every step. The next necessity our team had was that the framework should prioritize the stakeholders' needs. This is important because we didn't want a framework that would steer us away from the stakeholders' vision of the end product. We found that the ME framework best fit this need because the first two stages consist and guide the design in the vision of the sponsor's needs. Another necessity our team had in mind for a design framework was that we wanted an iterative process. This is crucial because our team wanted a process in which if we made a previous mistake we could refer back to a previous stage without breaking our process. The ME Capstone framework does a great job in being iterative because between every stage the user can go back to previous stages. The ME framework also guides users to specific stages if need be which allow for a better design process. The last necessity our team demanded from a design framework was that it needed to be flexible. What our team intended was that we needed a framework that wasn't so specific that if we decided to make a change it would throw us off the design process. The ME capstone framework was fitting in the sense that it provided us guidance while still allowing us to make some of our own decisions which fit the scope of our project. The *ME Capstone Design Process Framework* **Figure 11** consists of all of our team's necessities in five stages.

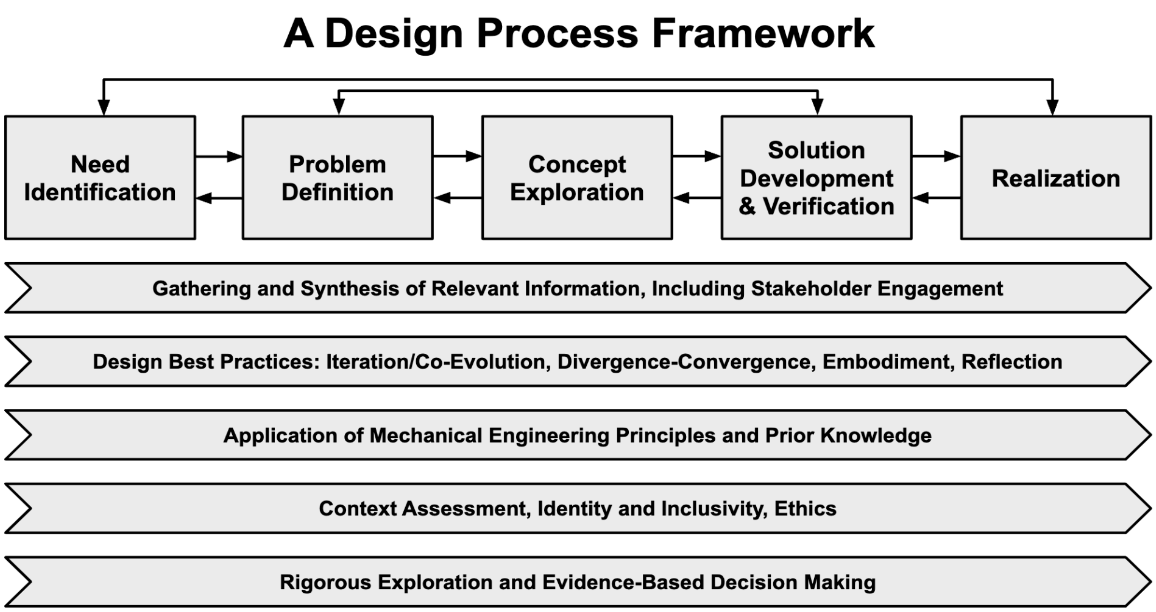


Figure 11. The five stages of the *ME Capstone Design Process Framework* are shown. The five stages consist of need identification, problem definition, concept exploration, solution development, and verification and realization. The five ribboned points are crucial thinking points for every stage of the process [4].

The five stages and integration of our project are as follows:

Need identification

Our team used stage one of the design process framework by first benchmarking the actual bigger picture of why Dr. RA Kastelein was conducting research on animals in the first place. We conducted our research by first finding why our problem is important, we researched the sounds made in the oceans by boats and oil companies and the effect they had on the marine life around them. We also decided it was necessary to research the science of hearing, particularly temporary threshold shifts. This was all key in understanding the bigger picture which was marine animals are exposed to audio disruptions that may be damaging to their hearing.

Problem definition

Before thinking about solutions our team needed to identify the framework of the problem at hand. By conducting interviews with both primary stakeholders, Dr. RA Kasteleins and Dr. Alex Shorter, our team was able to better understand the problems concerning the acoustic data being gathered by the D-Tag. From there, our team conducted benchmarking and literature reviews regarding Dr. RA Kastelein's ongoing research and reviewed the current packaging design and acoustic data. After realizing the problem at hand through interviews, researching, and benchmarking our team was able to come up with requirements and engineering specifications. At this stage of our process, our main goal was to find out the different needs and wants of both of our primary stakeholders and figure out what requirements would be necessary in a probable solution. Our team also wanted to see how we could test these requirements methodologically and measurably.

Concept exploration
During this stage, our team plans to have an outcome of different types of concept solutions that solve our acoustic issue at hand. So far our team has used different types of concept development methods such as design heuristics and morphological charts. Each team member was tasked to develop many different concepts that adhere to the requirements at hand. Our team members encouraged each other to look at previous sensor harnesses and placing methods but to also think outside the box and develop solutions that haven't been made. Once we developed concepts we collaborated and evaluated each concept and disregarded those solutions that didn't fit the requirements or specifications of our problem definition. After concept screening and evaluation our team went into the concept selection phase. In this phase, we decided to overview the advantages and limitations of each concept that was left. We looked at each solution in a Pugh Matrix which allowed us to give values to each design, the design with the highest scoring would be the one we would consider moving on with to the next stage of the design process framework.

Solution development and verification
During this stage, our team would like to focus on the concept picked from the previous step and develop a model in both CAD and a physical model. Using the physical model our team plans to test the requirements at hand. Our goal would be to meet the specification goals while optimizing our concept. This step will also consist of our team being in constant contact with our primary stakeholders to update them with our findings and incorporate their input. Our end goal with this stage is to have a justification of the answer to the prob and its verification based on evidence.

Realization
This is the last stage of our design process. In this stage, we hope to give Dr. RA Kastelein our new findings and have him test it. We would hope to find out if our solution worked for Dr. Kastelein's research efforts.

During our research into various design frameworks, our team deliberated between two equally promising options. The *ME Capstone Design Process Framework* discussed above and the *d.school's model of design thinking* design framework are shown in **Figure 12.**

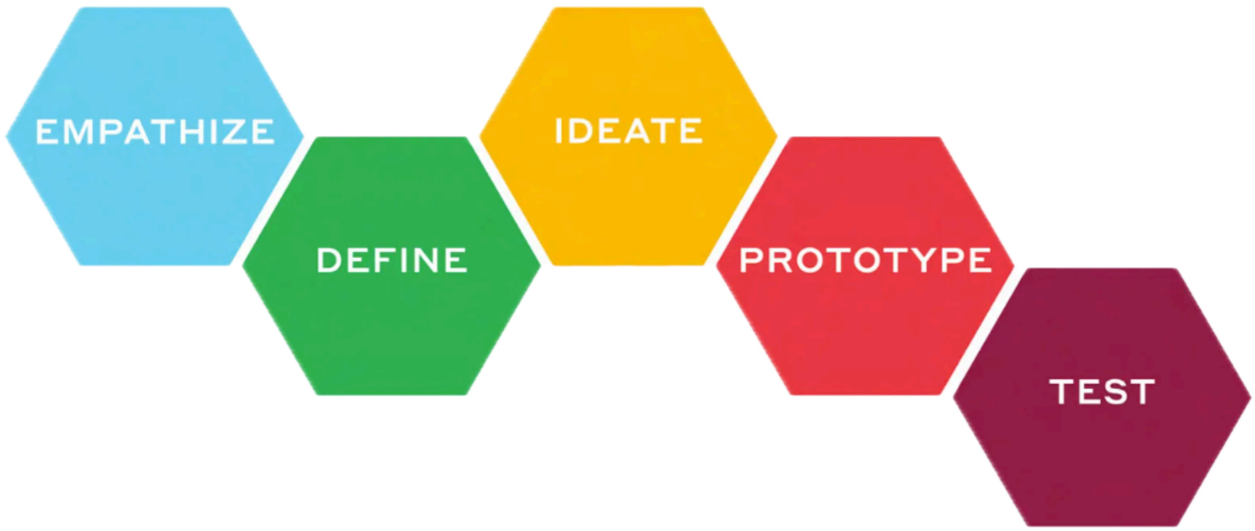


Figure 12. The image above shows different stages of the *d.school's model of design thinking* design framework. The stages consist of empathize, define, ideate, prototype, and test [5].

Our team determined that the *d.school's model of design thinking* design framework was not a better fit for our design process because its stages were not a good fit for our project timeline. The framework specified by *d.school's model of design thinking* ends with testing when our team lays a design framework that ends with a finished product.

While our team adopted the design framework provided by the 450 instructional teams, we also opted to incorporate additional stages that were not emphasized by them. We chose to include need identification because we thought it would be important to consider the needs of our project. After all, it provides the team with clarity of purpose and motivation in developing a solution. Our team also chose to include the realization phase as it would allow us to get back our stakeholder's feedback. It may be too late to fix the problems in the solution we create but it will allow us to realize the flaws in our process for future projects.

DESIGN CONTEXT

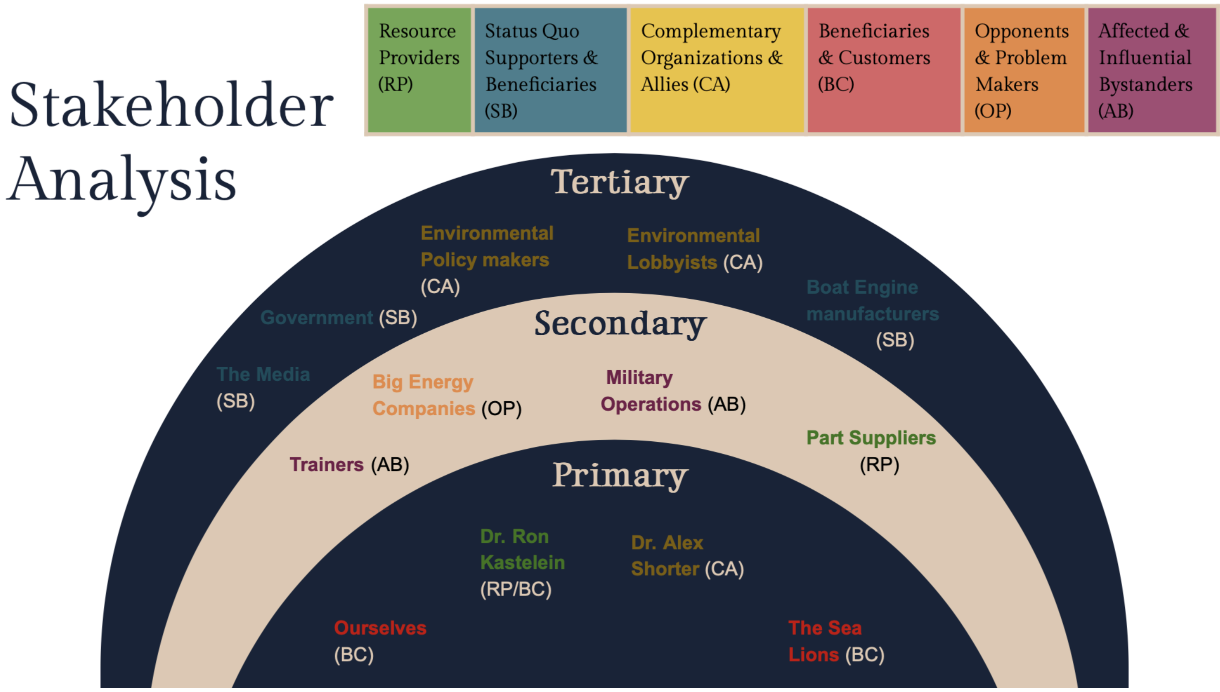


Figure 13. Stakeholder Analysis is broken down into primary, secondary, and tertiary stakeholders in terms of who has the most influence over, or the largest impact due to, the project deliverables. Each stakeholder fits into one or more categories outlined in the table to the top.

Breaking down our stakeholders, shown in **Figure 13**, the majority of those influenced by (or influence) our project are concerned with the environmental side of things. Our primary stakeholders are concerned with the maximum frequencies and sound pressure levels that can be experienced by marine mammals to come up with regulation that prevents organizations from producing sounds that can cause temporary and permanent hearing loss. The sea lions themselves would benefit from this research because outcomes would improve their environments and prevent the need to move. Our sponsors - Dr. Ron Kastelein and Dr. Alex Shorter - are primarily interested in bio-tagging and testing these frequencies. These stakeholders are positively impacted by this project, including ourselves who gain valuable experience and knowledge through research as well as interactions with peers and other stakeholders.

Many of these stakeholders could be negatively impacted by the results of our project as well. The results of the overarching research will cause limitations on sound levels that man-made sources, such as boats, oil drilling rigs, and military operations can expel. These organizations might need to spend time, resources, and money on changing current processes to meet these guidelines, which might have a “negative” impact on them. Considering military operations are often paid for using tax dollars, there’s a chance everyday workers and the economy in general are impacted as well.

The societal impact affected by this project is the way we generally hold the safety and security of animals with some value, and there needs to be some sort of plan in place to prevent our human efforts from negatively interfering with these animals' lives. We do not want any more endangered species. In general, our sponsors care most about the environmental and educational impacts, most definitely over profit. This project does not have much if any promise to be profitable, considering the technology used is specifically designed for research purposes and there isn't any audience besides other scientists and researchers who would use the product. The social impact seems to fall within the environmental category but isn't too high on the list of importance.

INTELLECTUAL PROPERTY

Our primary goal in this project is to prove the effectiveness of current acoustic sensors and their placement on the animal. Because of this, I don't think the order of priorities will affect our process much at all, and the overall social impact will not be greatly impacted either positively or negatively. Since the result of this project isn't so much a physical design or patented product but more scientific proof of what methods work best for accurate acoustic data, intellectual property doesn't play much of a significant role. If we were to continue this project's past research and move forward with attempting a new housing, packaging, or even harness design, we can see intellectual property having a slightly more important role, however, considering this will not be for profit the IPA would be more for academic reasons.

Our team owns any paper we write based on provided data and other research we conduct, and for the most part, until we move toward designing/building upon existing products, the D-Tag sensors are owned by the lab at the University of Michigan, and the harness, as well as the testing facility in the Netherlands, are owned by Dr. Ron Kastellein.

The overarching goal of this project is to aid in research that has ethical considerations in the form of human-wild animal interactions. Our team holds the safety of marine mammals and their habitats as a key value, which aligns in parallel with our sponsors. Because our project deliverables will be used by our sponsors to perform experimental tests on sea lions, there are interesting power dynamics within both our team and the interactions with these stakeholders. Within our team, we have a member who has more experience working with biologging technology and works directly with one of our primary sponsors - Dr. Alex Shorter - in a lab at the University. Because of this greater level of experience, this team member has a sort of power of knowledge over the rest of us who haven't had much if any exposure to such research. While interacting with our sponsors, they have the power to decide which direction our project will be guided in and therefore how our designs might end up looking for final design outcomes and deliverables. Our team plans to mitigate any unforeseen inclusivity issues that might arise by holding consistent in-person meetings to converse about how our sections of the project are moving and what if any problems we may be experiencing. We hold each other accountable for maintaining respect for each other as well as our stakeholders, and our instructional team has made it clear that any issues we may be uncomfortable with dealing with ourselves may be brought up individually and they can aid us in working through a solution if necessary.

Sustainability and Ethics

In terms of sustainability our team does not have any large concerns for our collar. There will only be a need for one collar to be developed so the environmental impact related to mass manufacturing can be disregardedThe collar will undergo thorough inspection both before and after each use, with continuous monitoring during its use. It is important to note that the collar will only be utilized within a controlled testing facility, ensuring minimal impact on the surrounding environment and other animals. As we work with existing items, we will work to reuse materials and be careful not to produce any waste. Using recycled materials is a possibility that most likely wouldn't have much of an impact on the cost.

It is critical to consider the ethical decisions when creating a new collar. Since our collar will be worn by a sea lion we are aiming to make a solution that is non invasive to the sea lion or the handler, and is comfortable. We plan to invest the time to create a solution that has accurate measuring capabilities because it will be informing future policies. Keeping integrity in our testing and analysis, as well as emphasizing transparency by giving true facts rather than making up data to fit specifications or appease stakeholders, are examples of ethical aspects in our design process.

Power Dynamics

As our professor (Dr. Shorter) has experience with this topic in detail and he has been involved with the design on the D-Tag solution in the past, our professor has valuable insight and indirect power over the design of our solution. In addition to this, Mike Reynolds, a team member, who works in Dr. Shorter's lab, has experience processing the data and therefore allows us to process the data more quickly during testing and can provide insight based on his familiarity with the tagging process. Lastly, the other important power dynamic is the dynamic between Dr. Kastelein and the group. As a biologist, Dr. Kastelein has admitted that he does not have the same familiarity with the rigorous and technical design process that the group is undergoing, and therefore does not understand the potential impossibilities of certain requirements with the project timeline we use. As a result, he maybe unfamiliar with some of the metric that group is using to assess the viability of a design or the process the group uses to develop alternative designs. However, in addition to this Dr. Kastelein has expert knowledge of the animals themselves and his input as to design considerations for the harness have guided the teams thought process about how to approach the design.

REQUIREMENTS AND SPECIFICATIONS

Table 1. Requirements and specifications that our team has decided to use moving forward in the design process.

Priority	Requirement	Specification	Source	Testing Method
High	Rotation-resilient SPL sensitivity	SPL Sensitivity needs to be axisymmetric around the axis orthogonal to the sound source direction with a range of than 7 dB across frequencies 0.6 kHz-40 kHz	[1]	We will test this requirement by testing different solutions by rotating them around the relevant axis around somebody that closely resembles the sea lion
High	Sampling Frequency	Sampling Frequency is at least 80 kHz	[8], [9]	This will come from internal parameters and be tested by measuring the highest frequency that our solution can measure from some source sound.
High	Ease of use (wearability)	-Must be able to be put on under 30 sec and taken off under 20 sec by one of our team -Attachment mechanism needs to have max SPL less than or equal to current clips*	Benchmark Parameters, Sponsor Data	-Timing human putting on harness on a sea lion-like object/human -Measure SPL with microphone and post process data
Medium	Recording duration	Needs to be able to record for at least 4 hours	[1], [7]	This will come from deducing the sampling frequency and the amount of memory each data point requires and then comparing that to the available memory.
Low	Interface with current harness	Needs to fit within 19.58 square inches of the current mounting plate (19.58 square inches is the current footprint of the current tag)	Sponsor	This will nominally be measured using a ruler or caliper.

Low	Impulse resistance	Must withstand impact against a wall of 242.25 N	[20], Sponsor Data	Apply impact load of 85 Kg moving at 3 m/s decelerating in 1 s

Rotation Resilient SPL

This requirement is the crucial of what Dr. Kastelein wants our team to improve. Based on the sample graphs in **Figure 10**, it can be seen that the range of sound pressure levels that the D-Tag is measuring is far too large and varied when the sea lion rotates. Dr. Kastelein would like this loss in sensitivity to decrease concerning the axis of rotation. Therefore, using his metrics for the tag-only rotation, we have deduced that the maximum range that our tag solution can have when rotated around an axis orthogonal to the sound source path of travel is 7 dB. Given that this is the primary issue that Dr. Kastelein wants us to solve, we decided to give this requirement the highest priority.

Sampling Frequency

Our solution needs to be able to collect frequencies that are relevant to the sea lions, our device needs to be able to sample at twice the Nyquist frequency of the sea lions. According to literature, sea lions can hear maximum effective hearing peaks anywhere from 35-40 kHz (Muslow et al. 2011; Cunningham and Reichmuth 2016). Therefore, to provide a conservative sampling frequency and to stay consistent with Dr. Kastelein's test (Kastelein et al. 2024), we chose our sampling frequency to be 80 kHz. We decided to give this requirement high priority because it must be met for our results to be accurate at all.

Recording Duration

Given the parameters of each of the studies that Dr. Kastelain performs, our team decided that no matter what solution we adopted must be able to record for at least as long as Dr. Kastelein's studies operate in a worst-case scenario. In the end, Dr. Kastelein's testing method involves putting the tag on the back of the sea lion and then taking pre-exposure measurements (i.e. measurements before exposing the sea lions to the fatiguing sound) (Kastelein et al. 2024 and 2020). Although this process is not clearly described as taking a certain amount of time, our team made a conservative estimate that this section of the test takes anywhere from 30 minutes to an hour. His next step is to test the exposure of the application of the fatiguing sound which he does for 1 hour (Kastelein et al. 2020). The last step is a post-exposure test which can take anywhere from 12 minutes to 2 hours (Kastelein et al. 2020). Therefore, based on this we made the conservative estimate that the data collection process will take a maximum of 4 hours. This requirement is a medium priority because of the necessity of being able to conduct the studies in a controlled environment, but is not a high priority because most data collection systems we foresee interacting with can already record for several hours.

Interfacing With Current Harness

Given that the seal has already been trained to use the old design, compatibility with it is essential for our updated acoustic sensor reconfiguration (Kastelein et al. 2024). The seal would need months of extra training if a different harness design was implemented (this estimate was provided by Dr. Kastelein). Given that this process takes extra time and money that would hinder the process of research, we have elected to not find a solution that would negatively impact the flow of research. This takes the form of making sure the solution that we have is compatible with the current harness. This criterion will be met by making sure that the device needs to fit within the previous area occupied by the current tag. It is important to note that this specification is subject to change in the future if we feel that a more accurate method for assessing the compatibility of the tag with the harness is found. Because of this reasoning, we feel that this requirement is not as high a priority as other requirements on this list.

Table 2. Benchmarking comparison between the previous solutions presented earlier as to their ability to meet our requirements.

Benchmarking With Previous Solutions

	Rotation-resilient SPL sensitivity	**Sampling Frequency**	**Recording duration**	**Interface with current harness**
HARP System	Meets Specification	Exceeds Specification	Exceeds Specification	Does Not Meet Specification
Sonobuoy	Meets Specifications	Does Not Meet Specification	No Data	Does Not Meet Specification
Hydrophone Grid	Meets Specifications	Meets Specification	Meets Specification	Does Not Meet Specification
D-Tag	Does Not Meet Specification	Exceeds Specification	Exceeds Specification	Meets Specification

Although we have included the HARP system and Sonobuoy in this comparison, these are not valid designs for our solution moving forward as they do not provide any improvements over the current solution that Dr. Kastelein has already (i.e. the hydrophone grid). The two solutions we will focus most of our time on as benchmarks to compare against are the hydrophone grid, which Dr. Kastelein has shown is accurate for a static environment, and the D-Tag which is currently the only solution that can interface with the harness and is consequently the most mobile.

ASPIRATIONS

There are certain requirements that we have that we have seen fit not to include in the list of formal requirements as they are either not critical or are not easily testable.

Aesthetically pleasing

Since our solution represents the University of Michigan and ourselves we would like to provide a quality product that does not look unprofessional. To this end, we would like our solution to have small aspects that separate a 'finished', professional product from a simple prototype. Small things such as quality fastening techniques, use of quality materials, 'clean' wiring, and that any manufacturing is completed to high quality.

Noninvasive

This requirement is quite critical to the environmental nature of our project. Any solution our group creates must not cause any physical harm, discomfort, or change in the behavior of the animals we are working with. However, since the harness that our solution must interface with is already not very invasive, this requirement is unquantifiable and redundant.

Reduction in drag / hydrodynamics

This would serve to be both noninvasive and reduce noise in the measurement. We would like to include this requirement in the future, however the group felt that we could not include it and be solution-neutral.

Minimize sound produced by attaching/detaching the harness/fixtures

When training the sea lions to wear a previous version of the harness, a new harness was quickly needed to replace the original version. This was because the first version slid over the head and caused sensory overload for the sea lions. When the new design was created an attachment mechanism that didn't produce loud noises was needed to not disrupt the sea lions. Therefore, we would require that our solution would need to be at least as quiet as the current solution. However, since the current solution has no data associated with how loud it is, we have no benchmark to compare to and quality method for measurement.

Hydrophones closer to head/ears

Our team hopes to relocate the hydrophones closer to the sea lion's ears as it will provide a more accurate representation of what the sea lion is hearing rather than having the D-Tag on the back of the sea lion. This requirement may not be achieved in the scope of the timeline given because the sea lion will have to get re-trained to wear a hydrophone closer to its ears. This process can take months or may not even be possible.

Improved UI
The current user interface programmed for the D-tag data is difficult to navigate and not as intuitive as Dr. Ron Kasetelein would hope. The software is old-fashioned and not user-friendly, and a simpler series of steps to work with the system could be beneficial for the biologists running the experiments. Dr. Kastelein envisions a series of buttons that allow the user to decide on a frequency and punch it in, then choose from a series of button options for how often samples of frequencies are read. This would make life easier for those running the tests, but is not necessary or necessarily in the scope of our project considering the software is not our team's specific objective.

All parts are waterproof and readily available (ISO)
Materials used in the manufacturing of the harness must be able to withstand prolonged water exposure, depth, pressure, effects of saltwater, and consistent removal and re-submerging. It would be very beneficial for any concept solutions for the harness and packaging system to minimize sound, be extremely durable, and have all parts easily accessible to the lab location. Current solutions using galvanized bolts rust quickly, seawater "proof" thread unravels each use, snaps and clips disturb the animal, and thick materials can increase water drag which negatively impacts swimming. Also, any parts that need replacement should be ISO-graded so that the lab can quickly and efficiently continue working.

PROBLEM DOMAIN ANALYSIS

Relevant Engineering Principles
Our project incorporates many different aspects of technical engineering principles that we have learned during our undergraduate education. While the design process, design context, and other non-technical backgrounds are important, having the necessary technical knowledge to apply to the problem is vital to the success of our group. **Figure 14** identifies the four main engineering principles that will be most relevant to our specific problem domain.

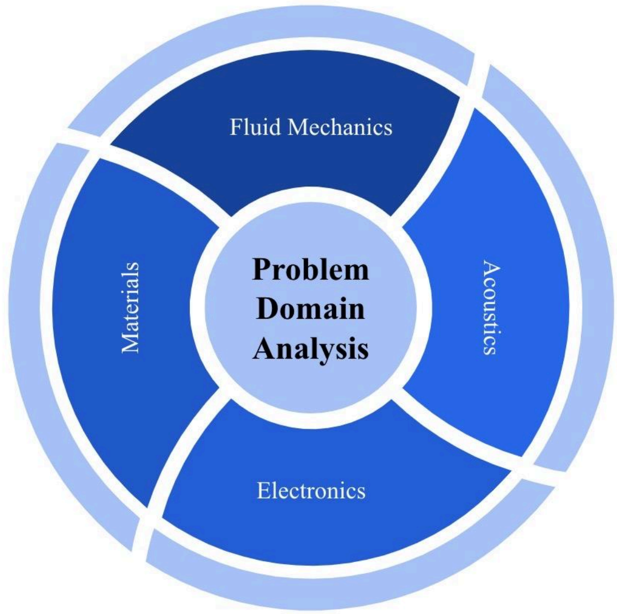


Figure 14. The problem domain analysis of our project, with the pertinent engineering principles being fluid mechanics, acoustics, electronics, and materials. A solid understanding of these disciplines will be vital to the technical success of our project.

Fluid mechanics is of obvious importance to our project, as the main setting of our testing and eventual final product is underwater. It will be important for us to consider many aspects of fluid mechanics, whether it be the hydrodynamics involved with the movement of the sea lion, the hydrostatics associated with keeping the harness and D-Tag in place, or simply how sound waves travel through water. Fluid mechanics is well known for its difficulty and non-intuitive, so it will be important for us to brush up on this topic as well as find ways to apply this knowledge to the problem at hand.

Another engineering principle that will be of huge significance is acoustics. Understanding how sound waves propagate through different mediums will allow us to make informed design decisions for our final product. Most of our previous knowledge of acoustics deals with their properties as they travel through the air, so it will be important to see how this differs from traveling through water. Additionally, knowledge of audiograms, hearing threshold shifts caused by certain frequency ranges, and how these signals are received for data processing will be crucial topics for background research.

Electronics is another big part of our project due to how the sensors and hydrophones embedded within the D-Tag operate. We may need to employ the use of printed circuit boards, or PCBs when coming up with possible design solutions later this semester. As such, having a good comprehension of how these electronics operate and how to choose models that will be most beneficial to our situation will go a long way in helping us stay on track and be efficient with our time.

Finally, having a good grasp of material properties will be of utmost importance to our design project. When choosing materials for our final solution, we will have to keep in mind both how our chosen materials will perform underwater and how they will interact with sound waves being processed by the hydrophones. We will want to choose a material that is somewhat water resistant to prevent absorption and thus underwater weight gain, and a material that will not be subject to attenuation, which would skew our data significantly. Attenuation is one of the main issues with the current design, so knowing material selection to minimize this effect will be invaluable to our team. It will also be important for us to select materials that are neutrally buoyant, or close to it.

ANTICIPATED CHALLENGES

When looking at our problem domain analysis, requirements and specifications, and other aspects of our project, we have come up with a few challenges that we foresee possibly coming up throughout our project timeline. Identifying these challenges now will be very beneficial in helping us solve them if they are to come up. However, we recognize that we will undoubtedly encounter challenges that we could not have seen coming.

Incorporating New Concepts into Existing Solutions

In solving the problems given to us by Dr. Kastelein, we will have to be careful how we implement new concepts into the existing “solution” to the problem. In our case, the existing solution is the current harness model, so whatever our final solution is, it will have to be compatible with this current model. This could prove to be difficult in many ways, most prominently being that this will put restrictions on some major characteristics of our design, such as sizing and material selection.

Recreating Test Conditions

Another challenge to consider is how we will recreate the testing conditions of our sponsor’s facility when performing our tests on our product. Since we do not have access to our sponsor’s resources located in the Netherlands, we will need to come up with a way to ensure that our product will be accurate in any research setting, regardless of size, depth, or location. This will certainly be something that we will have to keep in mind when conducting our engineering analysis and testing later this semester. Additionally, it will be important for us to find an appropriate material that will act as the sea lion’s body when doing our acoustic sensitivity testing, as this is something we obviously do not have access to.

Rules and Regulations

We will of course have to adhere to all rules and regulations regarding the treatment and safety of the sea lions. This involves keeping our design non-invasive as well as making sure we understand the guidelines set forth by legal documents such as the Marine Mammal Protection Act.

Accommodating for Separate D-Tag and Hydrophones
Our current alpha design involves removing the hydrophones from their current positions inside of the D-Tag housing and positioning them closer to the sea lion's ears on a collar, which will most likely be made of a neoprene-like material. This in itself presents many challenges, one big one being rewiring the electronics inside the D-Tag so that the hydrophones are still able to transmit accurate data. We will have to play around with this to ensure that rewiring does not present any major data accuracy losses. In tandem with this, moving the hydrophones out of the D-Tag means that we will have to waterproof the wiring, the hydrophones, and the area that the wires are coming out of the D-Tag. Finding waterproof wiring shouldn't be too difficult, but sealing up the D-Tag openings as well as finding appropriate hydrophone housing could be a challenge in itself.

Hydrophone Positioning
One major challenge that we will have to deal with is how we will position the hydrophones on the extended collar of our design. We suspect that the best configuration will be the hydrophones 180 degrees apart, to simulate the ears of the sea lion, but further testing will be needed to validate this claim. Consistency in testing and data collection will be a challenge during this process.

Manufacturing
Since we will be creating a new collar to be worn by the sea lion, manufacturing becomes a topic to be considered by our team. While we will be able to obtain the base material from an external vendor, actually shaping it into what we need for our design could be troublesome. We will first need to determine the exact dimensions we need it to be (which will be given to us at a later date by our sponsor), and we will then have to determine the best way to cut our material to prevent loose ends and fraying. Since sewing will be the most likely method we will be using with the neoprene, finding out the strongest and most efficient sewing method for this material will be a topic of research as well as experimentation for our team.

Conducting Final Acoustic Test with Full Circuit Board
Assembling the full prototype of our design could prove to be troublesome in itself, but specifically the electronics on the circuit board and making sure everything is waterproof and working properly will be essential in many of our verification and validation testing during the back end of the semester.

CONCEPT GENERATION AND SELECTION PROCESS

Filtration Process

Before introducing our team's initial concepts, we would like to outline the overall filtration process that we utilized to end up at our project's alpha design. **Figure 15** shows this process along with the filters we used at each step to narrow down our design selections.

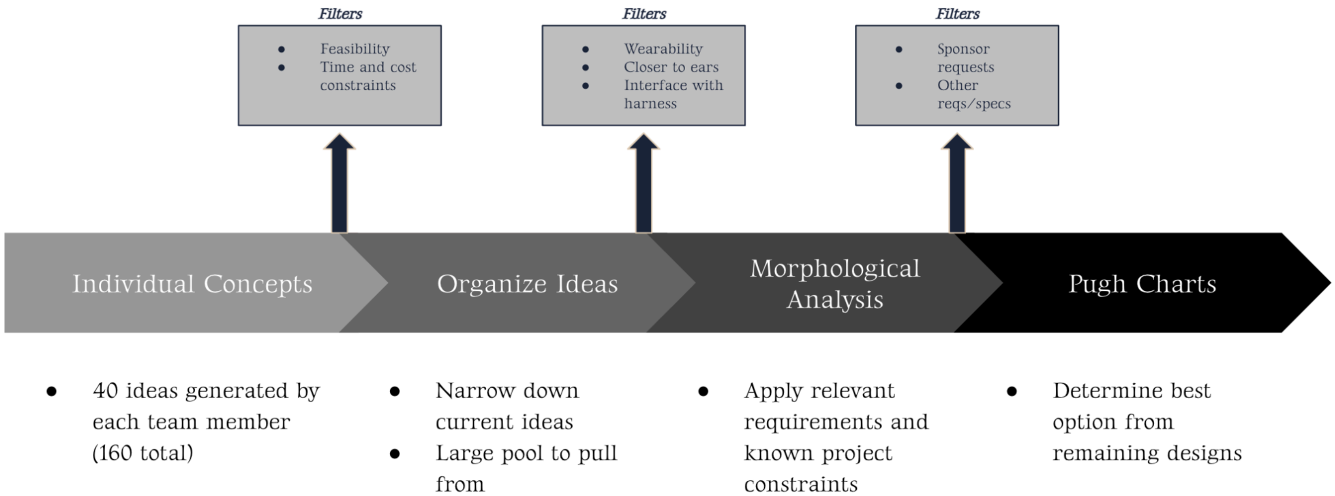


Figure 15. Visual representation of our filtration process.

Individual Concepts

To begin with the concept generation phase of our project, our team utilized the concept generation learning block. We used this learning block to better guide our concept generating thought process.

Before we started generating our diverse concepts our team discussed with our sponsor regarding what main components our solution would comprise of. We did this by first reviewing all of our needs without looking into the specification aspects of things. Once we determined all of our needs, our team was able to create three main sub functions for what our solution would consist of which are shown in **Figure 16.**

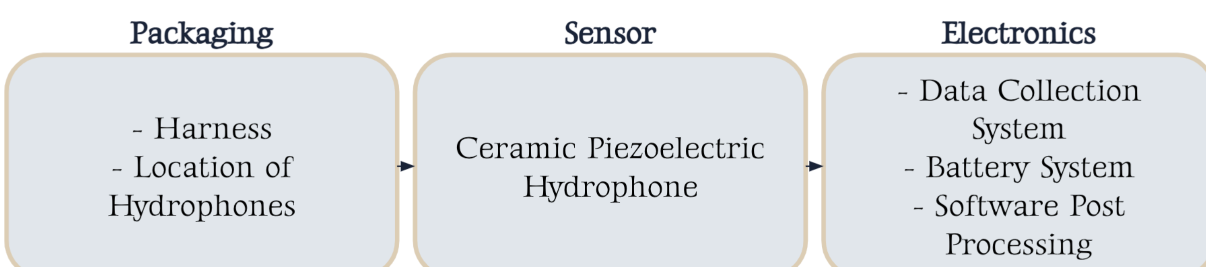
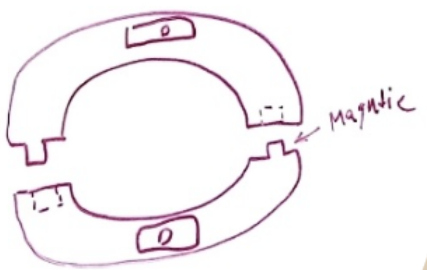


Figure 16. Functional decomposition of our overall project.

Our three sub functions could be broken down into packaging, sensors, and electronics. Although all three sub functions were necessary for our solution, we chose to have a larger emphasis on the packaging aspect of our product since the sensors and electronics had already been configured.

Using the learning blocks as a concept generating guiding tool, each member came up with 40 different design concepts. A concept generation method used by each team member was brainstorming.each member used different ways to strategize whether that be by sketching incomplete images to combine them with other sketches to create new ideas, trying to iterate a thought and even building up upon a solution. While we brainstormed separately we all made a mental note about the different rules that make brainstorming the most efficient and productive. These rules consisted of deferring judgment, encouraging wild ideas, building on others' ideas, going for quantity rather than quality, staying on topic, and being visual. The brainstorming method was very useful as it let each team member think of multiple unique solutions rather than focusing on trying to find a single "correct" solution. Another concept generating method used to generate ideas in a more systematic and analytical way was using a morphological chart. A morphological chart uses subfunctions on the Y axis of the chart and different solutions for each subsection on the X axis. The second step with using a morphological chart is to create combinations of the different subsection solutions.The morphological chart allowed for our team to generate solutions for every need/ subfunction.

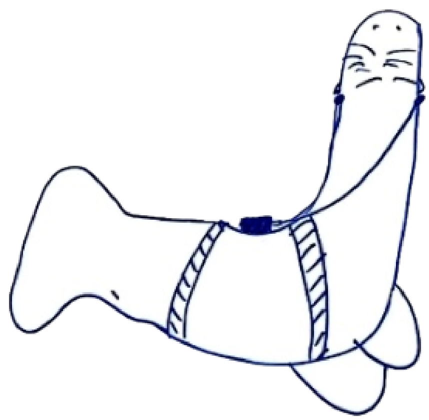
Utilizing various concept generation methods, our team was able to come up with a total of 160 solutions that were beyond the obvious solutions and created a variety of innovative ideas. These concepts are included in **Appendix X**. Below are five distinct solutions.



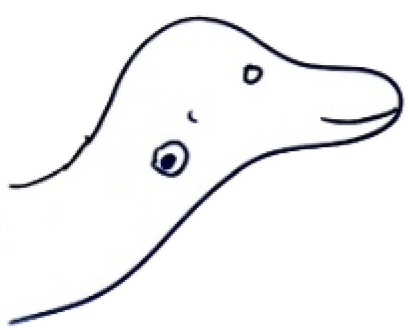
This solution concept is a two piece magnetic collar which allows the collar to be easily put on and taken off. The collar has a D-Tag on the bottom portion and a hydrophone on the top.

This design shows the sea lion using a mouthpiece which allows for the D-Tag and hydrophones to be near the ear without using any collars or harnesses.

This concept allows for the sea lion to move its head freely as it uses a layered collar design that also provides for more area allowing the D-Tag to be directly attached to the neck of the sea lion. The hydraphones dangle on an antenna allowing them to be near the ears.



This concept utilizes the D-Tag and previous harness but connects the hydraphones to the D-Tag using waterproof wires and connecting the hydrophones using strong agents that attract to each other through the sea lion's body.



This concept design utilizes the existing harness to hold the D-Tag but has bluetooth connected hydra phones that are secured to the sea lion via bio adhesive glue. This design focuses on the hydrophones being as close to the sea lion's ears as possible.

The solutions generated by each team member had some overlap in general idea but were very different in how each idea was conceptualized and designed. Every concept provided a hypothetical solution to our problem at hand.

Organize Ideas

To organize these ideas our team looked for similarities within all of the concepts' main components. Our team was able to categorize all the designs within four categories: neck collars, body harnesses, body harness and neck collar, no packaging. We chose to categorize the design concepts in this way because although the concepts varied in method and design they were similar in the packaging sense.

Morphological Analysis

The morphological analysis we chose to apply to our narrowed down ideas involved implementing filters based on specific sponsor requests as well as other requirements and specifications that weren't involved in the previous filtration step. Not only did these filters act as ways for us to rule out designs in our morphological analysis, but due to their importance, some of them were also used as criteria in our final Pugh chart. Note that they were able to be used again because, although the final designs could meet these criteria, some fit the criteria much better than others.

Specific requests from our sponsor were important aspects of our design that allowed us to eliminate certain designs that did not meet this criteria. One request from our sponsor was for our design to be able to be integrated into the current harness design. This was highlighted as an essential part of our final deliverable by our sponsor because it takes a long time for the sea lions to become used to wearing something on their bodies for extended periods of time. If we were to make a completely new harness, this could add a considerable amount of time to the training process. So, since they are already trained to be used to the current harness, Dr. Kastelein requested that our design involves the use of this pre-existing harness, and any add-ons be as minimal as possible. Another request Dr. Kastelein gave our team was to not include any velcro straps on any designs, as they could be invasive and irritating to the sea lion's hearing.

In addition to specific sponsor requests, we also incorporated some other requirements that we had previously created for our design. One of these requirements was for our design to result in the hydrophones in the D-Tag to be closer to the sea lion's ears for more accurate audio measurements. This is critical in that it is the main way for us to truly have more accurate data without overspending on some new, more powerful technology. Some other requirements that were taken into consideration were the design being noninvasive and the design not adding any unnecessary hydrodynamic drag forces, which would hinder sea lion's movement.

Pugh Chart

After performing a morphological analysis, we were left with four candidates for our alpha design. These final designs are pictured in rough sketches below in **Figure 17 (a-d)**.

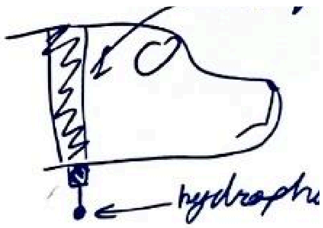


Figure 17a. Collar with inlaid hydrophones.

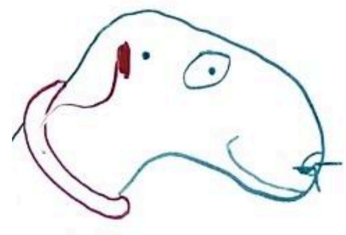


Figure 17b. Collar with hydrophones attached to antenna.

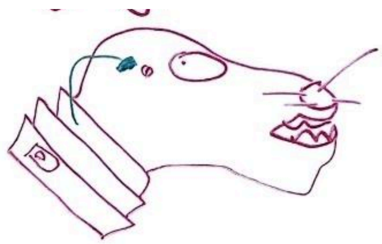


Figure 17c. Retractable collar.

Figure 17d. Cuff-like collar.

Looking at the design shown in **Figure 17a**, we can see that this design incorporates a "satellite harness" in the form of a collar worn by the sea lion. This collar will act as the new location for the hydrophones that are currently embedded in the D-Tag, which will fill the important requirements of more accurate data as well as interfacing with the current harness design. The D-Tag will stay in its current location on the back of the sea lion mounted on the harness, with the hydrophones being connected via waterproof wiring.

In **Figure 17b**, a similar concept is approached with a collar containing the hydrophones. However, the difference here is that instead of the hydrophones being directly attached to the collar, they extend outwards via some form of wiring and act as "antenna," getting the hydrophones even closer to the sea lion's ears. Although this design would provide the most accurate data, some issues come up with durability and sustainability of such a design.

Figure 17c employs a similar approach to the previous design with the extended hydrophones, however the difference here comes in the design of the collar. For this design, we had the idea to make the collar retractable so that it could be both more stable and move more fluidly with the sea lion's natural movements. The material of choice for this collar was some sort of 3D printed material that would have the necessary weight and flexibility needed for this concept.

Our final candidate for our alpha design is pictured in **Figure 17d**. This design is quite simple: we wanted to have an option for something that could easily be taken on and off of the sea lion while still moving the hydrophones closer to the ears. While the simplicity of this design is appealing, problems arise with its stability as well as not making it too tight on the neck of the sea lion.

These final design concepts were all compared against each other in the form of a Pugh chart, which is shown below in **Figure 18**. The criteria weighting as well as the final results are discussed below in the following sections.

Criteria & Weight	Interfaces with harness [5]	Wearability [4]	Close to sea lion ears [4]	Robustness [3]	TOTAL
Current Harness	0	0	0	0	0
Collar (inlaid hydrophones)	0	0	+1	0	4
Collar (antenna)	0	0	+1	-1	1
Collar (retractable)	0	-1	+1	-1	-3
Cuff	0	-1	+1	-1	-3

Figure 18. Pugh chart of final candidates for alpha design. The current harness is used as a baseline design to compare against the others, and the design highlighted in green indicates the design we chose to move forward with.

We chose our weighting for our Pugh chart criteria based upon necessities pointed out to us by our sponsor as well as parts of the design we deemed important, whether intuitively or through our requirements and specifications. The ability to interface with the current harness was given a weight of 5 (the highest of our criteria) based upon sponsor request for the reasons discussed in earlier sections. Wearability was assigned a weight of 4 because this criteria encapsulates our noninvasive requirements as well as ease of use for the trainers and researchers working with the sea lion. Another criteria that was given a weight of 4 was whether the design moved the hydrophones closer to the ears of the sea lion, thus improving the accuracy of our audio readings. Finally, robustness was given the lowest weight of 3. This criteria covers whether or not the design in question will be able to withstand the wear and tear from sudden sea lion movements. While this is important, the other criteria outweigh this due to them being the overall main focus of our project.

As we can see from the Pugh chart above in **Figure 18**, the design that best fits our weighting criteria is the collar with inlaid hydrophones. This design had a better score than all other designs by a considerable amount. As such, this is the design that we have chosen to use as the baseline for our alpha design. Note that this design is subject to changes/tweaking as we work through the beginning phases of prototyping.

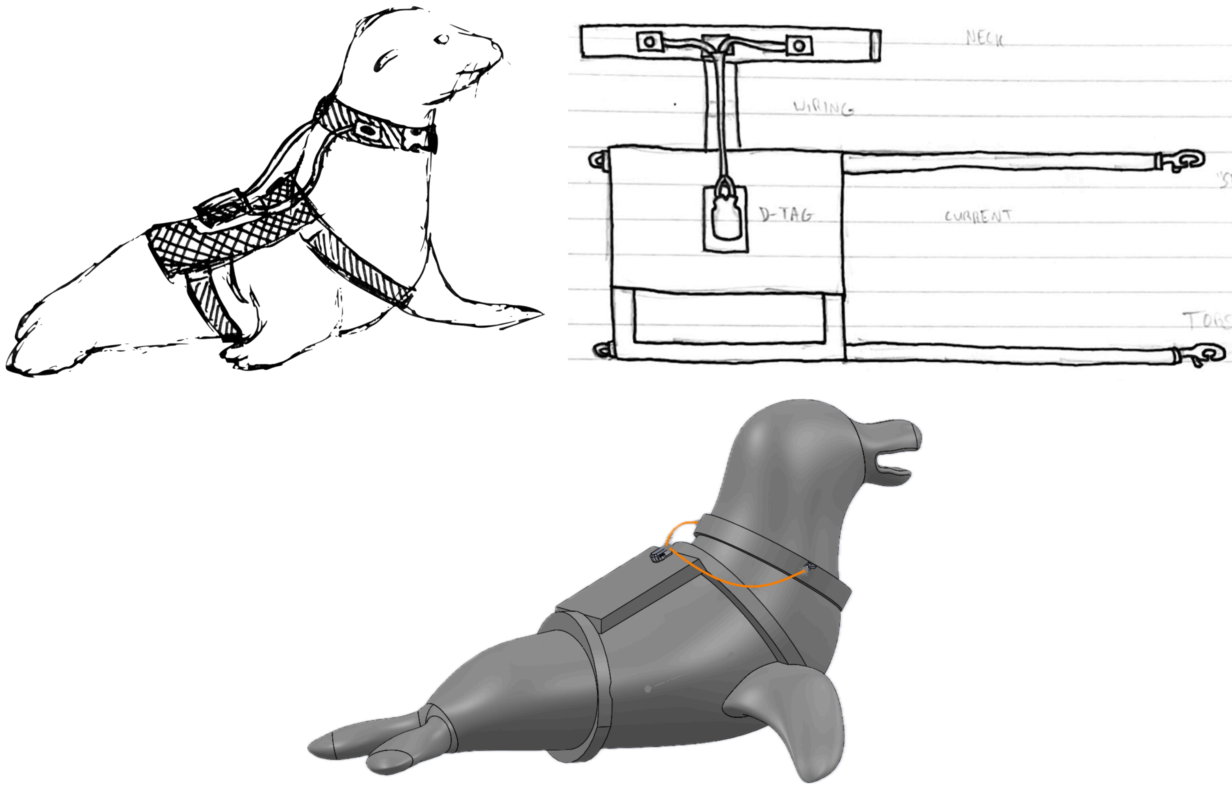


Figure 19. Alpha design concept 1 - Adapting current harness to attach thin collar extended by additional strap and elongated waterproof wiring.

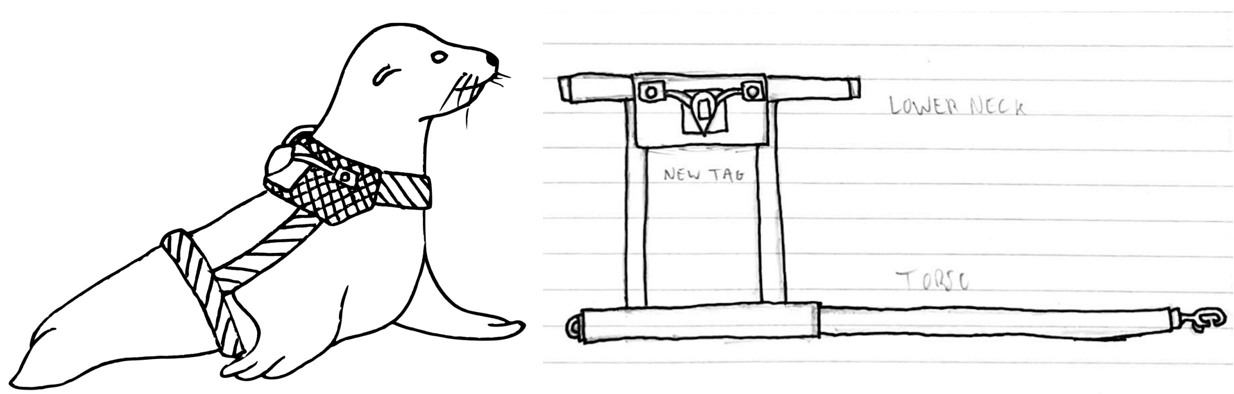


Figure 20. Alpha design concept 2 - Larger pad design nearer to the higher parts of the neck to house D-tag or updated electronics, still straps below torso.

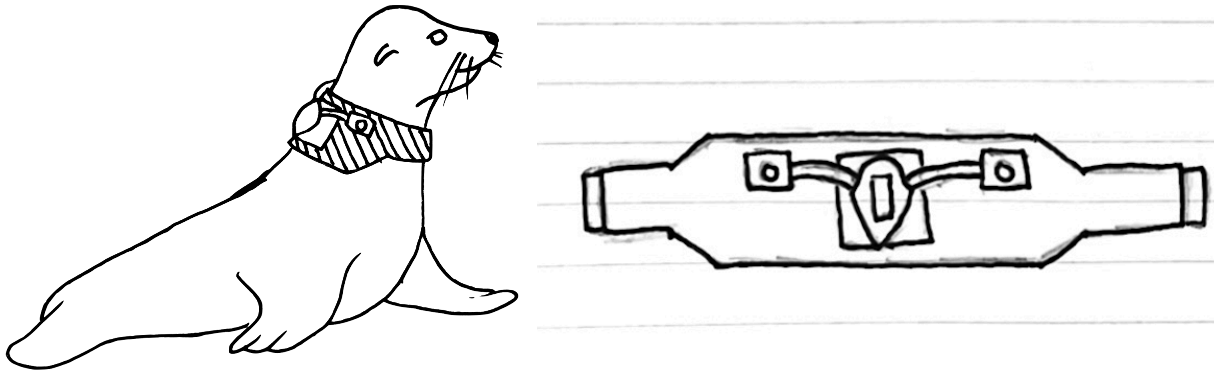


Figure 21. Alpha design concept 3 - Large pad/collar allowing for D-tag/electronics housing without need for additional material.

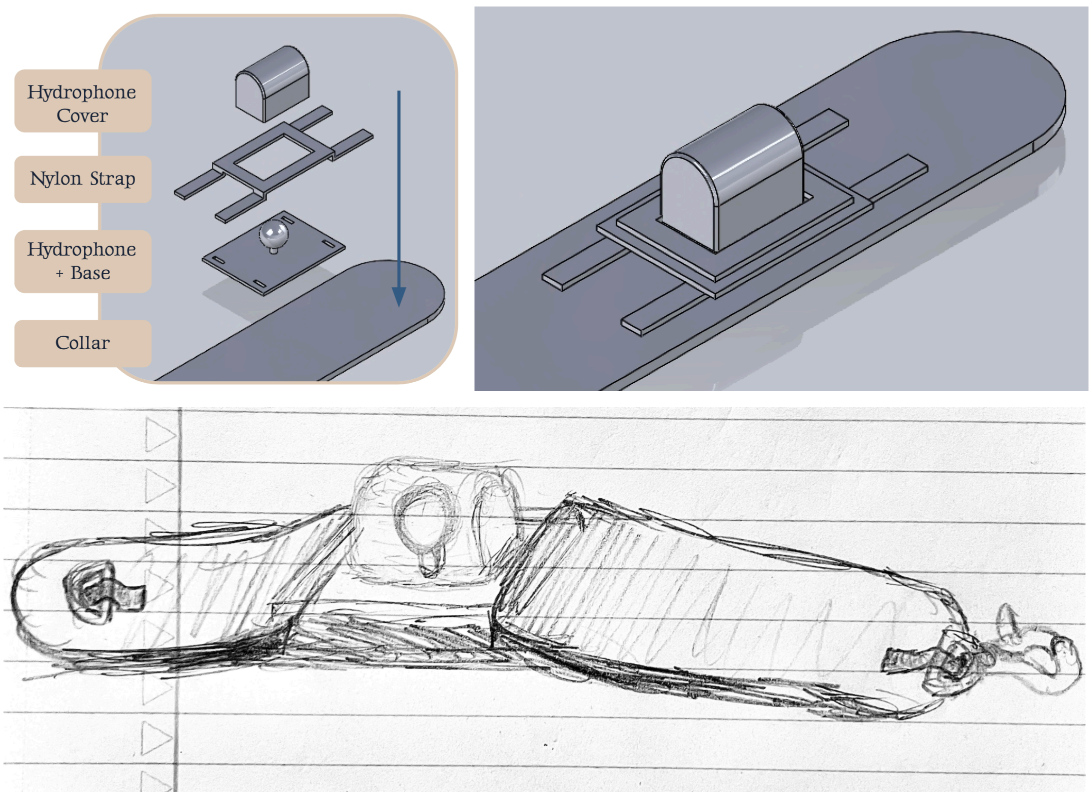


Figure 22. Hydrophone collar attachment option 1 - Nylon tie-down strap sewn down to collar base overtop of hydrophone platform/cover assembly

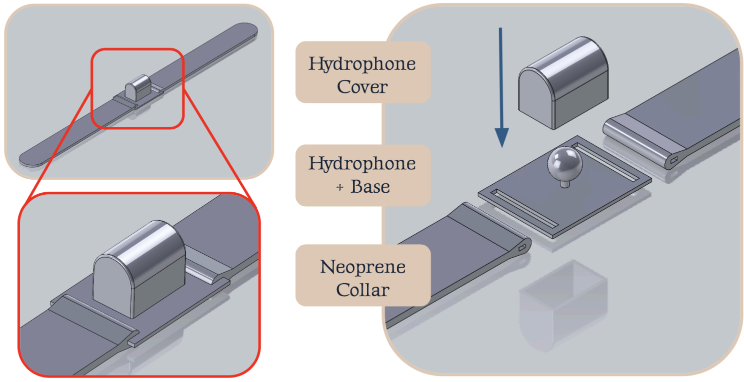


Figure 23. Hydrophone collar attachment option 2 - Collar straps connect directly to hydrophone platform

Hydrophone collar attachment option 2 reduces material used as well as the need for more thread/complex attachment methods.

PROBLEM ANALYSIS & ITERATION

Breaking down the current problem we are exploring, the main issues we are trying to solve are related to acoustics. The goal of remodeling and repositioning the harness system is to allow for more accurate sound pressure level (SPL) representation. In order to allow for recording data to be more accurately representative of what the sea lions actually perceive, our goal is to design, build and test some sort of harness system that allows for the hydrophones themselves to be as close to the sea lions ears as possible. Requirements that follow along with that goal include comfort/wearability and safety, as well as the option to be compatible with the current harness, shown in **Figure 24** below.

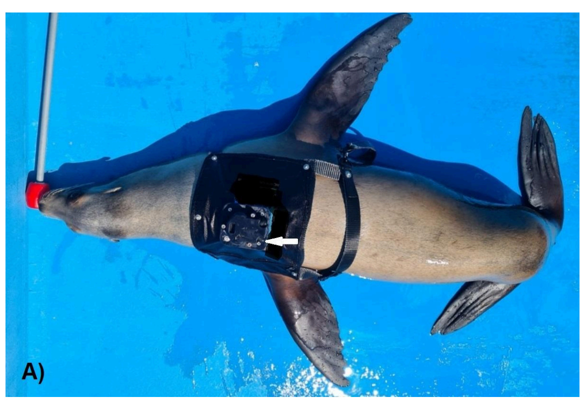


Figure 24. Sea lion wearing current harness design, D-tag attached at top with hydrophones facing backside *Videos adapted from given footage given by Dr. Kastelein **Images adapted from [2]

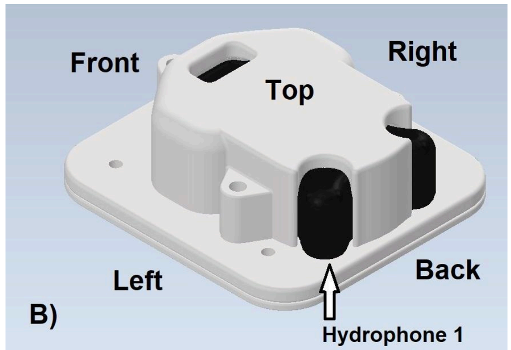


Figure 25. D-tag packaging assembly (Hydrophones within casing)

These goals have led us to outline a series of primary requirements that we must follow in order to generate a successful prototype. These requirements, as listed previously in **Table 1**, include the aforementioned accurate SPL representation, accurate frequency content, ease of use/wearability, recording duration, impulse resistance, and potentially ability to interface with current harness.

In order to properly analyze and address the specifications that go along with each of these requirements, we have broken down the fundamental engineering principles that will be necessary to include when beginning testing. A minor goal of the final product, included in the ease of use requirement, is hydrodynamics. We would prefer the collar and overall harness design to be sleek and provide as little drag while swimming through the water as possible. This will include considerations of fluid dynamics in terms of drag coefficients on the collar itself based on cross-sectional area and materials we use. Materials selection will also play a significant role due to comfort for the sea lions and waterproofing. Force analysis will be a significant consideration considering the need to be non-invasive on the animals, and since we're hoping to place our alpha design in a very sensitive area of the neck/head region we need to be especially careful. Tension of the collar will be affected by the clip choices we use, material of the collar, collar length and adjustability, as well as thickness and changes that submergence in seawater might make.

Acoustic Comparison Test

Our goal to generate accurate SPL representation by positioning hydrophones nearest to the ears of the sea lions has led us to consider the option that both hydrophones are 180 degrees apart from one another on the collar when placed on the nearly cylindrical neck of the sea lion. The issue we are trying to solve is the reduction in SPL quality due to rotation caused by animal motion. We can determine how well our alpha design addresses this problem and its specification based on testing methods such as attempts to record while a prototype collar is wrapped around a similarly sized, cylindrical shape under water and moved at different rotational angles. The assumption that approximately 180 degree hydrophone placement can be justified by theoretical analysis, but empirical testing at varying degrees of separation could be performed to further prove the validity of the choice.

Once our alpha design has been prototyped, and we are able to test SPL output based on hydrophone placement during rotation and variable movement, we can determine whether or not the selected concept satisfies our requirements based on comparison to previous D-tag data.

Strap Material Selection

When considering materials for the straps, our team decided to explore proven underwater materials instead of exploring alternate materials that would need extensive testing. With that in mind, we explored the harness that have been used for marine biologging harnesses in the past. Using the harness our sponsor uses [2] and the harness shown in **Figure 26**, we concluded that nylon was an acceptable choice for the strap material. In addition, exploring the harness as shown in [15], we also concluded that neoprene was a likely candidate for the strap material.

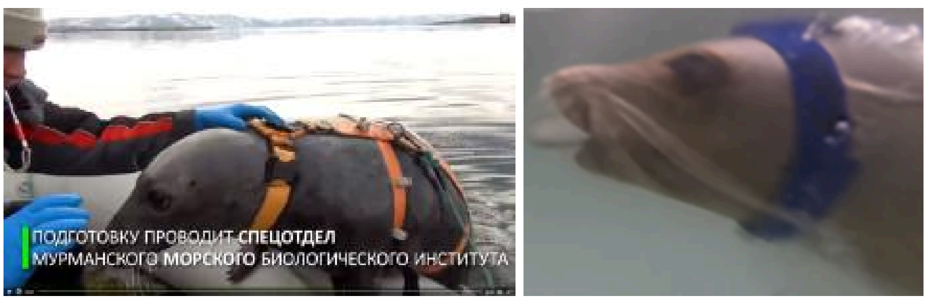


Figure 26. Harness from [14] (left) and harness from [15]. (Left) a harness made of nylon used by the Russian Military. (Right) a harness for kinematic data collection on sea lions.

Our sponsor has suggested that we use neoprene as he feels that it can be applied noninvasively to the sea lions. Finally, the group decided on neoprene given its ability to conform to a variety of neck sizes with little to no adjustment necessary. The second main reason that our group chose neoprene was because it can fit to the sea lion and be largely considered rigidly attached in comparison to the nylon strap which would need a tightening mechanism that would loosen over time. Both of these reasons tie to both our wearability and accurate SPL representation requirements.

Another important consideration when it comes to materials used in the collar is the selection of clips used for attachment. There are many types of fasteners available, many of which serve a very similar purpose and are equally intuitive, easy to use, cheap, and durable. The primary distinction to be made between each option is the amount of noise they make during use (both during attachment/detachment as well as during motion/testing). Our goal is to select the clips that will produce the lowest amount of noise, because this can be an additional factor in discomfort caused for the sea lion (especially considering the close proximity to the head and ears where the collar lays). In order to test for the clip that produces the least noise, we plan to perform a time series fourier transform. To start, we would perform a simple attachment/detachment test where we begin taking data, attach clip, detach clip, then record data for future analysis. The goal is to compare these test results between each clip option and select the option that provides evidence of minimal sound generation. Further testing could be done when the entire collar is prototyped and we can simulate the collar being worn around a cylindrical neck shaped object submerged in water during attachment as well as movement during a “swim”. One goal for our initial prototype is to allow for multiple clip types to interface with the collar so that multiple options can be used.

ALPHA DESIGN

When developing our Alpha Design, we were made aware of a hydrophone only receiver board that is an extension of a different style of tag. Our team elected to use this board as it was more fitting to our hydrophone only focus and the board was also smaller and lighter than the D-Tag. The E-Tag Hydrophone Receiver Board (referred to as E-Tag from here on out), is still under development but will be completed in the near future.

The Alpha Design we selected was one with the E-Tag mounted on the previous harness that Dr. Kastelein has already trained the animals to wear. From this mounting, There will be wires that run along a strap that connects to a satellite harness close to the sea lion’s neck. From there, the wires will run along the long axis of the harness to the hydrophone placed 180 degrees away from each other. The hydrophones will be connected to the strap using 3D printed mounting plates. These mounting plates will be attached to the strap through rivets and backing plates. The attachment mechanism for the straps will be swivel eye bolt snaps. The main harness depicted in the bottom part of **Figure 27** will be the previous harness design will be the previous harness design. This determination was made based on the notion that the sea lions are already trained to be comfortable with this harness and provides a proven, secure location for the data collection device.

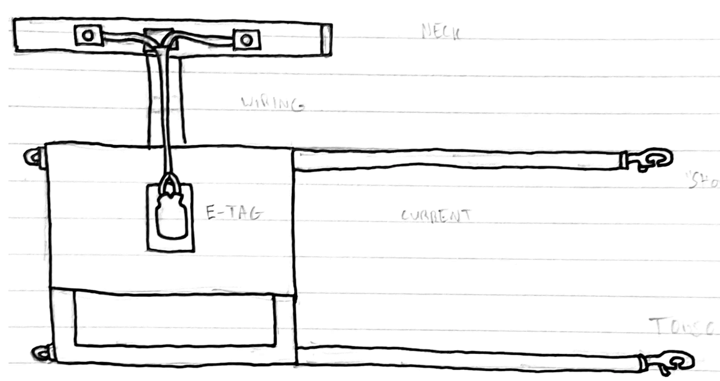


Figure 27. Alpha design concept 1 - Adapting current harness to attach thin collar extended by additional strap and elongated waterproof wiring.

The selection of the clip is temporary at this stage and is subject to change up the results of the testing we mentioned earlier. The neoprene was selected based on the analysis of the available materials from the earlier selection. The mounting plates for the hydrophones have been selected as they are part of the previous packaging solution that has been proven to work. And lastly, the move of the hydrophones to the neck of the sea lion was done for the SPL sensitivity requirement and on the suggestion of our sponsor.

ENGINEERING ANALYSIS

CFD of Electronics Housing

As shown in **Figure 28,** the housing for the electronics will need to sit on a mounting plate and should not cause significant hydrodynamic drag.

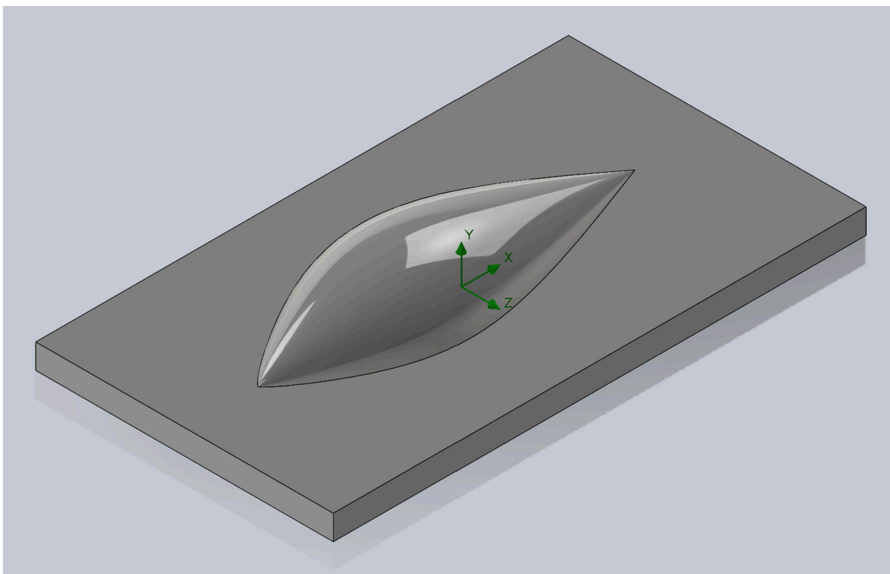


Figure 28. Sample of hydrodynamic housing on the mounting plate

Our team developed four potential solutions that represent practical shapes that could be used underwater. These solutions are shown in **Figure 29.** These designs will be compared against the model in **Figure 25** for both drag and lift.

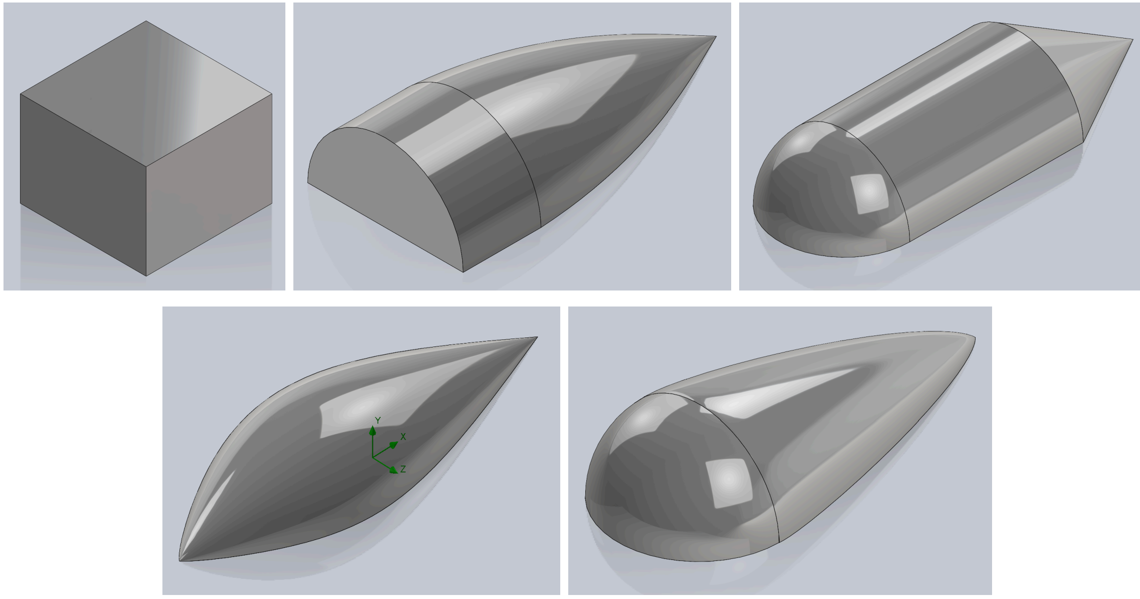


Figure 29. The potential solutions for the housing of the electronics. (1st row, left) design 1, (1st row, right) design 2, (2nd row, left) design 3, (2nd row, right) design 4, and (bottom) design 5

After this, we performed a simple flow model test in SolidWorks to test drag and lift forces for the model. We made the following assumptions

1. Gravity is neglected
2. No surface roughness
3. Excluding Internal spaces
4. Slip Boundaries
5. No Shaft Work
6. No Heat Added
7. Incompressible Flow

After this, we set standard boundary conditions to be 101.3 kPa, ambient temperature to be 20℃, and the velocity to flow along the chord line of all of the designs and for the velocity step from 0.4-6 m/s with a 0.4 m/s step. **Figure 30** shows an example of the flow model over design 2 with an initial condition of 3 m/s to help the reader visualize the flow model.

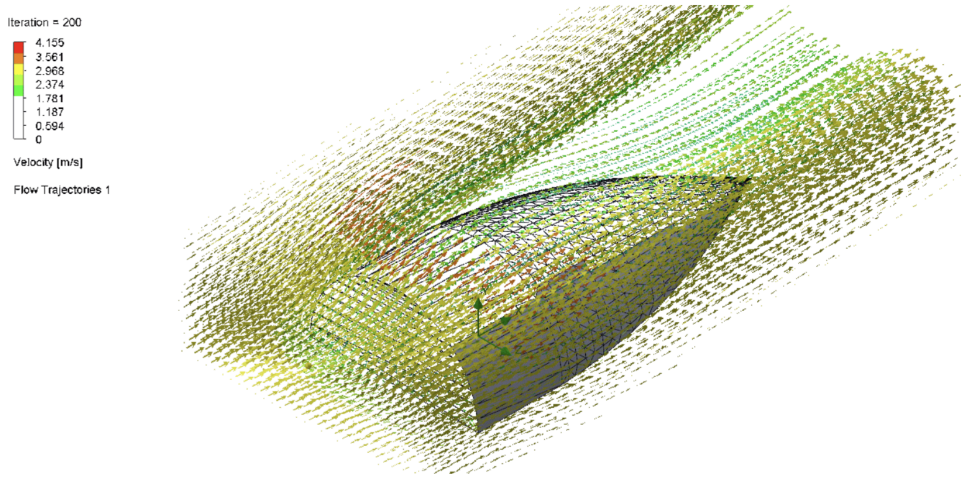


Figure 30. Flow model example with initial boundary velocity of 3 m/s

After running these tests for all five designs and the previous design, we created the following drag and lift curves from the data (**Figure 31**).

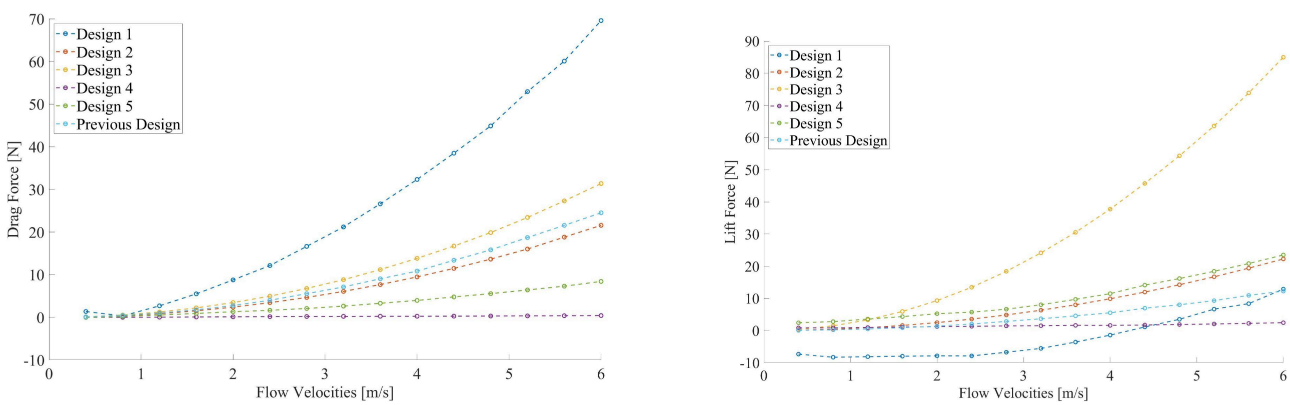


Figure 31. Drag and lift curves for the five designs our team created and the previous model for the electronics housing

From these results, it can be seen that design 4 is the best option as it provides the least drag while also having menial lift which will impact the sea lions swimming less. To verify that the results we had were accurate, we found an airfoil with a flat bottom that could be approximated to have similar characteristics as our model. The airfoil we chose was the Rhode St. Genese 30 [20] (shown in **Figure 32**) whose drag characteristics are readily available through the University of Illinois.

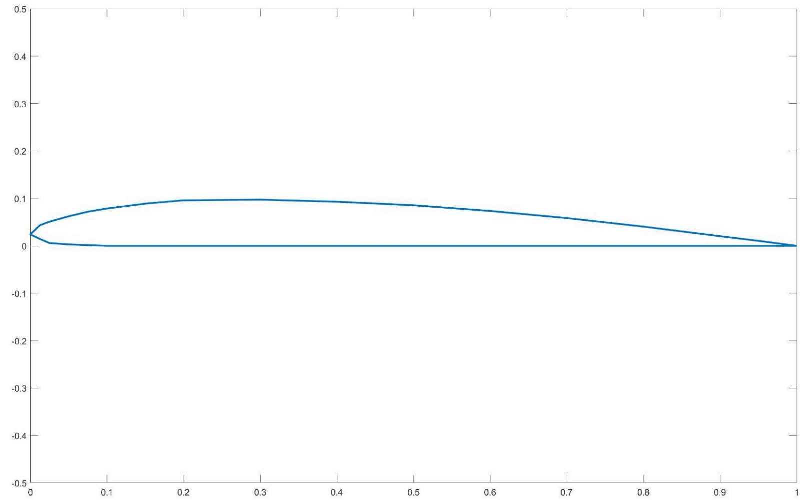


Figure 32. Rhode St. Genese 30 airfoil [20]

To validate our forces we elected to calculate the drag forces from the bottom and top of the range of our velocity regimes (0.4 m/s and 6 m/s respectively). We also made the following assumptions about the normalized airfoil:

1. Characteristic Length: Chord Line
   a. 0.207 m
   b. From one of the Design 2
2. Characteristic Area: Frontal Projected Area
   a. 0.0158 m^2
   b. Assumed to be rectangular
   c. Assumed to have the same width as Design 2
3. Density: 1000 kg/m^3
4. Dynamic Viscosity: 0.001 Pa*s [18]
5. AOA = 0 degrees

We then extrapolated the Reynolds numbers using **Equation 1.** for our scenario and got values of 82,800 and 1,242,000. These then informed our linear interpolations of the coefficients of drag from the numerical data provided in [19] and shown in **Figure 33**.

$$Re = \rho v L / \mu \quad \textbf{Eq 1}$$

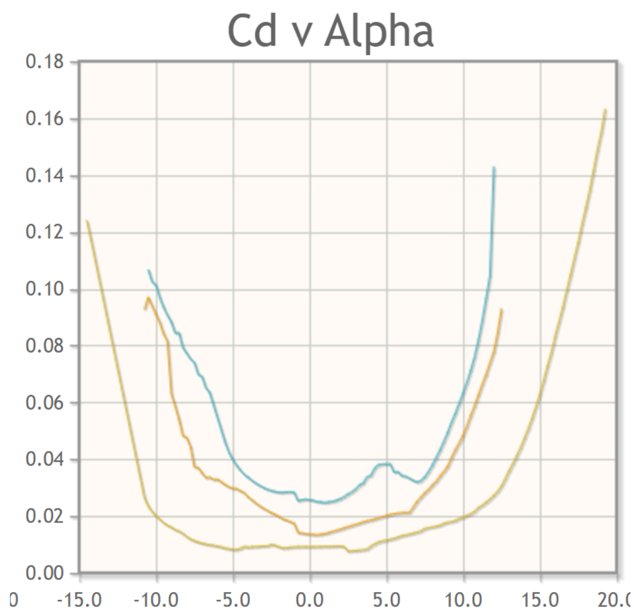


Figure 33. Coefficient of drag for Rhode St. Genese 30 airfoil for Reynolds numbers of 50,000, 80,000, and 1,000,000. Adapted from [19].

After obtaining the coefficients of drag we then calculated the drag using **Equation 2**.

$$F_d = C_d * (\rho v^2/2) * A \qquad \textbf{Eq 2}$$

For our flow regimes we got values of 0.0225 N for 0.4 m/s and 2.6563 N for 6 m/s. This validates our results for drag as they are within the same order of magnitude. Therefore, our conclusion is that design 4 (shown again in **Figure 33**) is the best choice for our design.

Clip Test and Short-Time Fourier Transform

Our collar will need to attach to itself around the neck since Dr. Kastelein suggested that sliding over the neck could negatively affect the sea lions' long-term perception capabilities. **Figure 34** shows the different clip strategies we are considering.

Figure 34. Different clip strategies our team is testing. From left to right, belt buckle, swivel eye bolt snap, carabiner, tactical buckle, and side release buckle.

Therefore, our team elected to test different clip strategies by measuring the acoustic pressure output using a simple phone microphone and then using MATLAB 2023b by MathWorks to compute the relative sound pressure level or *SPL* using **Equation 3**.

$$SPL = 20 * log(\frac{P}{P_{ref}}) \quad \text{Eq 3}$$

The results of the test are provided in **Table 3**.

Table 3. Sound pressure levels for the different clipping strategies.

Clip Style	Side Release Buckle	Carabiner	Swivel Eye Bolt Snap	Belt Buckle	Tactical Buckle
SPL (dB re 1 μPa)	269.6	262.4	252.5	255.3	272.8

From these results we decided to use the swivel eye bolt snap as it is the quietest solution, and thus the best for our purposes.

Shear Test

For the shear test, we created samples by attaching two pieces of two different materials[1]. together using four different attachment methods. We opted for a rough test where we attached a C-clamp to one end of a test sample and placed the other end in a vice. We then calibrated a force gauge for the load of the C-clamp and then lifted clamp until the sample critically failed.

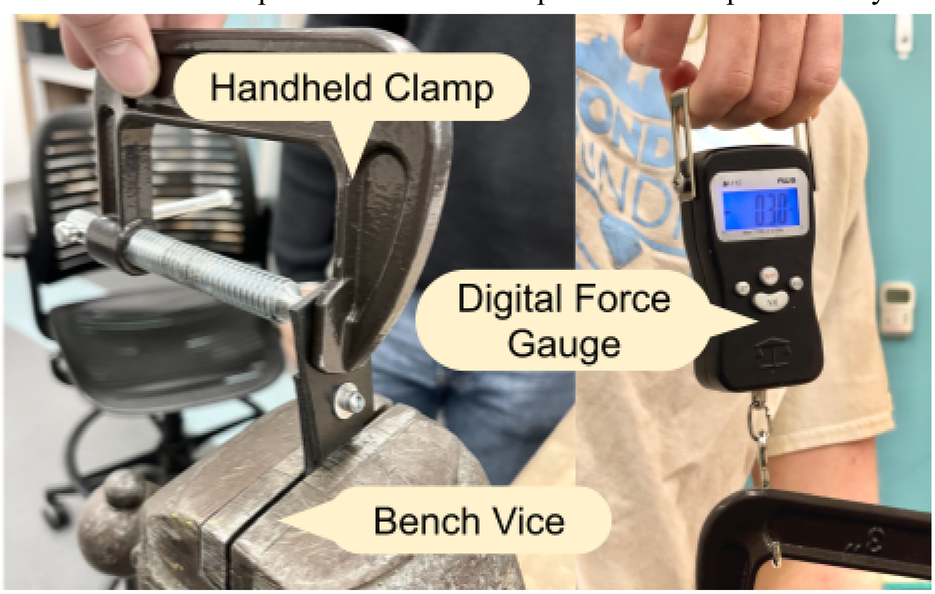
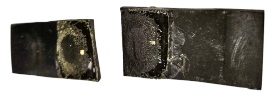
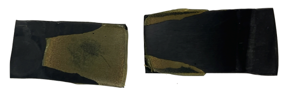
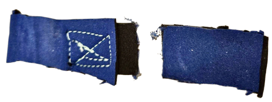
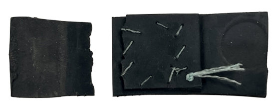
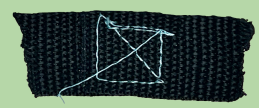


Figure 36. Stretch test experimental setup.

[1] Although we show three materials in **Table 3**, we only tested the neoprene foam and rubber as neoprene was recommended by our sponsor. The polyester strap was used a control group for the current design after assessing the stronger of the two materials and the strongest attachment mechanism.

Table 4. Stretch test (mock extensometer).

Force (lb)	**Wetsuit** (Neoprene foam)	**Neoprene** Rubber	**Polyester** Strap
Rivet	 0	 14.78	—
Adhesive	 0	 40.9	—
Aquaseal	 5.25	 9.6 (2.82)[2]	—
Marine Thread	 6.9[3]	 33.15	 92.8+

Shown in **Table 4** is our material bonding attachment stretch test results. Each test consisted of two 1x2 inch specimens of the respective material bonded together using the method on the left hand side (single specimen implies a single 1x2 inch piece by itself, not bonded to a second piece). **Figure 36** shows the experimental setup, where one piece is clamped down using a bench vice and the other is held using a handheld clamp. A digital force gauge is attached to the handheld clamp, and a force is applied in tension until the pieces separate. This separation could be caused by tearing of the material itself or even the bonding agent failing causing the two pieces to move away from each other.

Having issues with rivets, such as pulling through material and having excess material that would interact with the sea lion's body and cause certain harness manufacturing constraints, led us to remove rivets from tests on neoprene foam and polyester. We assume this to be without loss, though, considering our sponsor specifically mentioned not to use rivets due to their corrosive nature, interaction with the sea lion skin, and potential for noise or need for replacement. Every test ended in some form of specimen separation besides the polyester when sewn together with marine thread. This proves to be the optimal choice for collar clip attachment

[2] First test in parenthesis and second test outside
[3] Our team does not have confidence in this value as the material failed before the thread and at very low force

material, however we do consider the fact that tensions over 5lbs (which most other tests managed) would not be viable anyways considering that would choke the animal which goes against our requirement of non-invasivity. Further testing may be completed upon manufacturing of material specimens attached to the D-rings which will be used in clip attachment.

BUILD DESIGN

Electronics

Electronics play an important role in the functionality of the collar, enabling the sponsor to gather data on the underwater acoustics effectively. Below are the key electronic components shown in **Figure 37**.

SD Card

The Sd card serves as a storage device for the collected audio data captured during the recording process. The SD card allows for an easy and reliable method to transfer data to be analyzed and interpreted. The SD card provides ample storage capacity to accommodate continuous recording throughout extended durations

Battery

The battery provides power to the entire electronic assembly, the battery makes sure that recording can occur through the duration of the testing conducted by the sponsor.

Hydrophone Receiver

The hydrophone receiver’s main function is to manage the data taken in from the hydraphone. The hydrophone receiver first gathers signal through a line driver, this is to ensure data is not corrupted though the cables because of their length.The hydrophone receiver samples the signal through the hydrophones using high resolution and low noise ADC which converts the analog values into digital values. These values are then forwarded to the microcontroller using SPI.

Teensy Microcontroller

The teensy microboard reads the SPI bus, sending the gathered data to the SD card for data saving. The teensy microcontroller is also what allows for communication with an external computer to offload data and start/stop sampling.

Cord

The 0.295 diameter coaxial cable connects the Hydrophone receiver to the hydraphones themselves. The cables are both six inches each.

Hydrophones

Hydrophones are the acoustic data gathering sensors used in the collar. The hydraphones measure the changes in water pressure caused by sound waves and are placed so they are positioned near each ear of the sea lion.

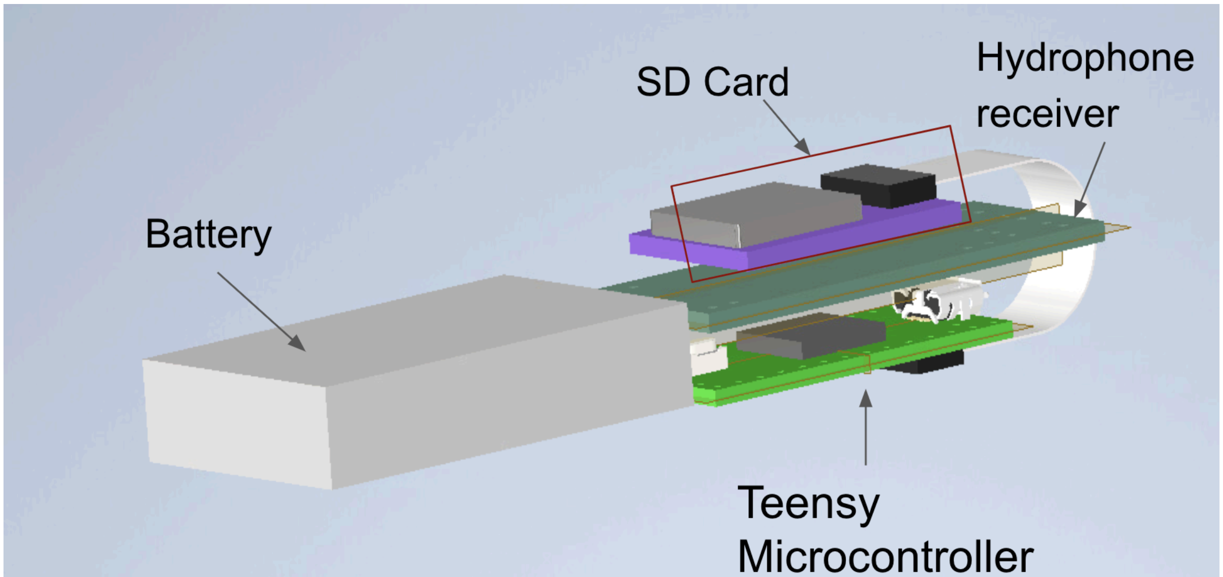


Figure 37. Electronic assembly which includes a battery, SD card, hydrophone receiver and teensy microcontroller.

Together, these electronic components form the collars audio recording system, enabling it to fulfill its purpose of capturing and analyzing underwater acoustic data which represents what the sea lion will be hearing, precisely and reliably.

Cover and Baseplate

After speaking with our sponsor our team decided to create a hydrodynamic cover that encapsulated the battery, SD card, hydrophone receiver and teensy microcontroller. After conducting FEA analysis on possible cover shapes our team had picked a design which would allow for the least amount of drag that still had enough space to hold the electronics in a secure position on the sea lion. Below in **Figure 38** and **Figure 39** is our cover CAD model and the dimensional drawing of the cover. The cover allows for both coaxial cables to run out the sides while keeping the key components secured to a base plate shown in figure 40 using four ¼ inch screws and sealed using gaskets along the edge of the cover. The screws enable easy removal of the cover, providing convenient access to the SD card by our sponsor.

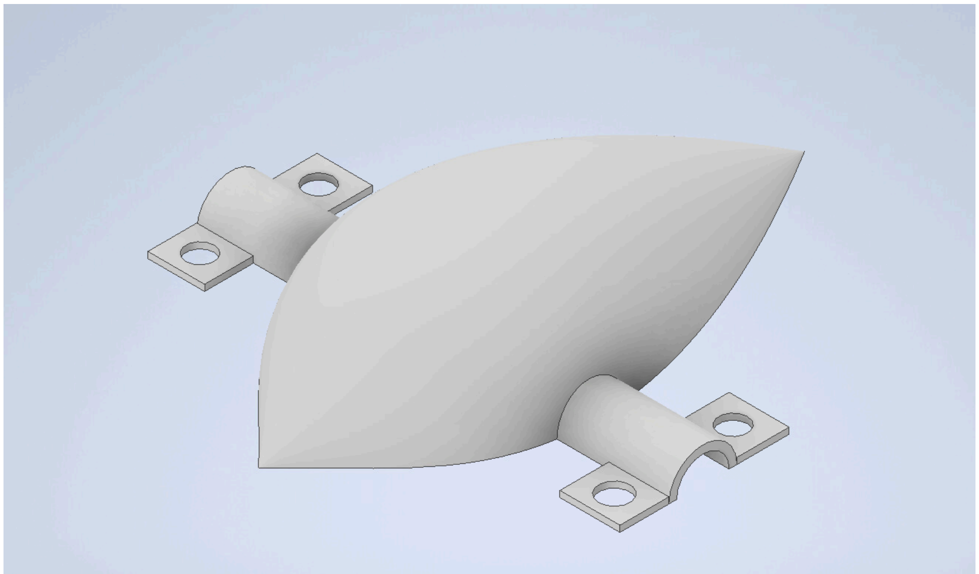


Figure 38: Collar cover that encapsulates the battery, SD card, hydrophone receiver and teensy microcontroller. On both ends there is a cable tunnel which allows for the coaxial cable to run out to the hydraphones.

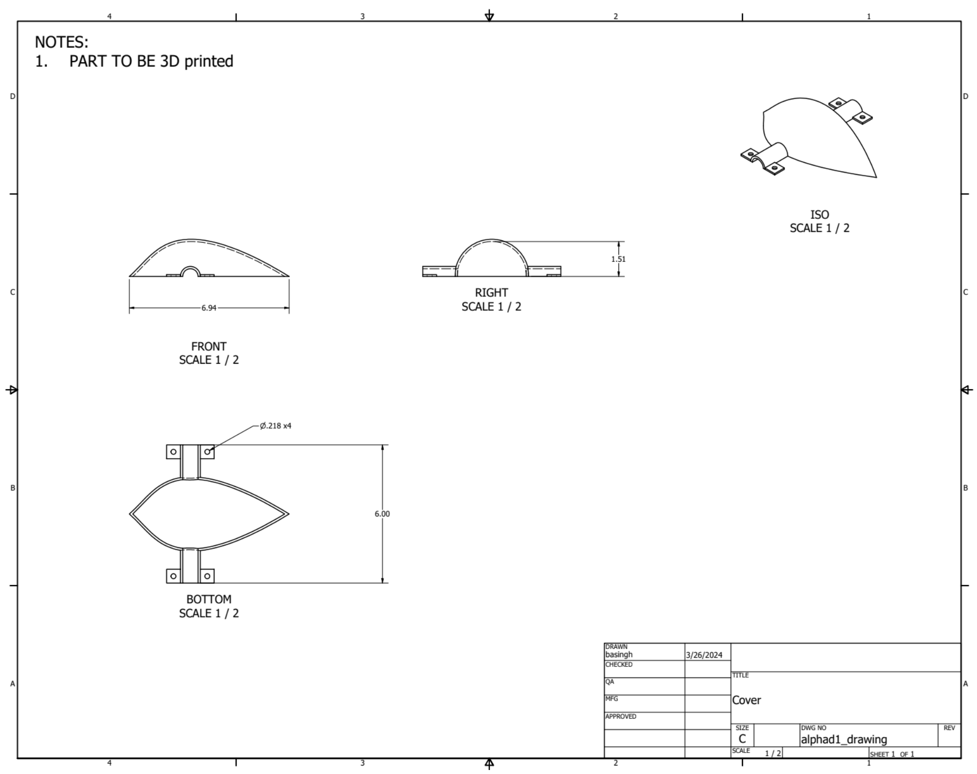


Figure 39: This figure shows the front, right and bitten view of the cover design with dimensions.

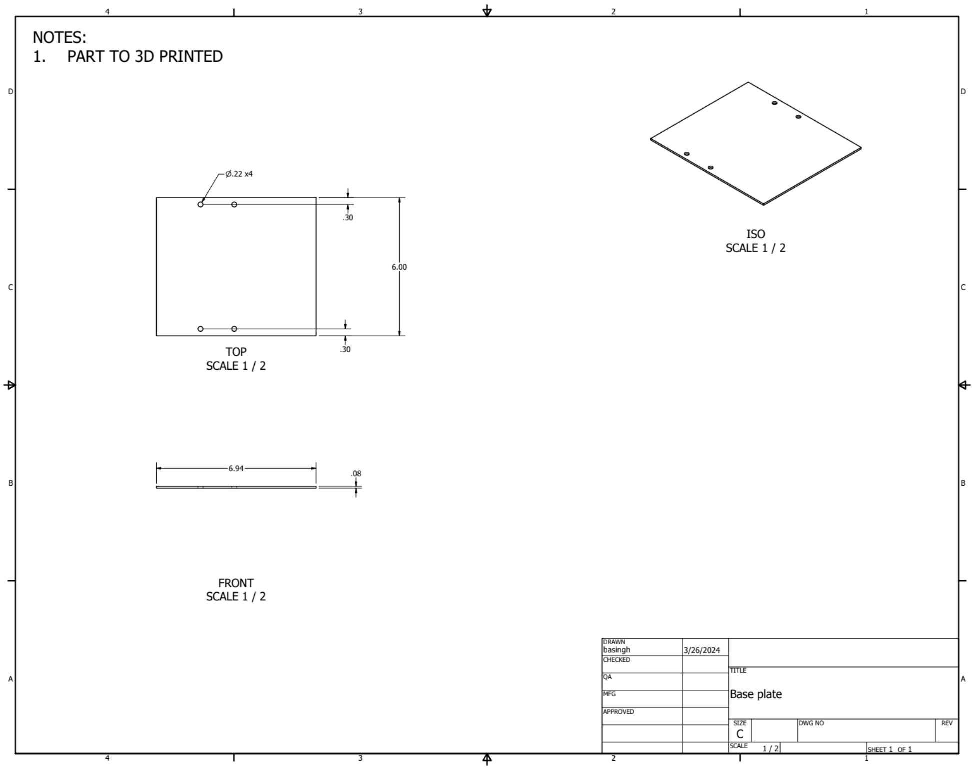


Figure 40. The engineering drawing shows the dimensions of the baseplate.

Both the baseplate and cover will be 3D printed using PLA, the same material as the previous D-Tag cover. This choice was made because the previous cover proved to be waterproof and durable, meeting the requirements for our sponsors' use. The full electrical components, cover and baseplate assembly is shown below in **Figure 41**.

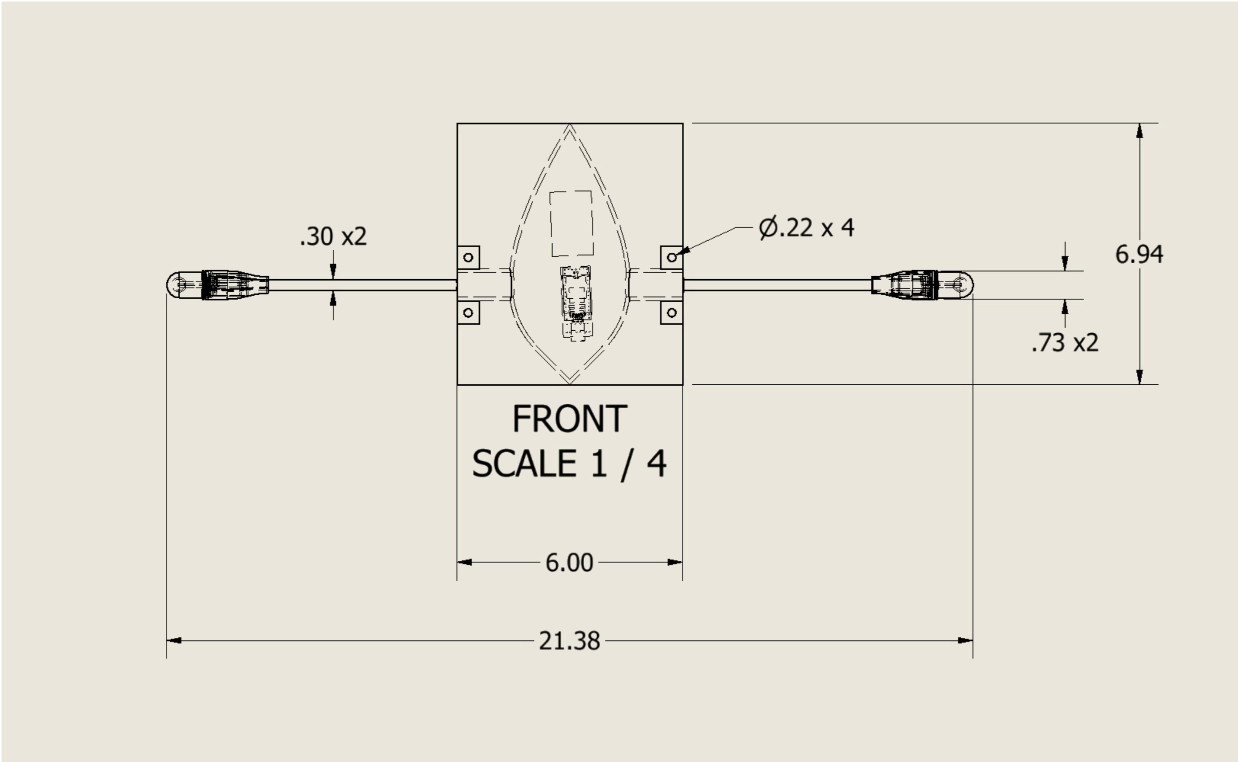


Figure 41. The drawing above depicts the cover, electronics and baseplate that will be used in the harness.

Collar/Harness

The primary materials used in the manufacture of the updated collar (and harness) will be the base neoprene foam (wetsuit fabric), polyester strap, stainless steel D-rings, nickel plated swivel eye bolt clips, marine thread for sewing as well as aquaseal for extra secure attachment. These materials are based on test results outlined above. Neoprene foam is flexible, lightweight, waterproof and hydrodynamic. Polyester does not absorb water and is highly durable. Stainless steel and nickel are corrosion resistant, and the swivel eye bolt clips make minimal noise during attachment and detachment. Marine thread is made for extra durability through water exposure, and the aquaseal is designed to bond these materials underwater.

The manufacturing plans are outlined in **Figure 42** shown below. The precise measurements of each of these parts is dependent on the final design of our electronics packaging as well as the exact measurements of the neck girth(s) of the sea lions used in experimentation. The figure shows approximate relative sizing of each component, but the final build might slightly differ in shape and size. Prototypes used in testing might not follow these exact steps, but will be of similar shape and provide sufficient packaging for electronics used in testing as well as straps for wearability verification. This manufacturing process is tentative and subject to change based on the teams decisions throughout the rest of the semester.

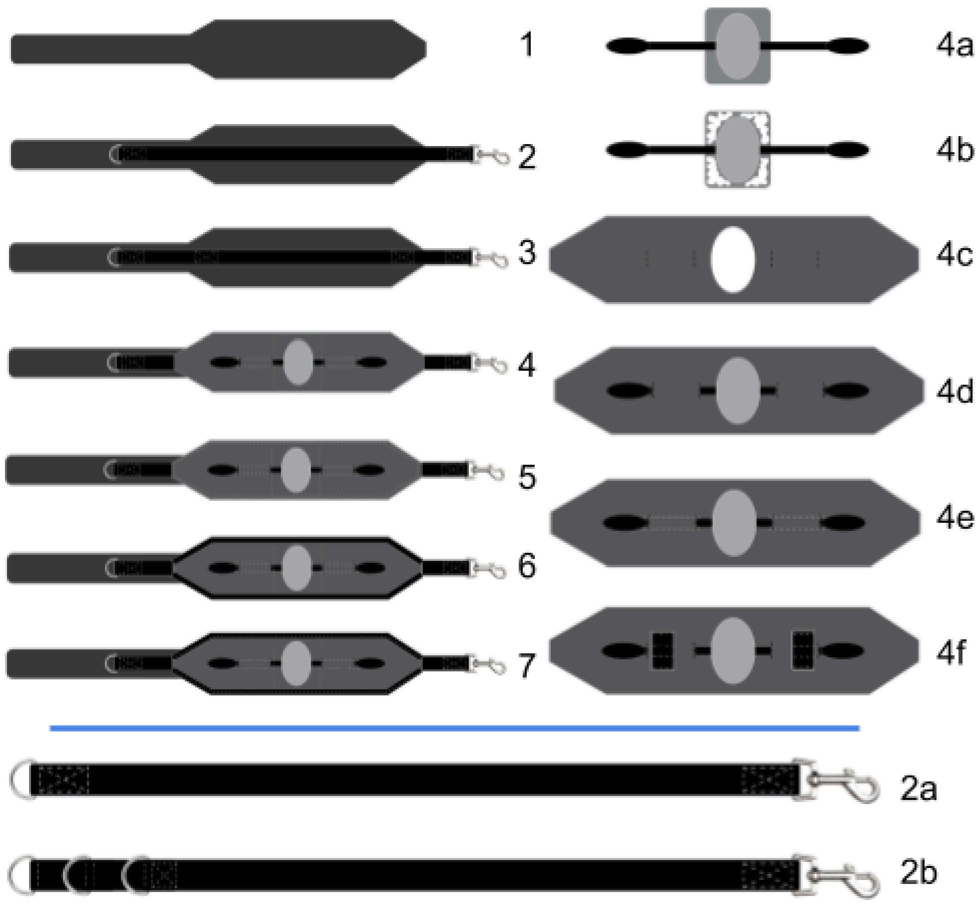


Figure 42. Collar manufacturing plan. (1) Neoprene foam base sheet (2) Wrap polyester strap through loops of D-ring and swivel eye bolt, stitch together (two options for adjustability with number of D-rings), lay on base sheet (3) Sew strap to base sheet (4) Glue electronics package through opening in neoprene foam top sheet 4c using aquaseal, thread hydrophone wires through slits cut in top sheet, either sew alongside the wires 4e or extra straps near hydrophones 4f (5) Sew through both layers of neoprene foam around the entire edge of the top sheet as well as around E-tag baseplate (6) Wrap polyester strap around edges where edge stitches are (7) sew strap edges together.

FINAL DESIGN

What is it?

The final collar design shown in **Figure 43** is very similar to the original build design. The collar is held together using polyester straps and neoprene rubber attached to clips and rings for attachment. This collar/harness will work by attaching the clips to the desired D-ring loop around the neck of the sea lion, followed by pulling the body straps down under the fins and around the axilla of the sea lion. These additional straps will serve to prevent the collar from slipping over the sea lion's head. Hopefully, due to the neoprene rubber, slight tension of the collar and the axilla harness straps, there will be minimal rotation of the collar and each hydrophone will be positioned next to the respective ear. A hand-rendered image of the sea lion wearing the final harness design is shown below in **Figure 44**. During the tests, the sea lion will follow its training instructions as usual, and the hydrophones will record SPL data next to the sea lion's ears which will keep the research accurate to what the animal actually hears.

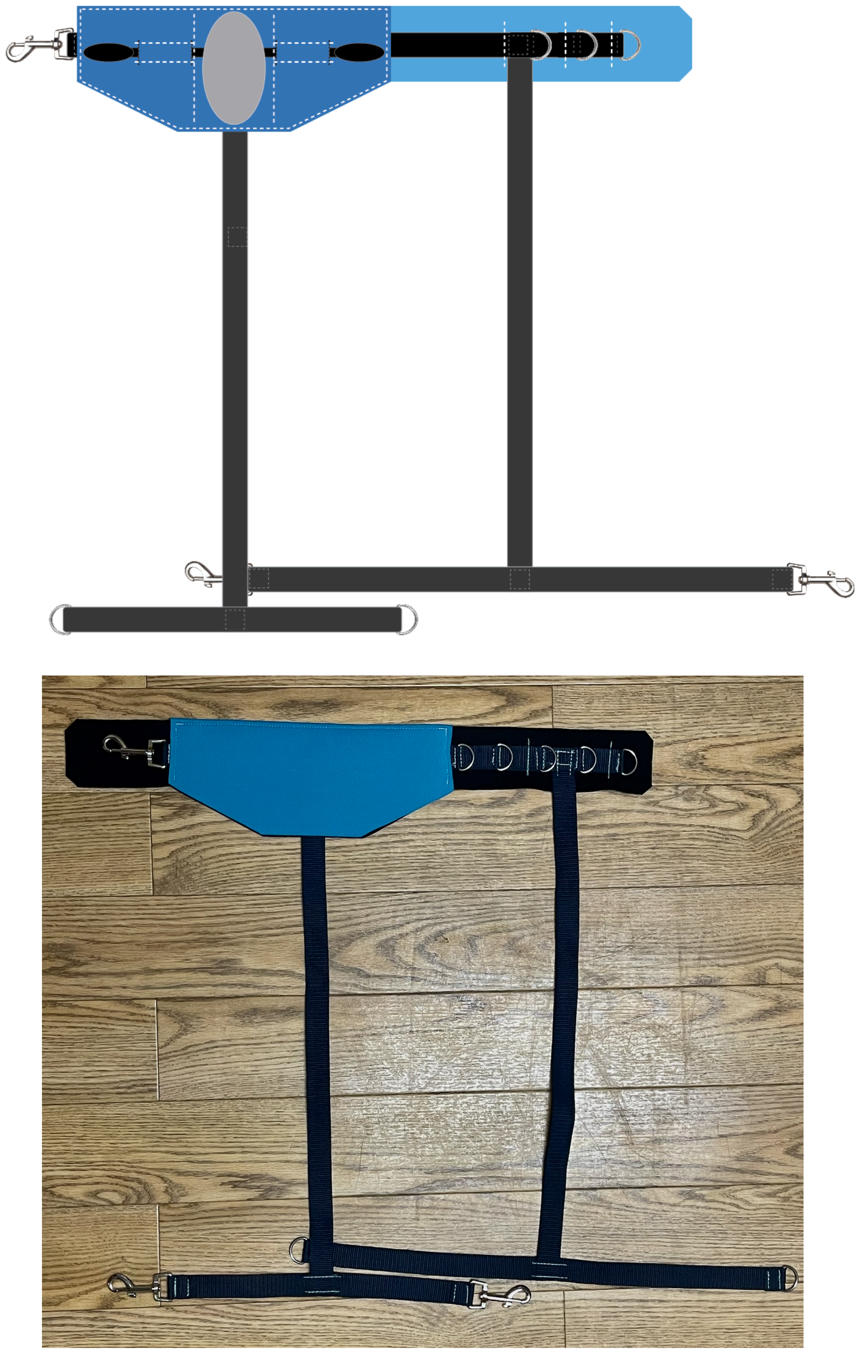


Figure 43. Final collar design and prototype. Neoprene rubber (blue), polyester strap (black & gray), resin electronics packaging (light gray), hydrophones (black round), swivel eye bolt snap (silver, left), D-rings (silver, right), sewn together using marine thread (white).

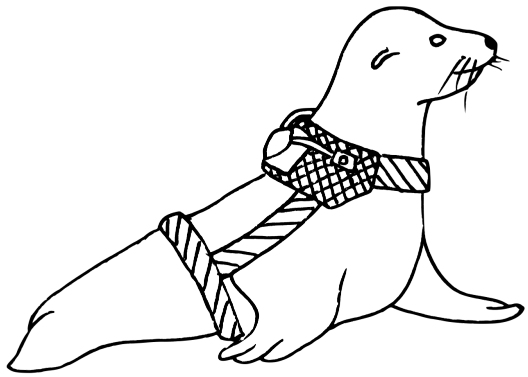


Figure 44. Collar operation when applied to a sea lion.

Material Selection
This design is based on the results from our experimentation and research. We believe that it will work very well based on the materials and packaging redesign chosen. The neoprene rubber is lightweight and doesn't absorb water, as well as softer which will allow for better sea lion comfort. Based on our extension tests, we found that it is also extremely durable even after soaking in saltwater. Polyester strap also has a very low water retention rate, and does not stretch much under tension. We found that sewing marine thread is the most durable option for attachment, compared to underwater adhesives and rivets. The metal attachment mechanism is nickel plated and stainless steel, which should withstand prolonged water exposure with minimal corrosion. The swivel eye bolt snap, when hooked to a D-ring, proved to be very quiet during attachment and detachment which will prevent any discomfort for the sea lions when applying the collar. The electronics package shown in **Figure 45** was designed to be highly hydrodynamic, producing minimal drag to reduce any impact on swimming. It is resin and will be glassed in with epoxy, which will keep everything waterproof and durable over time.

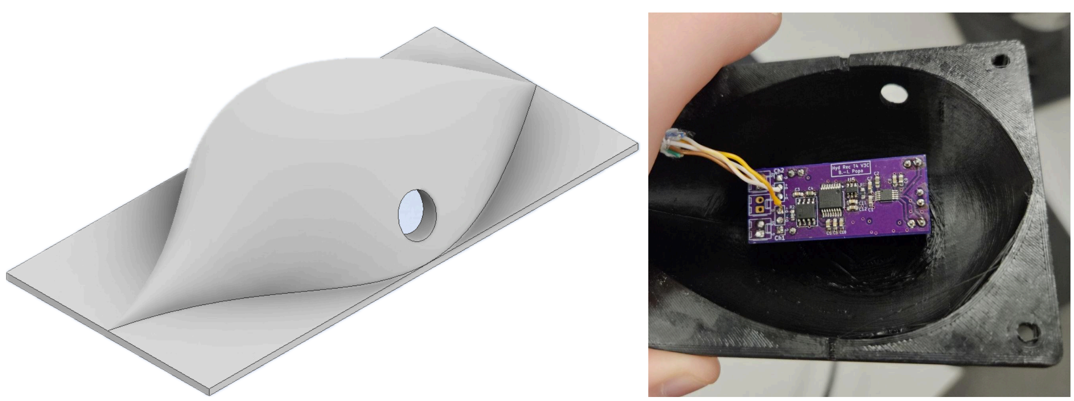


Figure 45. Electronics packaging CAD (left) and resin print (right)

Manufacturing
Considering this product will only be used on a single sea lion in Dr. Kastelein's testing facility, manufacturing on a large scale is not a factor. However, producing one of these harnesses

requires not much effort or cost of materials so in the event that research gets spread to a wider range (wild mammal testing for example), producing them should be a fairly simple task. Man hours sewing the materials together would be one of the largest limiting factors in production of these collars. The other difficult aspect of manufacturing the harness is the electronics housing. The hydrophones must fit through the packaging holes, aligned with the electronics inside as well as pins for data collection, then filled with epoxy to be glassed in and completely waterproof. Once this package is completed, it must be inserted into the collar similarly to **Figure 46**. The hydrophones need to be threaded through the neoprene and held in place in hopes that nothing gets deconstructed during use.

Figure 46. Initial packaging prototype (resin printed) inserted into neoprene collar using hot glue in place of any adhesives used and before sewn in.

This final design was the exact concept used during our build for testing verification and validation. Our team found reasonably priced materials to purchase for these builds, shown in detail in the bill of materials (BOM) shown in the appendix of this document. The electronics are being made in-house by Dr. Shorter's lab, and our packaging is made of a resin print which will be glassed-in using epoxy. The primary requirement for this packaging design is that it can fit all electronics and be waterproofed using the top and base plate. This build helped to show how sizing and movement can affect comfort and durability. Without being able to test on a sea lion in person, it's hard to tell the pitfalls of this design. We hope to verify that the hydrophones can record accurate SPL levels, and validate that the sea lion is willing to wear this collar or some variation of this design.

VERIFICATION

Table 5. Our verification of requirement

Priority	Requirement	Specification	Testing Method	Status
High	Rotation-resilient SPL	SPL Sensitivity needs to be	We will test this requirement by	In progress

	sensitivity	axisymmetric around the axis orthogonal to the sound source direction with a range of than 7 dB across frequencies 0.6 kHz-40 kHz	testing different solutions by rotating them around the relevant axis around some body that closely resembles the sea lion	
High	Sampling Frequency	Sampling Frequency is at least 80 kHz	This will come from internal parameters and be tested by measuring the highest frequency that our solution can measure from some source sound.	Passed
High	Ease of use (wearability)	-Must be able to be put on under 30 sec and taken off under 20 sec by one of our team -Attachment mechanism needs to have max SPL less than or equal to current clips	-Timing human putting on harness on a sea lion-like object/human -Measure SPL with microphone and post process data	In progress/Passed
Medium	Recording duration	Needs to be able to record for at least 4 hours	This will come from deducing the sampling frequency and the amount of memory each data point requires and then comparing that to the available memory.	Passed
Low	Interface with current harness	Needs to fit within 19.58 square inches of the current mounting plate (19.58 square inches is the current footprint of	This will nominally be measured using a ruler or caliper.	Failed due to different harness design

		the current tag)		
Low	Impulse resistance	Must withstand impact against a wall of 242.25 N	Apply impact load of 85 Kg moving at 3 m/s decelerating in 1 s	In progress

Many specifications of our design can be tested through verification methods learned via our sponsor, our discretion, the course learning blocks, and many other sources. The following subsections will outline the most important areas of our project that require or will require verification and how they tie back to our critical requirements and specifications.

Hydrodynamic Drag Testing

The hydrodynamic drag that we found through our CFD analysis on various housing designs (discussed in the engineering analysis section) gave us a good indicator of what shape our housing should be to give us the smallest possible drag force acting on our design. In doing so, this fulfills our requirement of reducing the amount of drag over a majority of the operating regions of the sea lion.

Clip SPL Testing

The SPL of different clip attachments, again gone into more detail in the engineering analysis section, allowed us to choose a clip that was effective in holding the collar together while also keeping the attachment as quiet as possible to not hurt the sea lion's ears as well as mess with data collection. Based on this test, we will be moving forward with a swivel-eye clip, therefore fulfilling our requirement of the clip being quiet when attaching and detaching the collar from the sea lion.

Neoprene Attachment Testing

The neoprene attachment test was important in determining the strongest and most effective method of attaching the material of the collar back to itself after threading it through areas like the baseplate on which the electronics will sit as well as the clip mechanism. This test was covered extensively earlier in the report and continues to be workshopped by our team as we find new materials to test. This test is vital in verifying that our collar has the fundamental strength to stay together in salt water and an unpredictable environment.

Acoustic Sensitivity Testing

This test will be completed once our team has a physical prototype of our build design, which will be our main focus moving forward. The test involves wrapping our collar around an acoustic shielding body, underwater, then playing sound from a point source while rotating the body. After this, we will analyze the data we collect and observe how accurate our acoustic readings are. The acoustic shielding body used in this experiment is used to replicate the body of the sea lion, so finding a material that suits this requirement is still something we will need to look into. The results of this test will help us verify that our design is omnidirectional, meaning that the orientation should matter very little in terms of what our gathered data should look like. Upon completion, this test will allow us to verify our requirement for an accurate SPL representation from our design. **Figure 47** below shows a visual of what this test setup will look like.

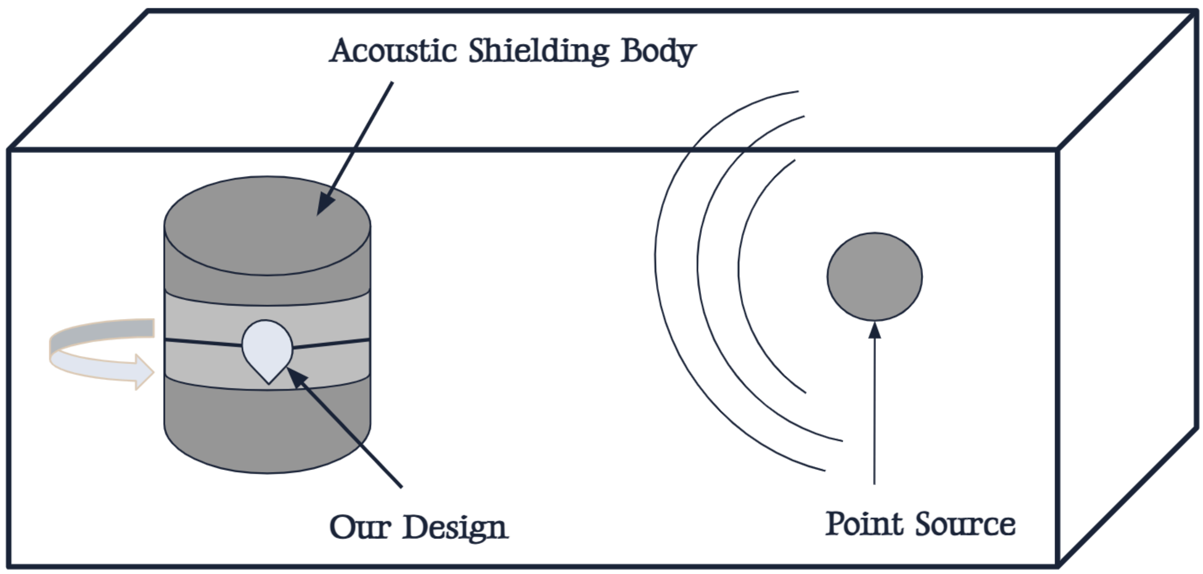


Figure 47. Acoustic sensitivity verification test setup. Note that this test will be performed underwater, as that is where our final design will be taking data from.

VALIDATION

Although many validation plans relating to our project may take us outside both our scope and the course's timeframe, we have come up with a few valuable validation plans regarding the performance of our final design. It is important to note that the following plans are all related to specifications that we can "test" here on our own, but not to the level of confidence that we can with our other tests (mainly those in our verification section).

Wearability Validation

While we plan to do some testing on our design to make sure that it is easy to take on and off and has no adverse effects on the sea lion, it is difficult for us to do this without having access to an actual sea lion. After all, how can we predict how still the sea lion will be when putting on the harness, or other seemingly random factors? It is also difficult to find an accurate placeholder, both in size and in material composition, for our wearability testing. So, one of our main validation plans revolves around getting feedback from our sponsor as to how easy it is for him and his trainers to handle putting the design on the sea lion. Obtaining this feedback would finally give us credible information as to how we can improve our design so that it fits our sponsor's specific needs.

Recording Duration

One of our specifications for our design is for our product to be able to operate for at least 4 hours, giving our sponsor plenty of time to gather the data he requires. While this may seem like an easy specification for us to test, there are some other factors to take into consideration. We do plan to run our tests to ensure our product can reach this recording duration threshold, but this doesn't necessarily guarantee that this will carry over to our sponsor's environment. Something could happen to our design when we ship it during transit to the Netherlands, or maybe our sponsor's testing facility brings up more environmental factors that we didn't consider or have to deal with in our testing. This is another case where we can ask our sponsor to conduct a usability test relating to this requirement, and from there go about reworking to accommodate any issues.

Impulse Resistance

Similar to the wearability validation, there is no way for us to completely and accurately predict how the sea lion will move or how much force it will exert on our design by bumping into walls or actions of that nature. Thus, while we can do our testing and ensure it can withstand a certain impact load at a certain speed, we cannot completely guarantee that there is nothing the sea lion can do to break it; that is simply out of our control. However, we can (and plan to) make sure that our design can impact loads greater than what we expect it to endure during use, which will give us a good safety net regarding this specification.

Overall User Satisfaction

Finally, we would love to get our sponsor's overall thoughts on our design after some time of him using it in a research setting. This would come in the form of a meeting with him after a month or two of him getting to play around with the design and see if it is as much of an improvement over the previous model as we hope it to be. A meeting such as this would provide us with a good general understanding of if our design met our sponsor's expectations.

DISCUSSION

With more resources and time, our team would love to investigate if we could use one hydrophone instead of two. The reason we would like to look further into using one hydrophone instead of two is because it makes reading the data for the researcher much easier. To explore, our team could set up an underwater test with a point source playing a known sound, then we could rotate the design through all three rotational axes and see the effects of attenuation. Comparing the received SPL values to the known sound, we could determine if a one hydrophone solution could be feasible or not.

Our design demonstrated strengths in many different aspects, notably in meeting the sponsor's key requirements. Something our sponsor made very clear was that our collar design needed to be quiet while being attached and detached to the sea lion and while the sea lion was wearing it. Our team did very thorough testing to find the quietest attachment methods and then researched methods to make them even quieter. Another key strength in our design was the fact our team was able to compress the necessary components of the acoustic sensing device to a smaller collar while having a more accurate representation of what the sea lion would be hearing by moving the hydrophones closer to the animal's ears. A notable strength in our collar design that also is worth mentioning is the capability to add an under fin harness that connects onto the collar itself. Although our team believes the collar would stay on, the harness ensures that. While our design shows promise in various aspects, there are some things that can be improved.Notably the size ability factor of our harness. Since we could not actually test the fit of our collar on the sea lion itself, our team put multiple D ring attachment sights for the handler to make a snug fit on the sea lion. Our team believes if we could make an improvement to our design we would add a sort of sizable attachment method that could secure the harness better. A solution our team thought would be applicable would be instead of stitching in the D rings in place we could attach an extending and retracting strap to the D ring that keeps a secure amount of tightness to the collar. This would also lower the need for the harness attachment to the collar.

Risks

Our team encountered many challenges during the design process, the major issue being the inability to determine the optimal placement for the acoustic sensing device. Our team addressed this issue by first creating various harness/ collar designs. These designs were then presented to our sponsor, Dr. Ron Kastellein, who then discussed each variation with his team made up of researchers and members who were experienced with the sea lion. This action plan proved to be beneficial as we could build upon a design that may work. Taking these steps in the initial design process was crucial as it minimized the risk of making an acoustic sensing device that would not be compatible with the sea lion. Although our sponsor and his team chose the design of our acoustic sensing collar, our final product is still at risk of not being viable since it is all up to the sea lion if it feels comfortable wearing the collar. These risks will be addressed once validation occurs.

REFLECTION

While Our project does not benefit humans for public health, safety, and wellness, it does have a large impact on the well-being of marine life, specifically sea lions. With a method to measure how anthropogenic sounds affect the animal, steps can be implemented to make a safer environment for the animal. Understanding how sounds like sea drilling, ocean wind farms, and boats affect sea lions can inform conservation groups and push for the protection of these animals' habitats. Although our project focuses on the effects of anthropogenic sounds on sea

lions specifically, our solution does indirectly impact the global marketplace. By creating a collar that can measure acoustic data, our team has found modification is simple to implement in various marine environments globally. Using the collar researchers may be able to determine why marine habitats are shifting or being destroyed by learning how anthropogenic noises affect marine species. With a solution that focuses on improving the marine environment, global marketplaces like fisheries can benefit as the stability and sustainability of marine ecosystems are enhanced, ensuring a more reliable and consistent supply of marine resources.
Social impacts could be seen with the use of our product. As more of the communities see what our product is being used for, the community may learn more about how anthropogenic sounds can have an impact on marine animals. In addition, the data collected using our collar can be used to inform policies aimed at decreasing the effects of anthropogenic disturbances in marine habitats, thus pushing for positive social change. While our project primarily pushes for a conservation outcome, an indirect impact on the economy can be seen as discussed above with those who depend on marine life as a source of income. Negative impacts could also be seen to some shareholders like big boat industries because they may potentially need to make expensive adjustments to account for the amount of anthropogenic noise they may be making.
Assessing the societal impacts of our design, our team constructed a three-tier stakeholder map. The map was broken into primary, secondary, and tertiary stakeholders. Through this framework, our team analyzed the impact of our design on each stakeholder at every level. Our objective was to come up with a solution that would be advantageous to most.

Inclusion and Equity

Differences in culture, privilege, and views greatly benefited our team whether it was between the team and team and the sponsor or between the team members themselves. Differences in culture, privilege, and identity allowed our team to come up with a diverse solution that incorporated perspectives and insights that were not otherwise attainable. Stylistic similarities and differences among team members fostered a variety of approaches and ideas, resulting in a more comprehensive and thoughtful solution. The diverse aspects brought by each member of the group allowed the team to think from a larger perspective and allowed for unique ideas. Our sponsors played a significant role in shaping each aspect of our designs. In particular, our main sponsor, Dr. Ron Kastellein, brought invaluable expertise in research and applied studies with sea lions. His guidance and insights greatly influenced every stage of the design process and ultimately contributed to the outcome of our project.

Exploring the power dynamics in our project was important to play into what each team member was good at. When looking at the power dynamic between the sponsor and the team it was important to notice how often we were looking up to our sponsors and asking them questions about if something would be feasible or not. It was crucial to have every aspect of the projects be approved by our sponsors who would in the end also be speaking for our end users. Within our team, power dynamics were characterized by a sense of equality among members, where everyone had an equal voice and contribution. However, individuals with extensive experience in areas such as manufacturing or CAD naturally assumed leadership roles in those specific aspects of the project. To make sure all the teammates' points of view were equally heard our team implemented regular discussion sessions and made sure all team members had the opportunity to discuss their opinions. Balancing the ideas of our stakeholders and the various members of the group was crucial to the final execution of our product. Our team found that having open group discussions between the team members and sponsors to discuss viewpoints was the best way to settle on a solution. Oftentimes our team listened to the sponsors as they had experience with the sea lion and the technology being implemented.

Ethics

When designing a new collar, it is imperative to take ethical considerations into account. We want to create a solution that is both comfortable and non-invasive for the sea lion and the handle. An ethical dilemma our team ran into was thinking about what may be comfortable for the sea lion without actually being able to test if it would. Our team went around this situation by using materials and mechanisms used in the current harness which was proven to be comfortable for the sea lion. Our team's ethics match the ethical standards we must hold as students of the University of Michigan, we value the safety of our subjects and also hope to come up with a product that meets university standards.

RECOMMENDATIONS

Acoustics

Our sponsor, Dr. Kastelein, had a few issues with the original D-Tag design with the main issue being the acoustic accuracy. Therefore, one of the main recommendations that our sponsor had was to move the sensor array closer to the ears as it would result in data more accurate to what the sea lions are perceiving. We opted to incorporate this recommendation as we had the technical wherewithal to achieve the request and we believe it will present more accurate data. In the same vein, our sponsor also recommended that we incorporate one omnidirectional hydrophone on top of the design instead of the two that are currently used. We chose to disregard this recommendation as we strongly suspect that this would not solve the acoustic attenuation that Dr. Kastelein registered and that the orientations that place the animal between the sound source and hydrophone will show attenuation similar to the original design.

Structural

Our sponsor also requested that any fasteners or other metallic components we used be 316 stainless steel. Since our design does not utilize any metallic fasteners, we did need to implement this recommendation. Dr. Kastelein also expressed an interest in finding a different solution that did not have a stopper plug for data collection pins as the stopper could work loose and be swallowed by the sea lions unintentionally. Our final design will feature pins that are grounded and in water and watertight so that there is no need for a stopper. Lastly, our sponsor recommended that our design feature a more robust housing design as the previous design has an issue with continuous use in the water. Our solution will incorporate a FormLabs Tough 1500 Resin as it is the industry standard material that has been proven to work on tags over long periods and is readily available through Dr. Alex Shorter's lab at the University of Michigan.

Materials

Dr. Kastelein also suggested that we should consider incorporating neoprene into the design. Since we found an example of a different research team using a neoprene foam strap on sea lions near the head, we thought that this recommendation had merit and we used it as the basis for our exploration of neoprene foam as a material choice. Regarding the attachment of the strap or collar, our sponsor expressed some reservations about the strap going over the head of the sea lion as opposed to being attached around the neck. He believed that this could negatively affect the sea lions' health as it would interfere with their perception. In addition, Dr. Kastelein wanted whatever attachment solution we came up with to be quiet to not impact the sea lion's hearing. For this, we ran a simple experiment to determine the sound pressure level and the attachment that produced the smallest sound pressure level during attachment and detachment. After this test, we found the swivel eye bolt snap was the best option.

CONCLUSION

Our project initially focused on improving the acoustic sensor and hydrophones embedded within the existing D-Tag model, which is currently mounted on a harness worn by sea lions. However, we later pivoted away from using the D-Tag in favor of using what we are calling an "E-Tag," which better suits our sponsor's needs and is less bulky than the D-Tag. We came up with new packaging as well as upgraded electronics to provide our sponsor with a more user-friendly and accurate design. In doing this, we will hopefully aid our sponsor in identifying the specific sound pressure levels emitted by various sources that are damaging to marine wildlife, specifically California sea lions. To prepare for this, our team has organized our findings in the form of this report, which outlines important background information, previous solutions to our problem, the design process we followed, relevant stakeholders, requirements and specifications for our design, our problem domain analysis, and some challenges we encountered throughout the project.

Our final design consists of a collar in which the electronic mechanism of the circuit board and data-collecting micro-SD card is encased within a hydrodynamic housing, with the hydrophones oriented outside this to provide a more accurate reading. We have worked throughout this semester to create a design process that will help us accomplish this, which is outlined in this report.

Upon completion of this report, our team's final steps are to send out our designs to our sponsor for validation and feedback. We have educated ourselves through research and analysis on the critical topics that pertain to our problem, and we look forward to seeing how our final product suits our sponsor in his research endeavors.

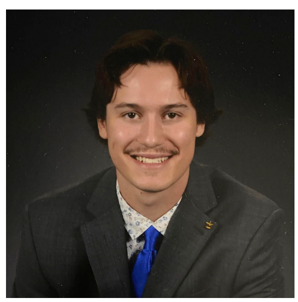
ACKNOWLEDGEMENTS

There have been many people who have helped us throughout the semester, and we would like to take this moment to point out those who have been of particular help. We would first like to thank Dr. Alex Shorter for his guidance through the design process and his expertise in biologging technology in his lab. Additionally, our instructional aids Adi Scharf and Anika Satish always had valuable input and dedicated a lot of time to seeing that our project was successful. Our sponsor, Dr. Ron Kastelein, also played a big part in providing us with the data and measurements we needed, and we greatly appreciate him taking the time to assist us despite the time difference. We would also like to thank Gabriel Antoniak for his consultation on the electronics and his ongoing work on the circuitry that we are using for this design. And lastly, we would like to thank Ethan McMillan for his assistance in the manufacturing process.

BIOGRAPHIES

Balpreet Singh

Balpreet Singh is a 22-year-old mechanical engineering student at the University of Michigan. As a young child, Mr. Singh has always been interested in aviation and automobiles. Growing up in Michigan and being so close to the auto industry Mr. Singh started to take an interest in making small RC cars and boats. Being a senior in mechanical engineering and doing a co-op at McLaren Engineering, Singh has decided to look into the research and development side of the automotive or aeronautical side of the industry. Mr. Singh plans to continue his path at the University of Michigan by completing his master's after working in the industry. Singh hopes to one day work for NASA or electric car manufacturing companies specifically in the powertrain division. Mr. Singh's favorite off-time activity is spending time with family and lifting weights.



Caden Corso

Caden Corso is a 22-year-old undergraduate mechanical engineering student at the University of Michigan. He is from Riverview, Michigan, which is located about 10-15 minutes outside of Detroit. Caden's interest in mechanical engineering comes from his curiosity about *how* things work, and how he can learn from others and apply his knowledge to improve the world around him. He took many mathematics and physics courses throughout his time in high school, which helped him come into his undergraduate years with a solid background in some of the fundamentals of engineering. Caden has accepted a job for post-graduation (anticipated graduation in May 2024) at a construction company called Mortenson, where he will be working on solar and renewable energy solutions in a traveling role. Outside of academics, Caden enjoys spending time outside, hanging out with friends and family, and staying active by working out and playing basketball/golf. Caden also enjoys reading, traveling, and playing guitar, as music is another of his passions.

Mike Reynolds

Mike Reynolds is 20 years old and a senior in mechanical engineering at the University of Michigan with an interest in biomedical applications of control theory and robotics. His interest in mechanical engineering came from his love for math and real-world applications that he gained from studying physics and differential equations during his junior year of high school. Working in Dr. Alex Shorter's lab over the past year has exposed him to the field of measurement and data processing in the biotagging field which has influenced his interests in the field of controls. After his anticipated graduation in December of 2024, he plans to continue in academia in preparation for his subsequent Ph.D. studies in controls and robotics.

Clifford Amadeo LeVeque

Cliff LeVeque is a 21-year-old undergraduate senior studying Mechanical Engineering. Growing up in Holt, Michigan, Cliff was originally interested in attending an art school to study design - Graphic Design in particular. After taking a three-year engineering course at Holt High School through Project Lead the Way (PLTW), he was convinced that the combination of creativity and communication skills paired with high-level mathematics and science could be a great fit for an engineer. Mechanical engineering specifically has allowed a deep dive into many realms of engineering, opening the possibility for specialization upon entering the career field.

Working as an intern at Plastic Omnium, Cliff has found an appreciation for manufacturing processes and machinery design. Cliff will graduate from the University of Michigan in May 2024, and plans to start his career as an entry-level engineer in Michigan; he hopes to continue working with Plastic Omnium in the near months after graduation.

In his free time, Cliff is a part of the Michigan Men's Water Polo team, where he has been a captain and the Vice President for two years. He also is the president of the Michigan Roundnet Club and plays Spikeball with Livonia Roundnet with whom he plans to qualify for Pro by the end of the 2024 season. Cliff also enjoys skateboarding, photography, and travel.

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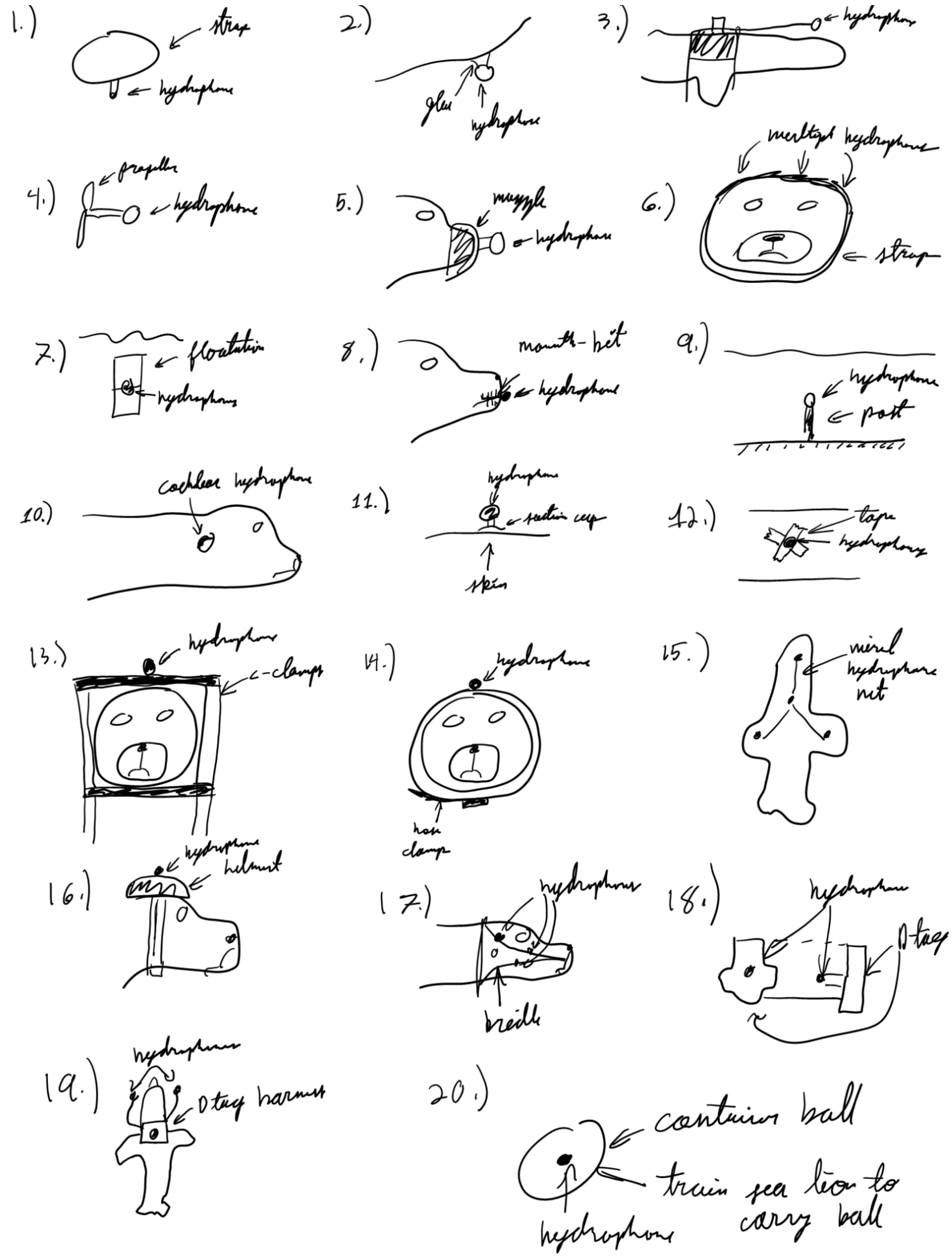
Appendix A: Concept generation examples



10. Attach product to user

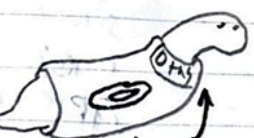
Design heuristics

1. Utilize opposite surface (76)

2. Bend

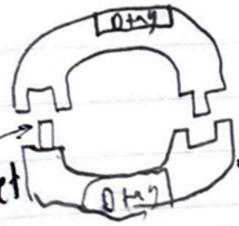
(make D tag into a spine type attachment that can move like a snake)

3. Mimic natural Mechanism

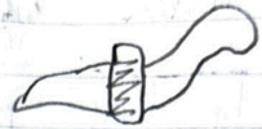


4. Simplify (60)

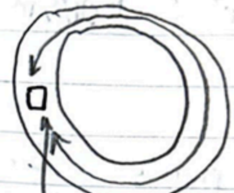
5. Make componants Detachible



6. Attach product to user



7. Allow user to reorant



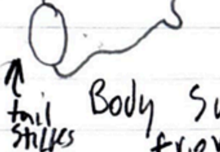
D tag collar has reorenting device that positions the D tag so its near ear at all times

8. expand (32)

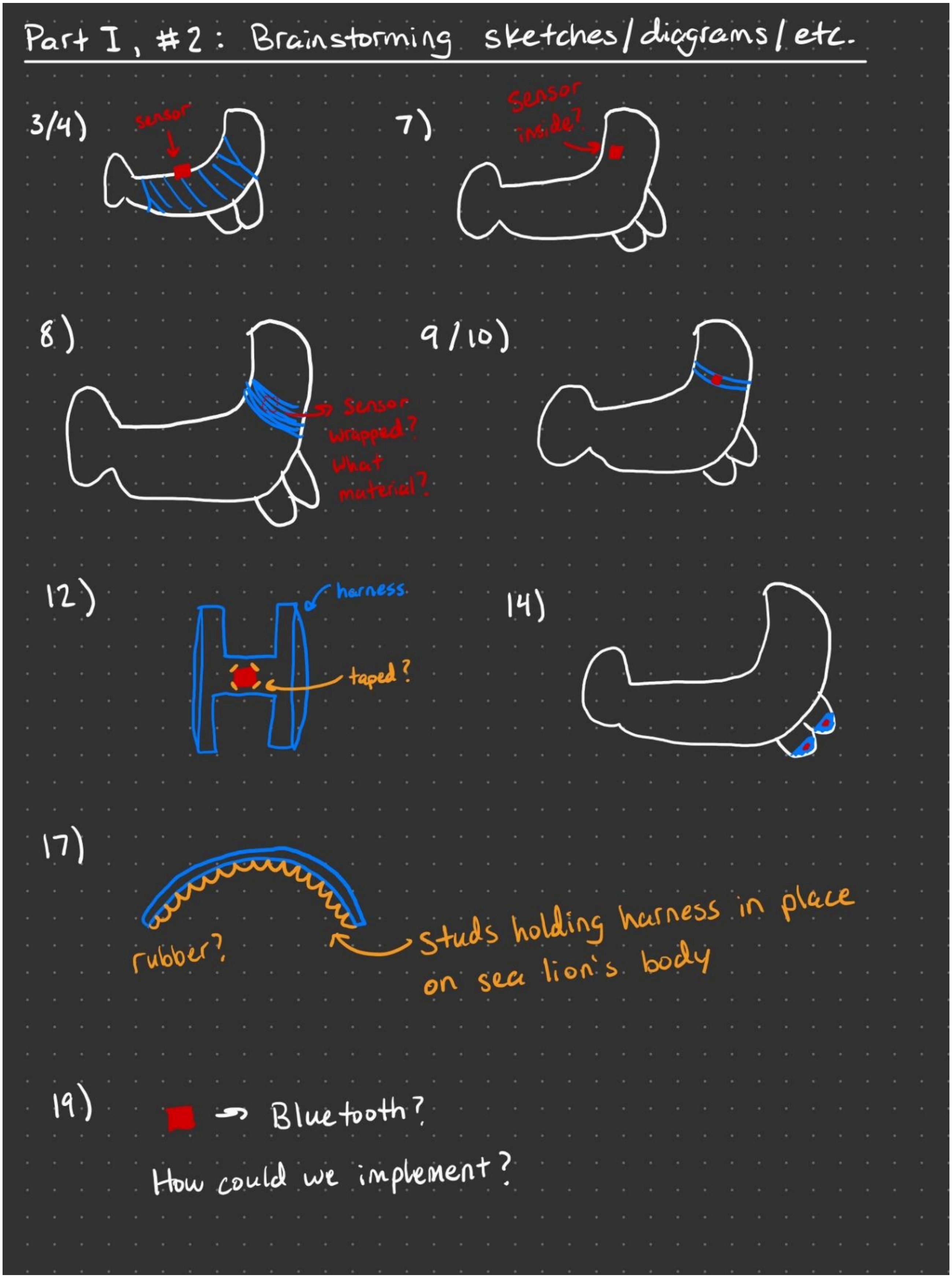
(like armo

expanding and manouvers collar that can be detat

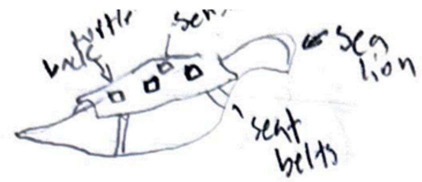
9. Use continuous Materi



Body suit made from continuous Material

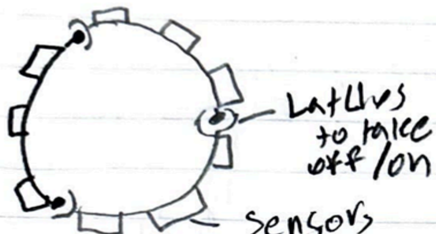

Part I, #2: Brainstorming sketches/diagrams/etc.
3/4)
sensor
7)
sensor inside?
8)
sensor wrapped? what material?
9/10)
12)
harness
taped?
14)
17)
rubber?
studs holding harness in place on sea lion's body
19)
→ Bluetooth?
How could we implement?

1.



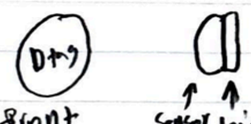
• turtle shell design that is covered with multiple sensors. attached using seat belts

2.



• necklace

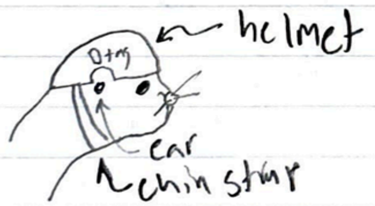
3.



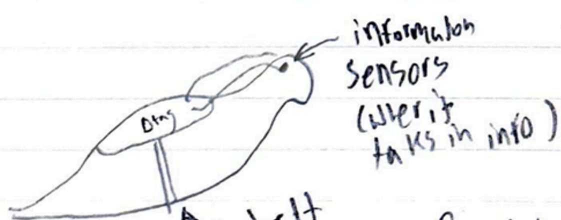
• goes above ear

• earbud sensors

4.

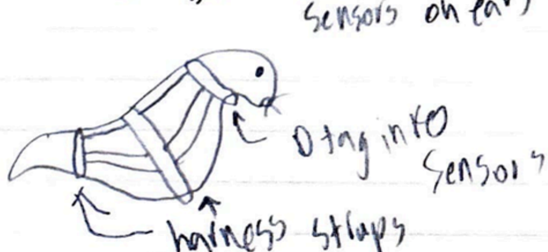


5.



• sensor on back but information sensors on ears

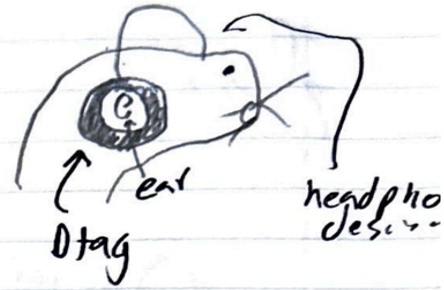
6.



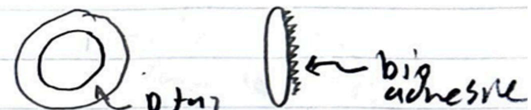
• secure

intenna style D tag that is attached using bio a

8.

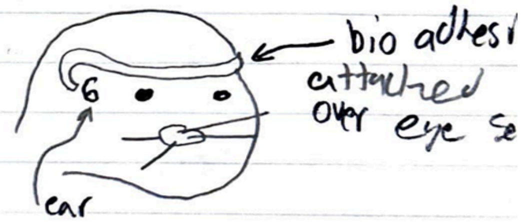


9.



• Doughnut D tag over/on ear

10.

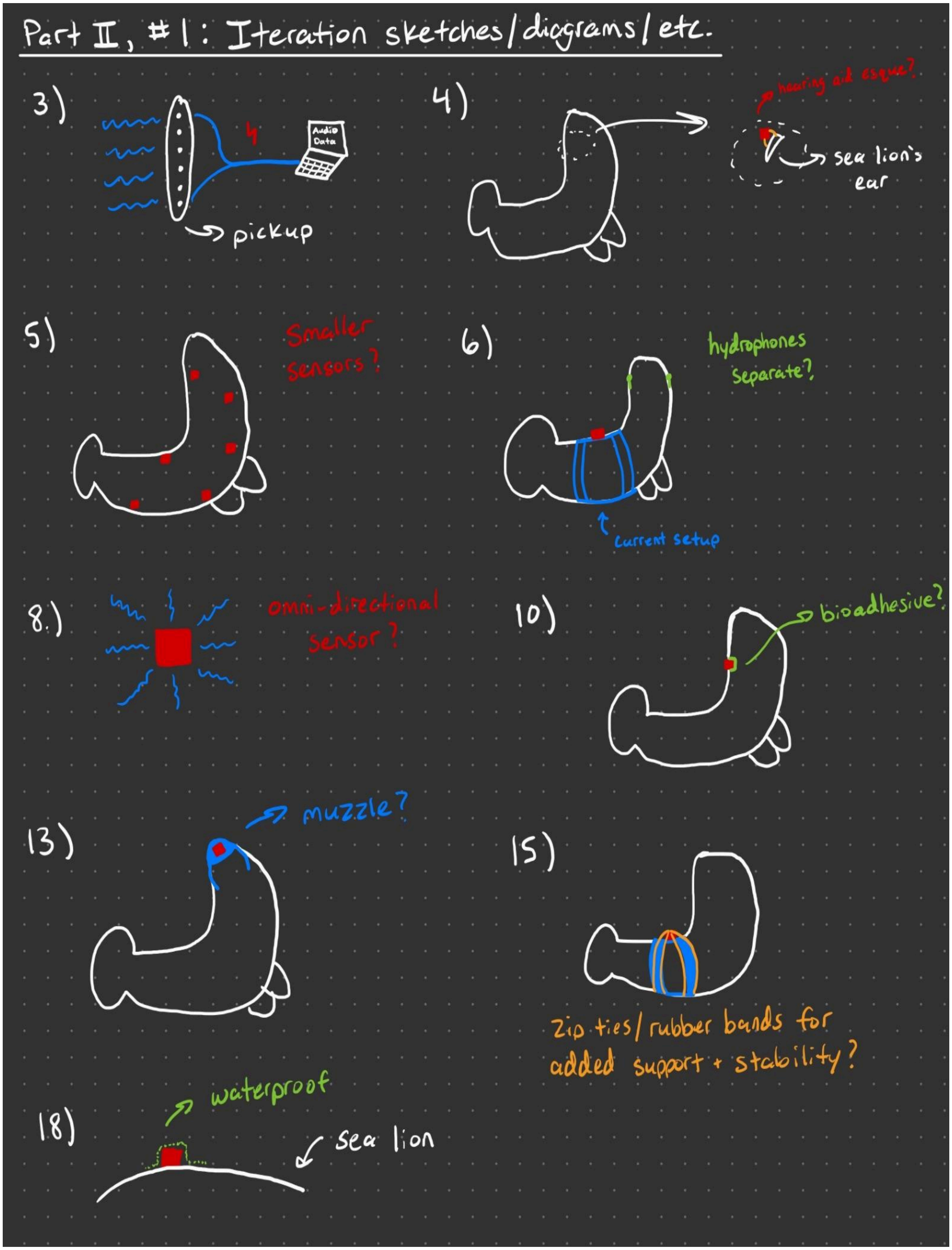


11.

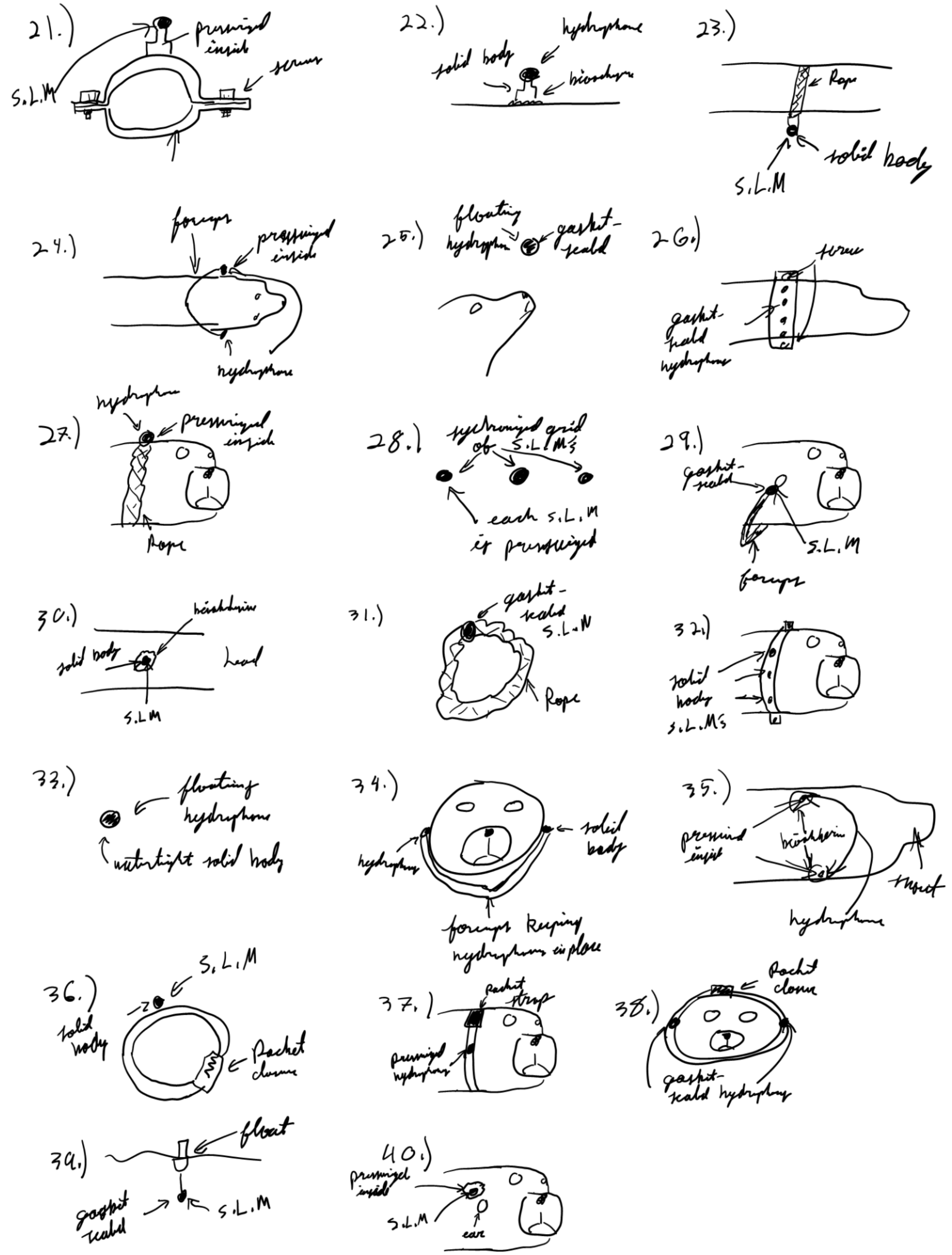
latching under chin device

12.

latches around



Part II, #1: Iteration sketches/diagrams/etc.
3)
Audio Data
pickup
4)
hearing aid esque?
sea lion's ear
5)
Smaller sensors?
6)
hydrophones separate?
current setup
8.)
omni-directional sensor?
10)
bioadhesive?
13)
muzzle?
15)
Zip ties/rubber bands for added support + stability?
18)
waterproof
sea lion


21.)
pressurized inside
screws
S.L.M
22.)
hydrophone
solid body
bioadhesive
23.)
Rope
solid body
S.L.M
24.)
forceps
pressurized inside
hydrophone
25.)
floating hydrophone
gasket-sealed
26.)
screws
gasket-sealed hydrophone
27.)
hydrophone
pressurized inside
Rope
28.)
synchronized grid of S.L.M's
each S.L.M is pressurized
29.)
gasket-sealed
S.L.M
forceps
30.)
bioadhesive
solid body
head
S.L.M
31.)
gasket-sealed S.L.M
Rope
32.)
solid body
S.L.M's
33.)
floating hydrophone
watertight solid body
34.)
solid body
hydrophones
forceps keeping hydrophones in place
35.)
pressurized inside
bioadhesive
hydrophone
snout
36.)
S.L.M
solid body
Pocket closure
37.)
Pocket strap
pressurized hydrophones
38.)
Pocket closure
gasket-sealed hydrophones
39.)
float
gasket sealed
S.L.M
40.)
pressurized inside
S.L.M
ear

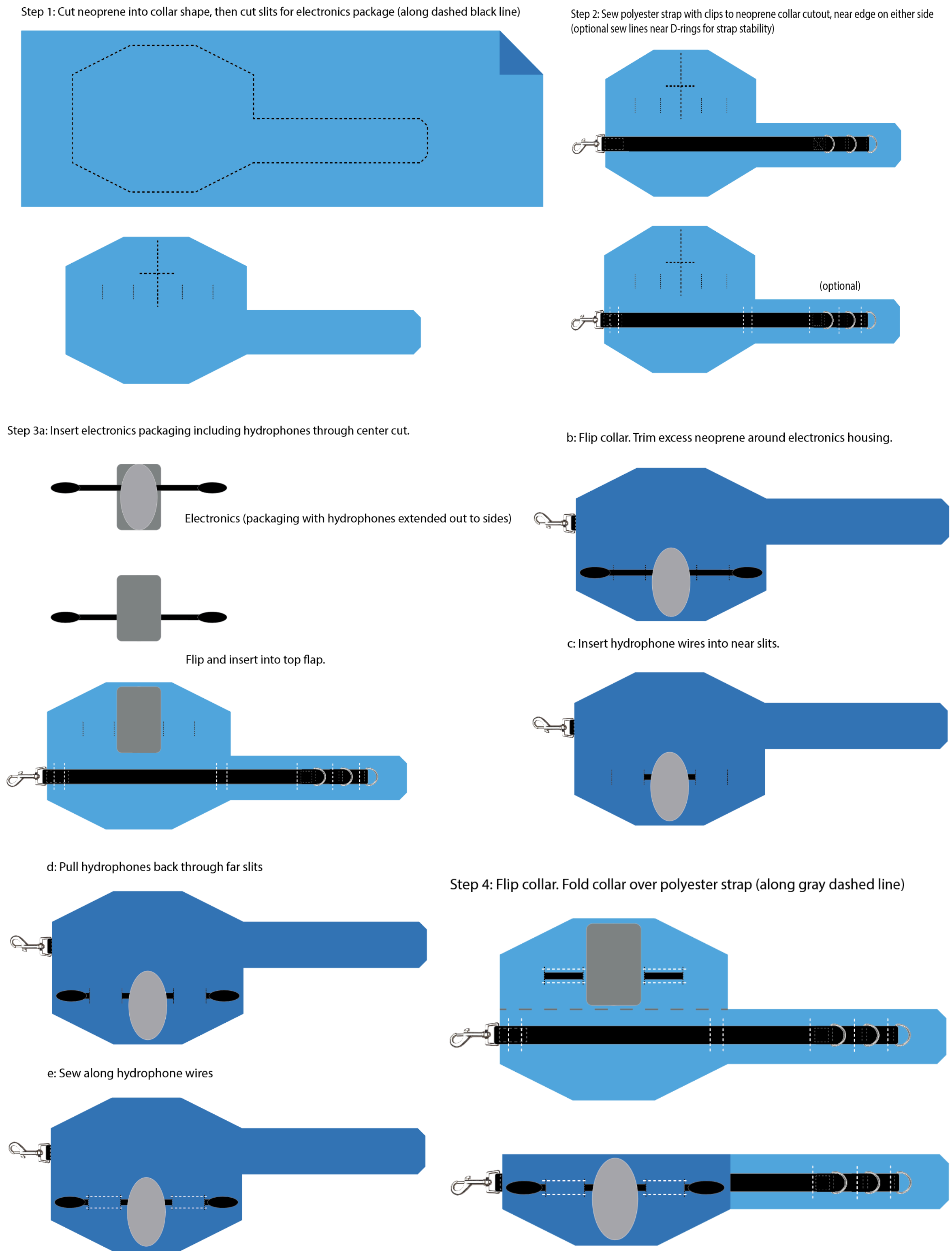
BILL OF MATERIALS

Part	Description	Source & Serial Number	Quantity	Unit Cost	Cost
Neoprene	Wetsuit material roll (1x4 ft)	amazon.com B0B14CDQ3T	0.5	35.17	17.585
Polyester Strap	1” by 16.5 yard	amazon.com B0BMLBG3V1	3 (/16.5)	9.99	1.816
Swivel Eye Bolt Snap	Nickel-plated steel clip (10pcs)	amazon.com B07D3M6TTD	3 (/10)	12.99	4.33
D-Ring	304 Stainless Steel 1” (30 pcs)	amazon.com B09L17MP2G	6 (/30)	9.99	1.998
Marine Thread	Polyester bonded (1500 yds)	amazon.com B0CGV198PF	1 (/15)	9.99	0.666
				TOTAL	**$26.395**

MANUFACTURING/FABRICATION PLAN

Step by step instructions for building our final design are shown below in **Figures X-X**. Electronics packaging manufacturing will be performed in Ann Arbor and sent to Dr. Kastelein when completed, however the neoprene and polyester collar with attachment clips can be made quickly and easily using materials ordered using the BOM.

Figure A1. Prototype examples


Step 1: Cut neoprene into collar shape, then cut slits for electronics package (along dashed black line)
Step 2: Sew polyester strap with clips to neoprene collar cutout, near edge on either side (optional sew lines near D-rings for strap stability)
(optional)
Step 3a: Insert electronics packaging including hydrophones through center cut.
Electronics (packaging with hydrophones extended out to sides)
Flip and insert into top flap.
b: Flip collar. Trim excess neoprene around electronics housing.
c: Insert hydrophone wires into near slits.
d: Pull hydrophones back through far slits
e: Sew along hydrophone wires
Step 4: Flip collar. Fold collar over polyester strap (along gray dashed line)

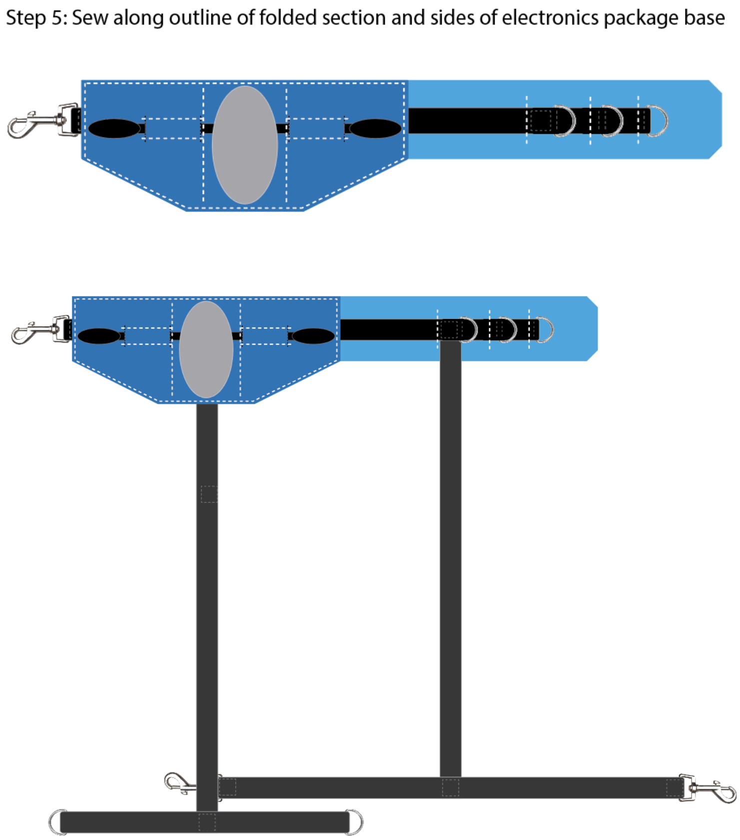


Figure A2. Collar manufacturing process

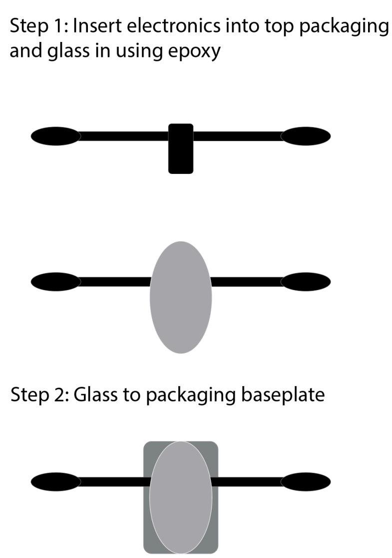


Figure A3. Electronics assembly process

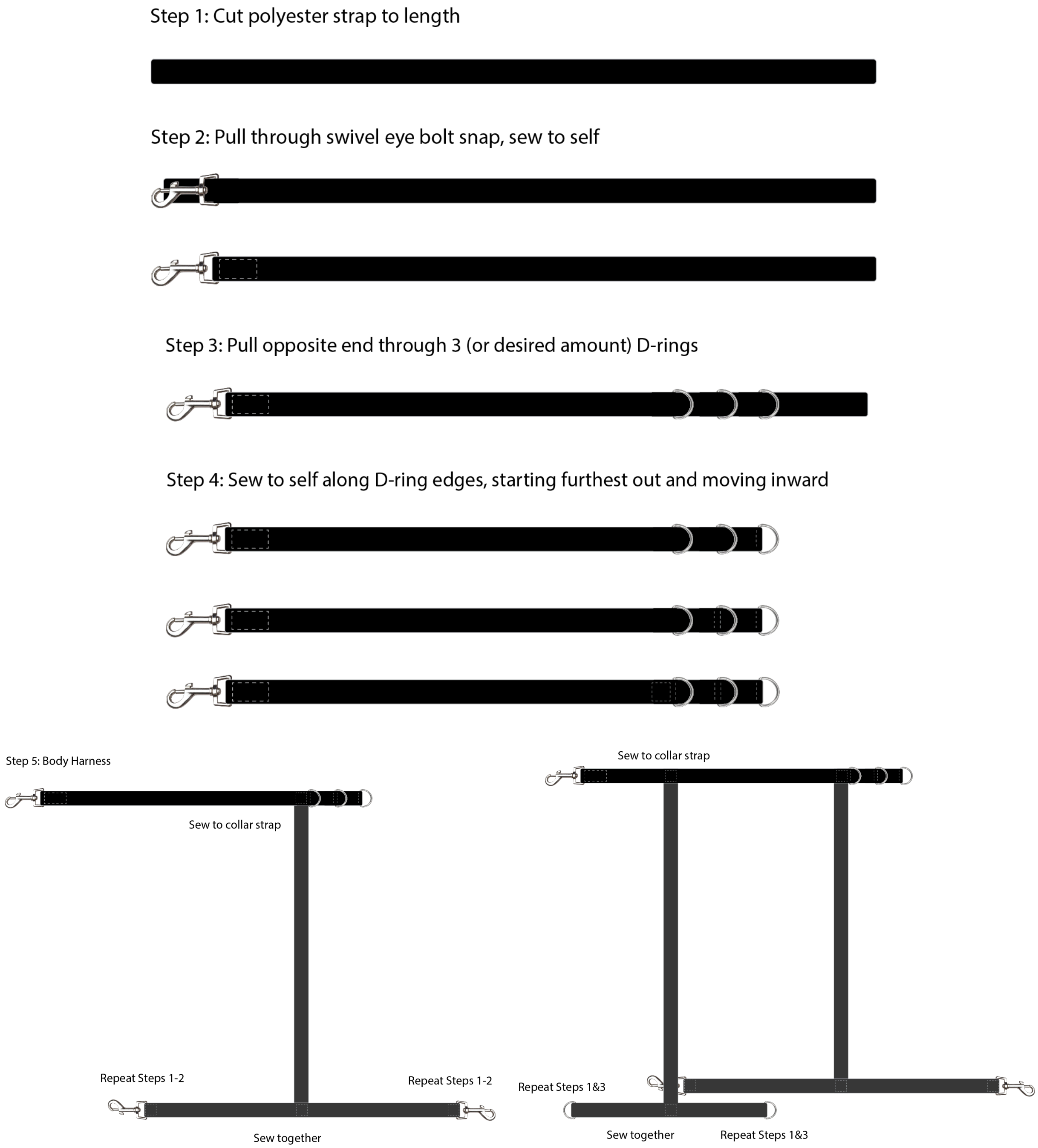


Figure A4. Collar strap manufacturing process