UNIVERSITY OF MICHIGAN ME 450

FINAL REPORT

TEAM 28: SQUID SPEED

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EXECUTIVE SUMMARY

The Woods Hole Oceanographic Institution is interested in studying the ethology of longfin squid because of their importance in the ocean ecosystem. For this purpose, they have previously developed the *iTag*, a reusable biologging sensor tag with an integrated inertial measurement unit and magnetometer which record the squid's motion as it swims. Our team was assigned the task of integrating a dedicated speed sensor into the existing iTag, which would allow the tag to more accurately measure the swimming speed of the animal. Our selected tag design was required to accurately measure the flow speed around the squid while also having minimal impact on both the existing sensors and the squid's natural behavior.

Based on our sponsors' suggestions, the team selected a speed sensor design that had previously been explored on another sensor tag, which consisted of a magnetic Hall-effect sensor and rotating turbine element. At present, we have successfully integrated the new speed sensor onto the existing iTag PCB without significant interference to the magnetometer, and have confirmed that the addition of the impeller to the exterior of the current sensor package will not significantly increase the drag of the iTag. Due to time limitations and a reduced capacity for in-person work, we have not yet been able to create a prototype of the updated iTag with a functioning impeller. However, our separate analysis of the iTag internals and external package suggest that our design would fulfil the specified requirements.

We recommend that future teams interested in this subject prioritize finishing the integration of the iTag system and performing physical validation of the redesigned iTag, which we were not able to achieve during this semester. In order to physically validate the redesign, we suggest programming the Hall effect sensor switch reading, calibrating the sensor to eliminate directional bias, and using the magnetometer to determine the general direction the squid is swimming. Additionally, we also suggest waterproofing the sensors and testing the tag in water for more accurate measurements than extrapolating air readings to water. Finally, the team has identified several potential design changes to the prototype iTag, including moving the Hall sensor cavity nearer to the impeller in order to improve reading accuracy, and elongating the tag body to mitigate magnetic interference. Implementing these changes will improve the functionality of the tag to make it more suitable for our sponsor's needs.

TABLE OF CONTENTS

1. BACKGROUND

1.1 The Importance of Bio-logging

Since the mid 20th century, bio-logging has become a common methodology for data collection on wild animals. Bio-logging refers to the process of attaching data storage tags to animals to give insight into the animals performance and/or their surrounding environment [1].

Bio-logging is important for a variety of reasons. For one, it gives rise to ethology, or the study of animal behavior. Use of bio-logging techniques enables researchers to study animals that are difficult to observe in nature, like marine animals or volant animals (those that can fly or glide). In addition to being used on difficult-to-access animals, bio-logging benefits ethology by enabling researchers to study the biomechanics of and human impact on animals in the wild. With this knowledge, humans are able to make the necessary changes to mitigate their disturbance on wildlife. Bio-logging tags can also measure three-dimensional, fine scale movements more accurately than measurements obtained from remote instruments used in observational settings.

As noted in Figure 1 below, research using bio-logging can be question- or data- driven. Question-driven research begins with a specific question in mind that is hoped to be answered using bio-logging, and sensors are chosen in hopes of answering that question. Data-driven research instead begins with gathering a broad amount of data on the animal in hopes of making general conclusions and deriving more specific questions from analysis of that data. Once the initial data is collected, sensors may be added or removed based on what information they have and what they still need.

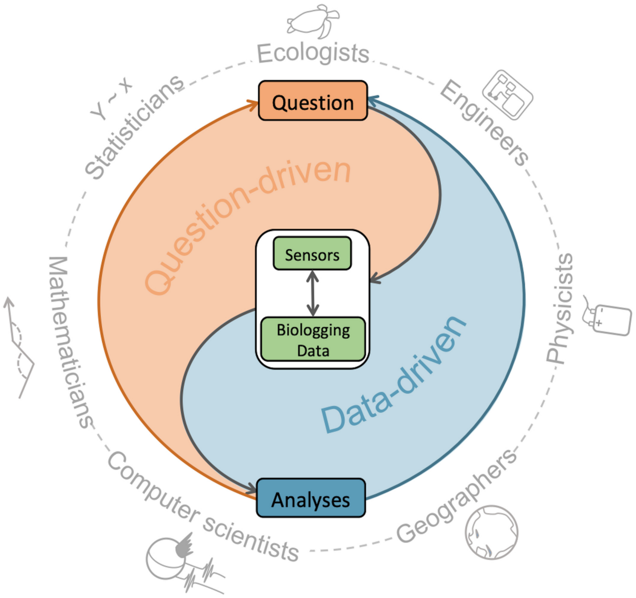


Figure 1. Yin-yang relationship of bio-logging question- and data- driven motivations for research. Taken from https://besjournals.onlinelibrary.wiley.com/doi/10.1111/1365-2656.13094

For example, scientists in Antarctica tagged Weddell seals to understand their maximum diving capacity; knowing a seal's maximum capacity - limitations - gives rise to understanding how they perform certain tasks. Scientists measured maximum and instantaneous depth of a dive, as well as total dive time. Additionally, they also observed the seals' behavior with an under-ice chamber during the latter part of the study. Scientists drilled a single breathing hole miles away from the original site of capture. The isolated nature of these holes forced seals to return to the drilled site for breaths in between dives, making it easy for scientists to capture the tag and analyze the data. Tags were attached to the seals in an unknown fashion. The use of bio-logging allowed scientists to tag multiple seals over many dives. Using a traditional observational study would have limited the number of seals to those in site, as well as restricted the observations to behavior above the ice [2].

Prior to this study, large samples were conducted with seals but with little accuracy. This new study found that seals could dive about 70 % deeper than previously thought [2]. This new information raised questions about what happens to the free air within marine mammals' lungs, upper air passages, and intestines under such great pressure due to their depth underwater. Following Figure 1, this study began as data-driven as researchers hoped to learn more general information about seals by gathering data on their diving patterns. However, once they began to analyze the measured data, the research became question-driven as the researchers had specific questions they hoped to answer in future studies.

1.2 Why Are Squid Important?

Squid possess many unique features among other marine animals that make them valuable to scientific research. For one, they are one of the few aquatic species that are capable of directionally-independent swimming, and are also known to have two distinct methods of locomotion in finning and jetting [3]. Finning is characterized by slow movement in which the squid swims with its fins, and strong mantle contractions are not obvious [4], whereas jetting is characterized by sustained movement driven by jet propulsion through mantle contractions [4]. Squid locomotion is also uniquely tied to their respiration and energy use. Squid pull water in, pass it through their gills, then eject it during jetting. Due to this link between energy and respiration, a squid's energy and oxygen expenditure can be understood through investigation of its movement.

On a broader scale, squid also play a vital role within the ocean ecosystem. As shown in Figure 2a, they occupy a central position in the marine food web, acting as both a predator and prey. This connects squids to a broad range of marine life, either directly or indirectly, as shown in Figure 2b. Additionally, squid make up approximately 20 % of global fisheries' landings [6]. Squid's prominence in the ecosystem is only expected to increase as they seem to be thriving under global warming. Understanding how squid have adapted to the changing ocean environment may be critical to understanding how global warming may impact other species.

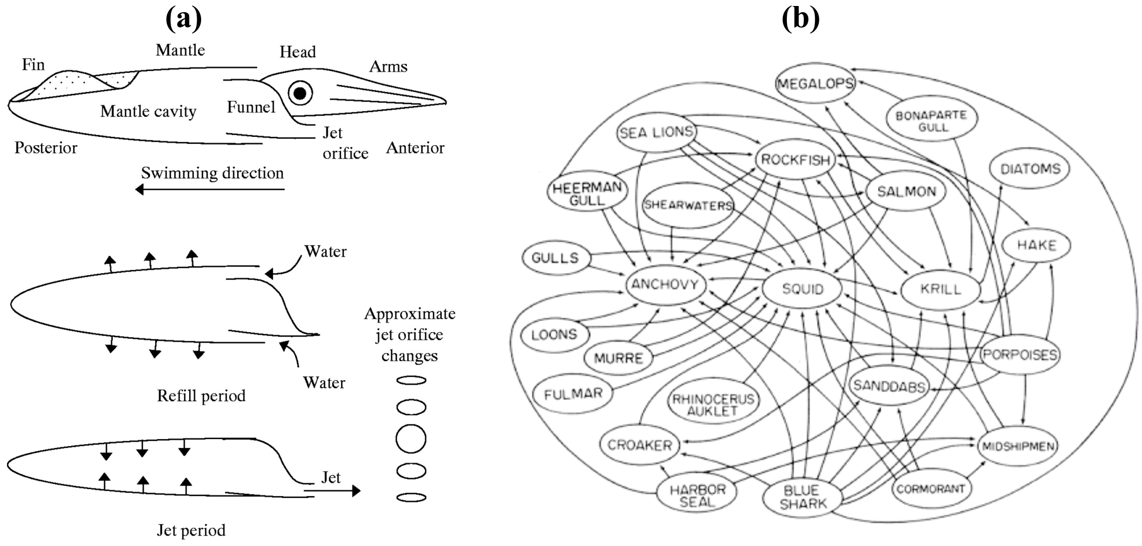


Figure 2. a) Anatomy of squid as it relates to swimming. patterns. Taken from https://jeb.biologists.org/content/208/6/1125. **b)** Marine food web. Taken from Morejohn et al. 1978.

1.3 How Are Squid Currently Being Tagged?

To understand the ethology of squid, the Woods Hole Oceanographic Institution (WHOI) has developed the iTag, a specialized bio-logging device. A three-view drawing of the latest iteration of the iTag is depicted in Figure 4 below.

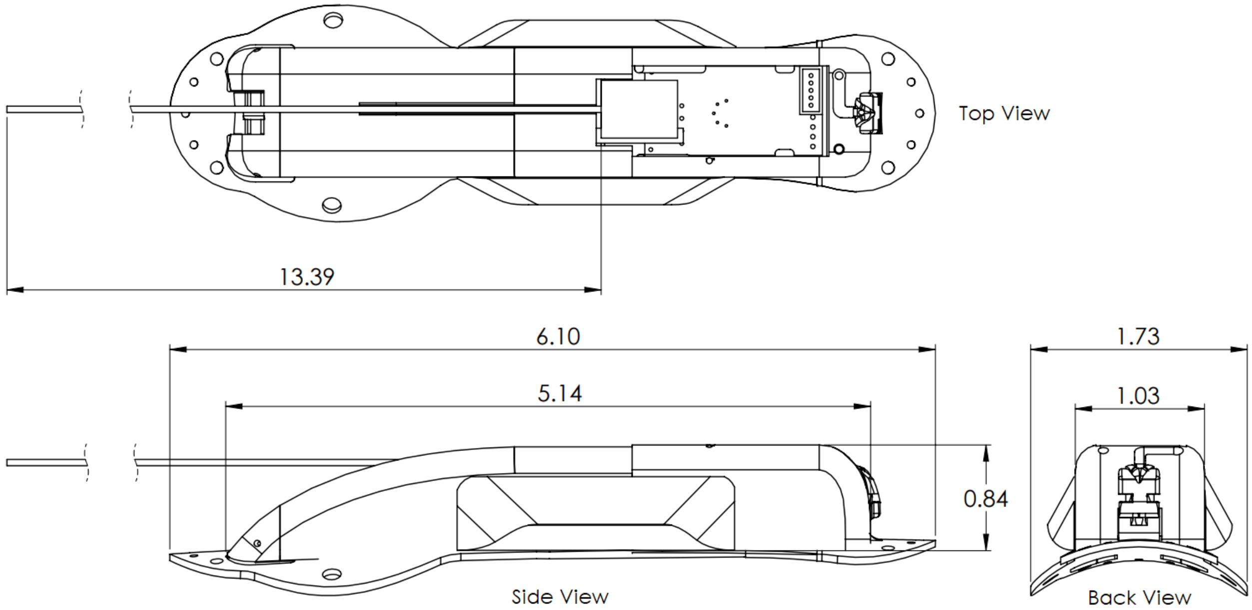


Figure 4. CAD drawing of the iTag V9 design. All dimensions are in inches.

iTags may be used on both squid as well as other animals including dolphins. In the case of squid, the iTag is used primarily to observe the squid's swimming patterns, and to identify when it is finning, flapping, or jetting, as well as its instantaneous depth and its swimming orientation. The device contains various sensors to give rise to squid movements: a 3D Inertial Measurement Unit (IMU), a pressure sensor, a temperature sensor, and a light sensor. The device records data for a set length of time, then detaches itself from the animal for recovery by scientists. One sensor that the iTag currently lacks, however, is a speed sensor.

1.4 Why Measuring Squid Speed is Important

A speed sensor is an important part of a bio-logging device for many reasons. First, it enables insight into the biomechanics of the animal, foraging ecology, and energetics. Squid have unique swimming patterns and using a speed sensor can forge a better understanding for their patterns for scientists. Second, scientists want to understand the metabolic cost of the animal, which cannot be measured directly. Third, a speed sensor can be used to estimate mechanical power, which is directly related to metabolic cost. Since force cannot be directly measured, drag and speed are needed to measure power. Last but not least, using a speed sensor provides direct measurements of an animal's speed. This is more accurate than the current set up, a 3D IMU containing an accelerometer, which requires an integration of the acceleration measurements to get speed. This method of integration also integrates noise and decreases accuracy of the true value of the squid's instantaneous speed.

2. PROBLEM DEFINITION

We were assigned the task of integrating a new speed sensor onto an existing iTag device for squid. This new sensor must accurately measure the speed of the squid in water. Additionally, it must neither interfere with the functionality of any existing sensors nor the squid's natural behavior. This task included designing and fabricating new sensor housing, sensor integration, as well as validation of the final product.

The addition of a speed sensor enabled valuable insight into the squid's movement and therefore their respiration and energy consumption. To add this sensor, we decided to use the current iteration of the iTag as a starting point. This means we planned to make changes to the housing and base if necessary, but we believed we were able to obtain a working design and prototype relatively quickly. Our stakeholders commented on their preferred speed sensor, but we explored other sensors for speed measurement to ensure we selected the best option. Once we had a working prototype, a large part of our task was to test the tag and sensors to ensure that it meets all requirements and records data accurately. This was achieved with simulations and empirical measurements. Finally, once the design was validated, we thought of expanding usage of the tag to other marine animals.

3. REQUIREMENTS

Once the problem was properly defined, it was broken down into a set list of requirements. This was accomplished through extensive communication with the stakeholders in order to guarantee that the requirements would properly fulfill the stakeholders' goals for the project. The requirements are listed in order of priority in Table 1 below, while also being separated into three categories.

Table 1. The stakeholder requirements, separated into categories and numbered in order of priority.

Category	Requirement	Description
Accurately Measure Speed	1. Accurately Measure Speed	Speed sensor must record accurate data
	2. No Magnetic Interference	Magnetic element of speed sensor must not affect other data
	3. Directionally Independent	Must measure speed forwards and backwards
Have Minimal Effect on Squid	4. Low Drag	Addition of speed sensor must not add excessive drag
	5. Appropriate Size for Squid	Speed sensor must fit reasonably within bounds of existing tag
	6. Neutral Buoyancy	Overall buoyancy of new casing and base must be neutral
	7. Low Mass	Addition of speed sensor must not add excessive mass
Be Recoverable and Reusable	8. Long Battery Life	Battery of new tag must be able to last for long deployments
	9. Reusable	New tag must be able to be deployed several times

The first step in creating the list of requirements was to determine specific goals the new iTag should be able to accomplish. This thought process led to the three categories seen in Table 1. The first and most important was that the iTag needed to be able to accurately and reliably gather data. Within that category, the highest priority was the ability to accurately measure speed, as that was the primary purpose of this project. Next in priority was no magnetic interference. The speed sensor we used had a magnetic element, and it was important that the magnet did not interfere with any of the other sensors on the iTag. Last in this category but still third overall in priority was the speed sensor needs to be directionally independent. This means it must be able to measure speed in both directions since squids can travel both forwards and backwards.

The next category was that the iTag must have minimal effect on the squid. This is due to ethical considerations and making sure no harm or discomfort is caused to a living animal, as well as concerns about data quality. If the iTag changes the behavior of the squid, it will be difficult if not impossible to draw meaningful conclusions from the data. Under this category, the highest priority requirement was the iTag needed to have low drag to have minimal effect on movement. The next requirement was the iTag had to be an appropriate size for squid, and fit on it comfortably. The iTag design we were given satisfies this requirement, so the focus for this project was to keep the added speed sensor reasonably within the dimensions of the given tag. The next two requirements were the tag needs to have neutral buoyancy and be low mass. These were both important in having a minimal effect on the squids movement.

The final category was the new tag needed to be recoverable and reusable. The first requirement in this category was that the tag needed to have a long battery life. Deployments can be up to two and a half days, so the goal of our tag was to try to approach that number. The last requirement was for the tag to be reusable, as it is currently. The given tag is deployed and recovered multiple times, so our tag should be able to do the same. However, the quality of data does take priority over the quantity which is why this category was deemed the lowest importance.

4. SPECIFICATIONS

We converted our stakeholder requirements into a series of engineering specifications that our final design strived to meet. For each requirement, research and client discussions were used to create a concrete specification along with a method for testing the specification. The testing methods were simplified for the limited timescale of the ME 450 design process. These specifications are shown in Table 2 below.

Table 2. The stakeholder requirements and corresponding engineering specifications.

Stakeholder Requirements	Engineering Specifications
Accurately Measure Speed	≤ 10% error in measured distance using the speed sensor compared to known distance traveled [5]
No Magnetic Interference	< 5% impeller induced magnetometer error relative to total magnitude [6]
Directionally Independent	< 4% measurement bias in either direction [6]
	Able to measure flow speeds ≥ 2 m/s [7]
Low Drag	≤ 10% increase in drag compared to current tag design at squid swimming speeds [8]
Appropriate Size for Squid	Width ≤ 1.13 in [9] Length ≤ 5.33 cm [9]
Neutral Buoyancy	≤ 5% increase in tag weight in water [10]
Low Mass	< 10% increase in total mass compared to combined mass of current tag design and standalone speed sensor [11]
Long Battery Life	> 60 hours [12]
Reusable	Survive ≥ 6 deployments [13]

A. Accurately and Reliably Gather Data

The specification for accurate speed measurement was found by researching a previous speed sensor implementation on a dolphin biotag [5]. This specification was planned to be tested by dragging the tag through a tow tank at reasonable speeds for a squid and comparing the speed sensor output to cart speed. The specification for magnetic interference was determined from the spec sheet for the magnetometer [6]. This specification was planned to be tested by comparing the raw noise magnitude of the magnetometer to the noise magnitude of the magnetometer when the tag is moving at reasonable squid speeds. The specification for directional independence was found through a combination of the specification sheet for other sensors on the existing biotag [6] and research into squid movement patterns [7]. Our plan was to make different calibration curves for each direction [5]. This specification was planned to be tested by dragging the tag through a tow tank at reasonable speeds for a squid in each direction and comparing the speed sensor output to cart speed. The speed sensor's output was to be compared to video analysis.

B. Have Minimal Effect on Squid

The specification of low drag was found through research into the impact of underwater drag on marine life [8]. This specification was tested by running CFD on the given tag and current speed sensor, and comparing that result to CFD run on the final tag design. The specification for appropriate size for squid was found through research into the adult size of the veined squid [9]. This specification was tested by measuring the footprint of the final tag design. The specification for neutral buoyancy was found through research into how squids utilize their negative buoyancy to swim more efficiently [10] as well as client engagement. The client provided insight into the current methods for balancing the buoyancy of the tag. Therefore, this specification was to be tested by measuring the final tag design's weight in the water. The specification for low mass was found through research into industry standards for biotags [11]. This specification was to be tested by measuring the final tag design's mass.

C. Be Recoverable and Reusable

The specification for long battery life was found through a combination of client engagement and research into the psychological impacts of catch and release fishing on marine life [12]. The client provided insight into the length of time that tags operate for and frequency of deportation for a single tag. This specification was planned to be tested by running the tag from full battery life to 0 % battery life several times. The specification for reusability was found through a combination of client engagement and research into water ingress standards [13]. The client provided insight into how the tags are repeatedly deployed in the same trip and in the same season. Within the confines of the ME 450 design process, this specification was planned to be tested by running the final tag design underwater for 24 hours.

5. CONCEPT EXPLORATION

5.1 Concept Generation

Since the given iTag is fully operational and does not require re-design to function, we believed that the biggest design decision was how speed would be determined. Although we have been referring to a speed sensor, the sensor implemented did not necessarily have to directly measure speed in order to find it. It was also possible to integrate acceleration or take the derivative of position to calculate speed. To generate as many ideas as possible, we created a mind map shown in Figure 5 below.

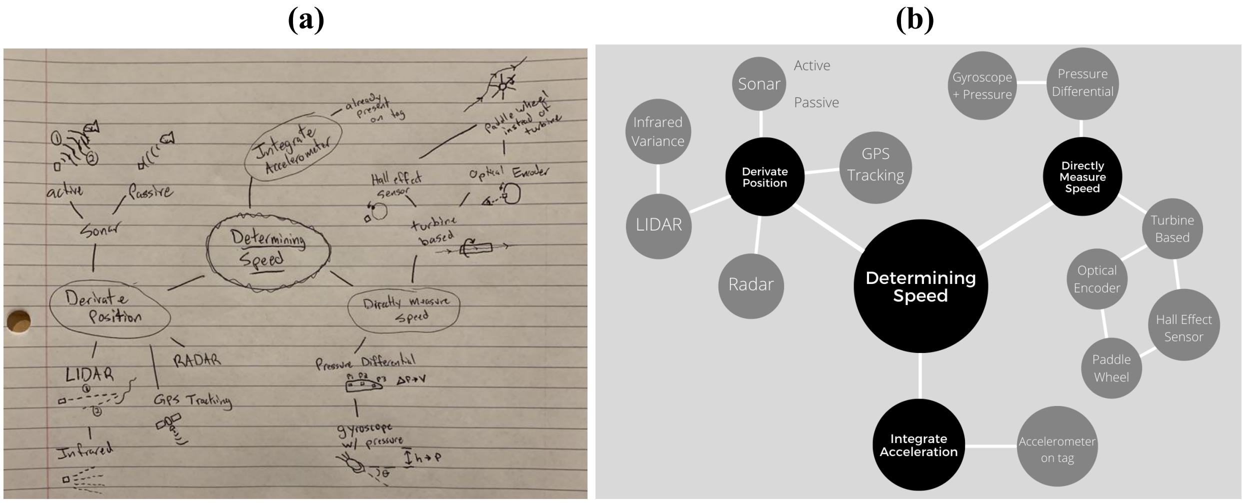


Figure 5. a) The hand-drawn mind map with sketches. **b)** The same mind map remade for readability purposes.

The three major categories of the mind map were: to differentiate position, directly measure speed, or integrate acceleration. Different concepts branched off from the main categories as well as other concepts based on our thought process during the concept generation. The final concepts can also be seen in Table 3 below.

Table 3. The final list of concepts to measure speed.

Category	Concepts
Differentiate Position	Active sonar Passive sonar LIDAR RADAR GPS tracking Infrared variance distancing
Directly Measure Speed	Hall effect sensor + turbine Optical encoder + turbine Pressure differential Gyroscope combined with pressure
Integrate Acceleration	Accelerometer

The two sonar options rely on sound to determine position. Active sonar sends out sound and measures how long it takes for that sound to bounce back, while passive sonar listens for sound from various sources in the environment to triangulate position. LIDAR is similar to active sonar, but it sends out light beams instead. RADAR is also similar but with radio waves. GPS tracking uses satellites to determine position. Infrared variance distancing sends out many infrared waves to scan the environment, and based on how that scan changes can calculate position.

The Hall effect sensors and optical encoder both rely on a rotating element to determine speed. As the flow of water spins the rotating element, the Hall effect sensor counts each time a magnet completes a rotation, while the optical encoder counts each time a light source completes a rotation. The speed at which the count increases is calibrated to determine speed. The pressure differential relies on the pressure difference between the front and back of the tag. When the squid is moving forwards, the water compresses to a greater pressure than the water at the back. This can be used to find the speed. The gyroscope can be used with pressure sensors to determine speed as well. By measuring the rate of change in the pressure sensor, the vertical velocity can be determined. The squid's orientation can be found from the gyroscope and by assuming that the squid is moving in a straight line to minimize drag [14], the other two velocity vectors can be determined through trigonometry.

Finally, integrating acceleration can be used to find the speed as well. This is simple as the accelerometer directly measures the acceleration of the squid.

5.2 Concept Selection

Extensive research was conducted on different means of measuring speed underwater. Integrating acceleration, differentiating position, and directly measuring speed were all explored. Integrating acceleration could be done via the already existing accelerometer in the iTag. Differentiating position is possible using sensors such as: active sonar, passive sonar, LIDAR, infrared variance, GPS tracking, or RADAR. Directly measuring speed is measured from a Hall effect sensor plus rotating element, an optical encoder plus rotating element, a pressure differential system, or a gyroscope pressure combination.

These ideas were evaluated for ability to accurately measure speed, power draw, and feasibility. Integrating the existing accelerometer, LIDAR, infrared variance, GPS tracking, and a pressure differential system were all too inaccurate to give the speed measurements that were needed for our project, as well as not feasible given the size limitations and power consumption [15, 16, 17]. Additionally, a gyroscope and pressure sensor combination could not accurately measure a squid's speed given its complicated maneuvers [14]. LIDAR, infrared variance, RADAR, and an optical encoder with a rotating element all required too much power to meet our specifications [18, 19]. Due to a combination of the constraints of the ME 450 design process and the skills that our team possesses, passive sonar and RADAR were deemed impossible. Additionally, active sonar was discarded for ethical concerns about the potential impact of the noise on both the squid and its surrounding environment [20]. We determined that the most promising method for measuring speed is a Hall effect sensor plus a rotating element [21]. The Hall effect sensor measures the magnetic field density. If a magnetic element is attached to the rotating element, the

Hall effect sensor can be used to measure changes in the magnetic field strength over time, from which the frequency of the rotating element can be determined. Dealing with the magnetic interference caused by the permanent magnet as well as only measuring rotational speed and not velocity will be dealt with in the next section.

5.3 Concept Challenges

Two areas of potential concern with the implementation of this particular sensor were magnetic interference between tag elements and directional independence in speed measurement. Ideation was specifically focused on generating solutions for these areas of concern.

The Hall effect sensor requires a spinning magnetic element attached to a rotary device. We settled on using a turbine for the device. A drawback deemed was a potential interference with the magnetometer that already exists on the iTag. The first potential solution was to separate the turbine and magnetometer. Different arrangements of the turbine, Hall effect sensor, and magnetometer can minimize interference while still allowing the Hall effect sensor to function. Design concepts for the housing, such as having two housing sections or empty housing to provide buoyancy, were believed to contribute to the possible arrangements. Ideally this would be the only solution required; however, two other methods were generated if the interference is still too high at the maximum separation distance. One option was to code the magnetometer reading to interrupt when the turbine is at a specific point in its rotation. This would make the interference constant, and that constant value could be subtracted from the magnetometer reading. The other potential option was to record the magnetometer normally and to estimate the turbine position at each magnetometer reading. The turbine interference could be estimated and subtracted from the magnetometer reading. However, the simplest option, and the one we use to resolve the issue is to have the spinning magnet far enough away from the magnetometer that there is no interference.

Unlike most marine life, squids possess the ability to swim both forwards and backwards. The Hall effect sensor and turbine design is capable of generating speed measurements in both directions; however, the ability to determine which direction the squid is moving is challenging. Any potential method can only be confirmed by tow tank testing, but three potential methods were generated. The first method was to use the accelerometer. The accelerometer would mark the deceleration and change in direction of the squid, which could be used alongside a speed measurement to provide velocity. The second method was to use machine learning to determine the direction of movement. If there are any subtle differences between forwards and backwards movement, K-means clustering could potentially be able to determine which direction the squid is moving [22]. Additionally, PCA based anomaly detection or one class SVM could be used to detect errors and mark data for further investigation [23]. The third generated method was to utilize the other sensors that already exist on the tag. For example, the pressure sensor could determine if the squid is moving up or down. This vector could then be used to contextualize the speed measurement data's direction.

5.4 Design Opportunities for Selected Design

Once the Hall effect sensor plus rotating element design was decided on, additional concept ideation was devoted to the housing and sensor design. Four potential rotors were generated and then evaluated through a Pugh chart. This Pugh chart can be seen below. A turbine, paddlewheel, oscillating rudder, or propeller were all deemed potential solutions.

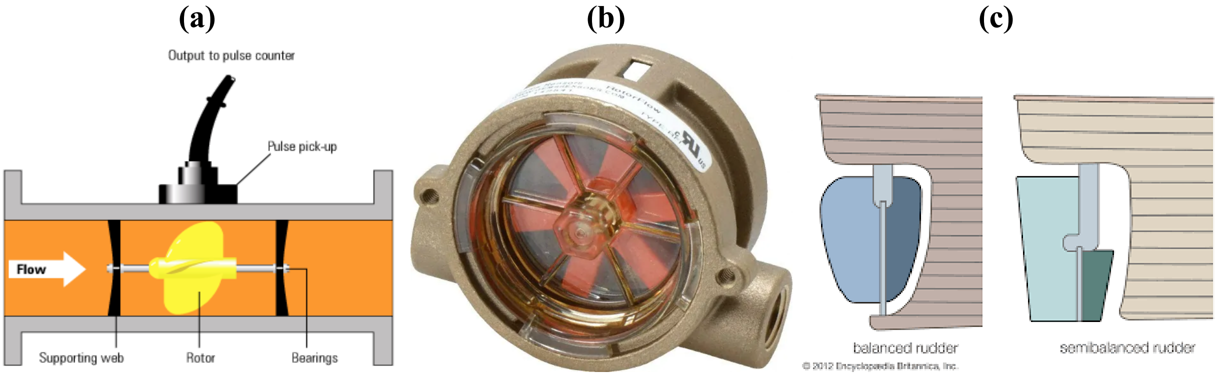


Figure 6. a) Axial turbine flowmeter. Taken from *https://www.spiraxsarco.com/learn-about-steam/flowmetering/types-of-steam-flowmeter*. **b)** "Paddlewheel" flowmeter. Taken from *https://www.mscdirect.com/product/details/74245333.* **c).** Rudder deflection sensor. Taken from *https://cdn.britannica.com/28/3828-050-F98B7AC8/Examples-rudders.jpg.*

These elements were evaluated for range of motion, additional drag, and consistency. Two of the designs stood out as potential options: the turbine and the propeller. Both were capable of producing consistent data but the turbine has an advantage in additional drag and the propeller has an advantage in range of motion. Additional drag was considered the more important consideration, so the turbine was chosen as the rotating element.

Table 4. Pugh chart for comparison of rotating elements.

	Turbine	Paddlewheel	Rudder	Propeller
Range of Motion	0	1	-1	1
Additional Drag	1	-1	0	0
Consistency	1	1	-1	1
Total	2	1	-2	2

Our team planned to make extensive use of computational flow dynamics (CFD) and this analysis was used to inform the details of the housing design and turbine placement. Concepts were generated primarily to provide options to explore with CFD analysis rather than to examine within the concept generation phase of design. Locations for the turbine were thought of to be: placing towards the front or back of the tag, or even on the left and/or right side. Additionally, the housing can be manipulated.

6. PROTOTYPE DESIGN

6.1 Redesign Generation

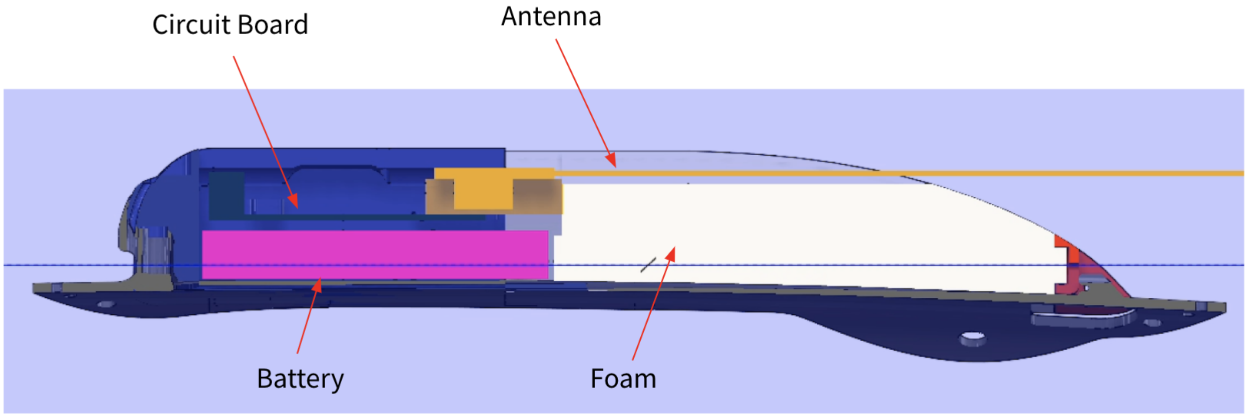


Figure 7. Section view of current iTag electronics configuration.

The provided iTag, as shown in Figure 7, has a 3D printed body on the left-most side of the figure that holds the circuit board, battery, and the VHF sensor connected to the antenna. The right-most side of the housing is almost entirely foam to provide buoyancy to the tag. In order to quickly produce and test the addition of the impeller and Hall effect sensor, we added those components to the right side where there is currently only foam, seen in Figure 8.

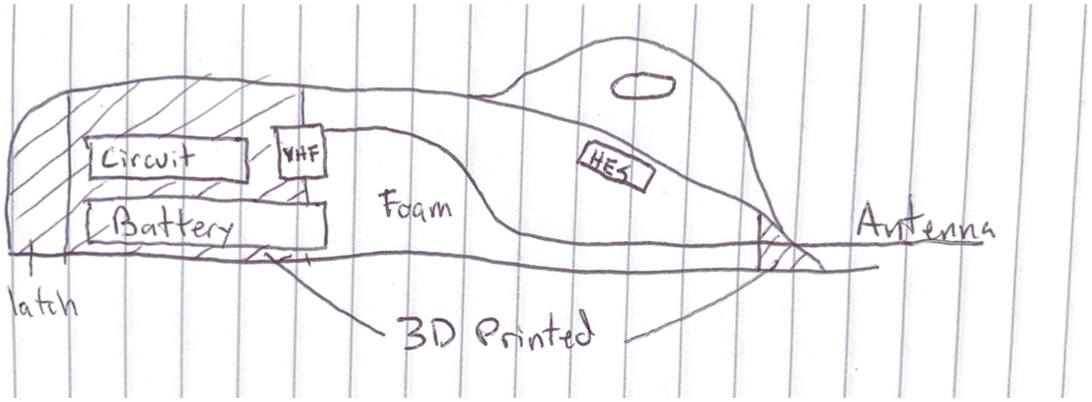


Figure 8. Initial design for addition of Hall effect sensor and impeller.

Since there was nothing within the foam at the time of redesign, the impeller and Hall effect sensor were believed to fit cleanly into the foam portion of the tab, and the antenna was able to be bent out of the way. This design was chosen to minimize the number of changes to the interior of the tag and focus on producing accurate measurements.

This configuration was approved by our stakeholder, as they were excited about the location of the turbine and Hall effect sensor. Our stakeholder also noted that the center of gravity needs to be on the left-most side as seen above so that the antenna will point up when the tag is floating, which is satisfied in our chosen design. We considered several locations of the circuit board, but found the configuration above to allow the greatest distance between the Hall effect sensor and magnetometer. After further tests, it was deemed that there needs to be an additional 1.1 inches (2.8 cm) of horizontal clearance between the Hall effect sensor and magnetometer. See Section 7.2 for further explanation on the matter.

6.2 CAD Model

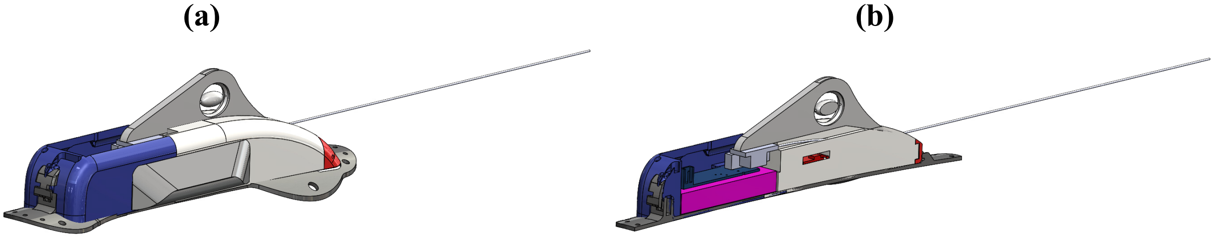


Figure 9. (a) Isometric view of our redesign. **(b)** Sectioned view of our redesign.

Compared with the original design, Figure 7, our design has a few changes added to it. Attached to the housing is a turbine / impeller system. This was the chosen rotor mechanism as the produced results are more consistent and there is an additional drag factor to consider.

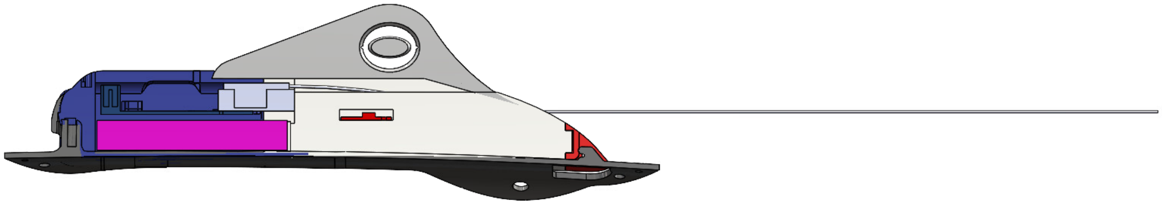


Figure 10. Rightview of sectioned CAD model.

Additionally, two more design changes were made. First, the Hall effect sensor was added to the iTag and placed under the impeller. This is the most optimal location for the sensor as the Hall effect sensor needs to read the rotations from the turbine, as well as maximizing the distance to the magnetometer on the circuit board to minimize magnetic interference, the second most important engineering specification. To account for the addition of the impeller and the Hall effect sensor, it was determined that the antenna needed to be lowered to not interfere with the two additions. A Three View Drawing of the model can be found in Appendix C. A simplified model used for computational fluid dynamics can be found in Appendix D.

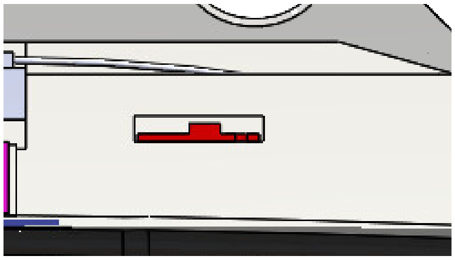


Figure 11. Zoomed in view of the foam section within the rightview of the sectioned CAD model.

As shown in the figure above, the antenna was bent to account for the addition of the impeller and Hall effect sensor. The antenna's path goes between the Hall effect sensor and impeller, and exits the housing below the impeller, as shown in the zoomed out view of the rightview (Figure 10). This was deemed an acceptable path design as the diameter of the antenna is negligible compared to the sensor reading of the Hall effect sensor from the turbine. Furthermore, to minimize stresses in the antenna, there are no sharp bends in the wire, which this current path does not contain.

7. SENSOR INTEGRATION

7.1 Data Output

Several sensors already exist on the current iTag model. To confirm our understanding of each sensor as well as to potentially catch any concerns, each of the sensors was run through a test. The accelerometer and gyroscope were tested by moving the tag from a horizontal to vertical position. The gyroscope correctly read the rotation and the accelerometer read the change in the gravity vector. The graph for this test is Figure 12 below.

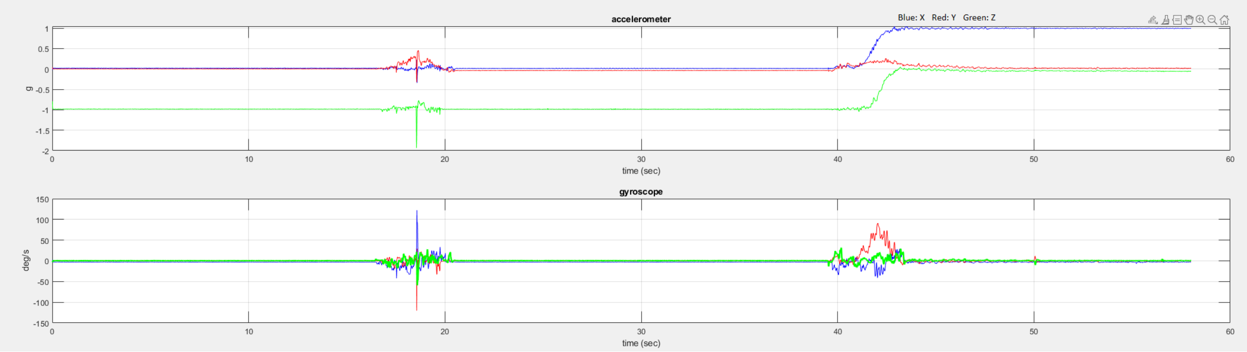


Figure 12. The accelerometer and gyroscope test

The thermocouple was tested by taking the tag from a warmer environment into a colder environment. The slow decrease in temperature from the cold environment can be clearly seen. The graph for this test is Figure 13 below.

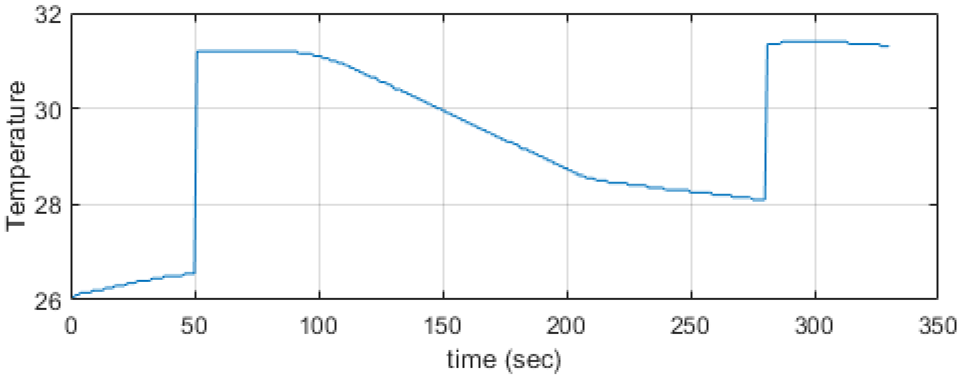


Figure 13. The thermocouple test.

The light sensor was tested by shining a flashlight directly into the cavity of the iTag. The data from this test was inconclusive, which supports the need to place the light sensor in a more accessible location in our designs.

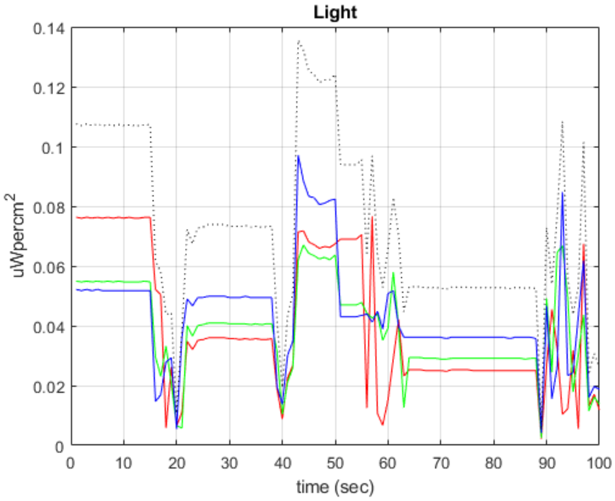


Figure 14. The light sensor test.

The magnetometer went through two tests. The first was to confirm that it clearly showed a change in heading. This test was conducted by placing the iTag on a table and waving it back and forth at a steady pace. This behavior is shown around the 75 to 110 second mark in Figure 15 below.

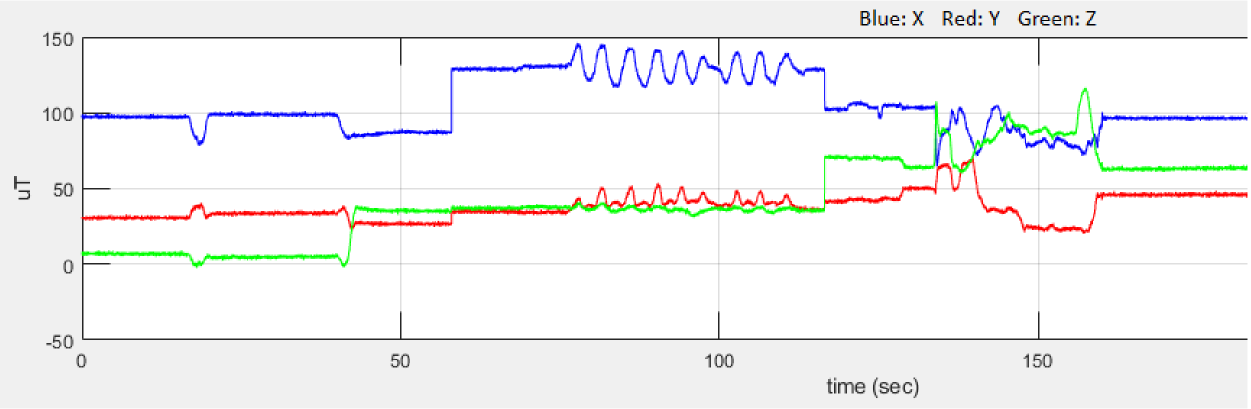


Figure 15. The first magnetometer test, showing oscillations as a result of steady back and forth movement.

The second test was to get a specific heading from the magnetometer values. This test revealed the need to calibrate the magnetometer for each tag. Differences in manufacturing of each PCB as well as solder leads to each board having a distinct magnetic field. This interference is constant and can therefore be calibrated out of the final results. To calibrate a tag, it was rotated through the entire sphere of potential headings. When visualized, the uncalibrated results form an ellipsoid. Calibration consists of fitting this ellipsoid to a sphere and centering it at 0. Before calibration a 205 degree heading was read as 280 degrees. After calibration the same 205 degree heading was read as 209 degrees. The graphs for before and after calibration are Figure 16 below.

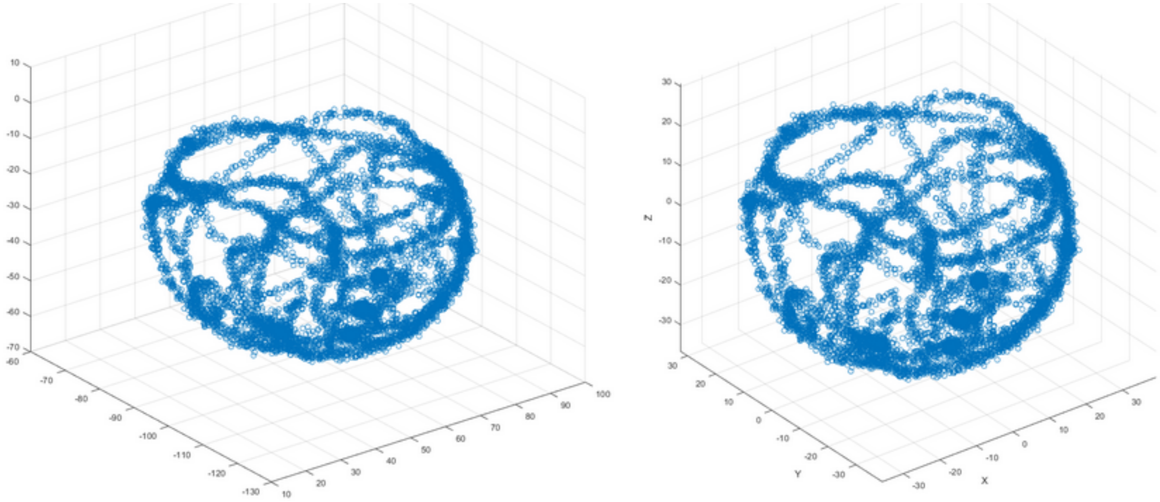


Figure 16. On the left is the magnetometer readings before calibration. On the right is the magnetometer readings after calibration.

7.2 Magnetic Interference

The magnetic interference that the impeller would induce on the magnetometer has been a concern for this project. At the closest position that the impeller could be positioned relative to the magnetometer the interference completely overwhelmed the data. Figure 17 below shows the interference. The immediate jump after 50 seconds is the impeller being introduced, and the wavering at around 75 seconds is the impeller being rotated.

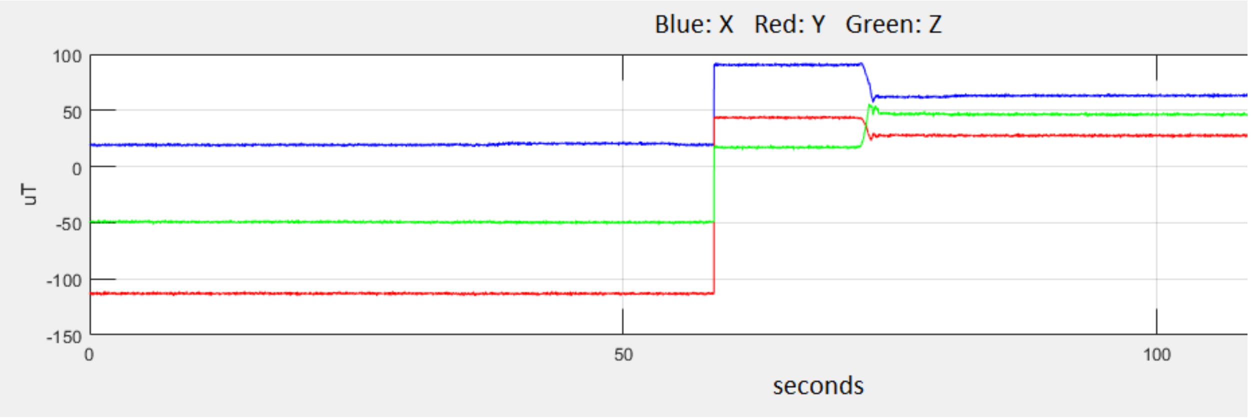


Figure 17. The potential impact of the impeller on the magnetometer reading.

The maximum separation of the impeller and magnetometer horizontally was 3.5 inches. At this horizontal offset, the influence of the impeller on the magnetometer was tested at 1/16 inch increments until a distance was found that led to less than 5 % error in the measured angle. This vertical offset was found at 1 3/16 inches. Because this separation was reasonable, our team saw no need to explore other options to decrease magnetic interference. To simplify CAD development, the total distance was changed to a slightly lower height at a greater horizontal distance.

7.3 Integrated Circuits

For the solution to read the spinning of the impeller a Hall Effect Sensor needed to be integrated into the existing PCB. A Hall Effect Sensor outputs a voltage relative to the strength of the magnetic field affecting it. The 1 bit ADC built into the sensor converts the signal to either a true or false output. This output switches between true and false when the magnetic field passes a certain strength. The result of this is the Hall Effect Sensor output switching every rotation of the impeller. These switches can be recorded and used to find the speed in water.

The magnetic field strength that would induce a switch in the Hall Effect Sensor output was hardwired into the supplied board. Testing was required to determine the distance between the Hall Effect Sensor and the impeller that will cause a rotation of the impeller to reliably cause a switch. The impeller was repeatedly rotated at different distances from the Hall Effect Sensor with the output being measured by a voltmeter. A 9 mm distance between the axis of the impeller and either the closer face of the Hall Effect Sensor was found to be effective. There wasn't any measured difference between either the top or bottom face of the Hall effect Sensor.

Figure 18 below shows the PCB that is currently used in the iTag. The pins that can be used for recording the Hall effect sensor output are marked with a red dot. These red dots correspond to pins PA18, PA19, PA22, and PA23 from left to right. For our tests, PA19 was used.

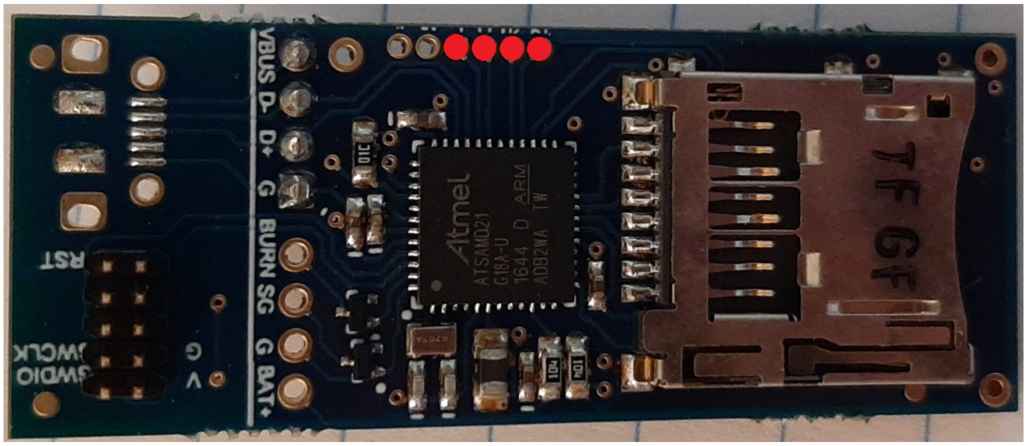


Figure 18. A close-up view of the PCB with pins PA18, PA19, PA22, and PA23 marked.

8. COMPUTATIONAL FLUID DYNAMICS (CFD)

8.1 Baseline Squid Analysis

To gain a better understanding of the squid's natural movement and drag characteristics, CFD analysis was done on a simplified squid model without any tag attached. The model was created in Blender, then imported into Solidworks to be converted to a parasolid, and finally imported into Star-CCM+ for CFD analysis. The model is shown below in Figure 19.

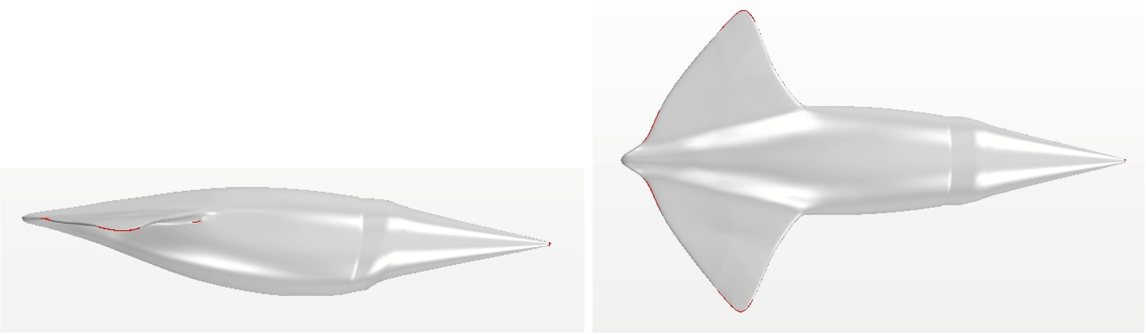


Figure 19. A side and top view of the squid model in Star-CCM+.

In Star-CCM+, the squid model sat within a domain that would simulate flowing water. The squid is situated 5 body lengths from the inlet with 15 body lengths behind it. This spacing gives enough space for the flow to be fully developed when it reaches the squid, and for the wake to fully develop behind the squid. The domain and squid within it can be seen in Figure 20 below.

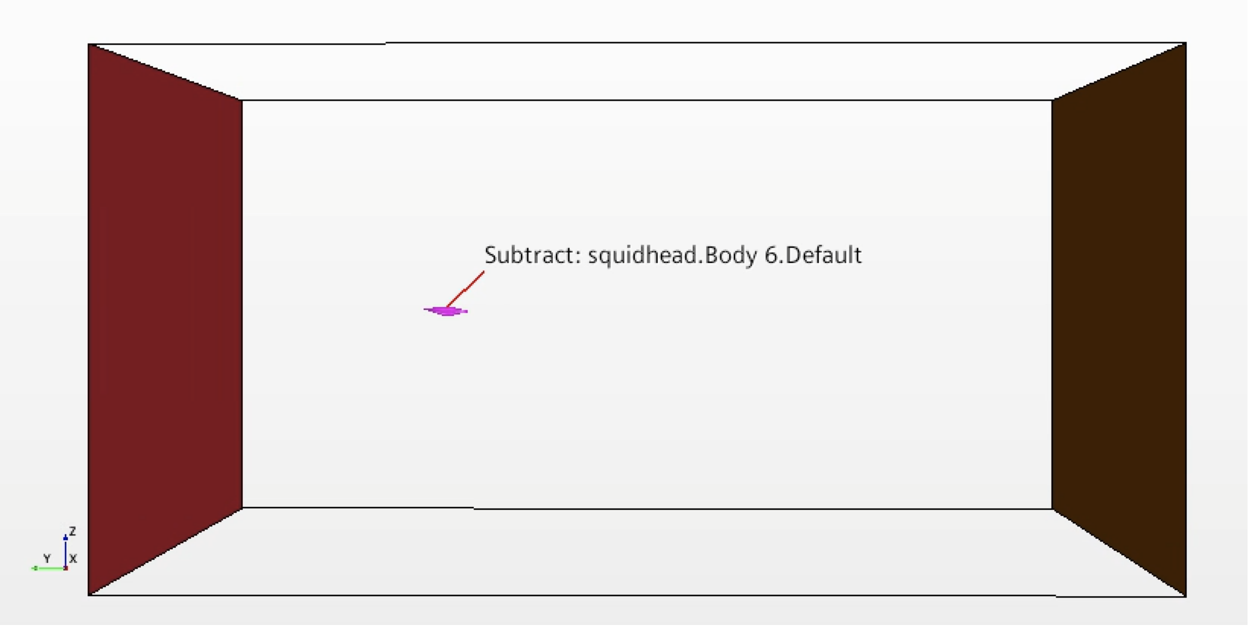


Figure 20. The domain of the CFD simulation. This is the volume that will represent the flowing water. The walls are hidden. The squid model is in pink and labeled “subtract: squidhead.Body 6.Default”.

The squid was simulated at flow velocities of 0.5 m/s, 1/0 m/s, and 1.5 m/s, both forwards and backwards. The model was meshed with refinement around the squid and its wake, which can be seen in Figure 21 below.

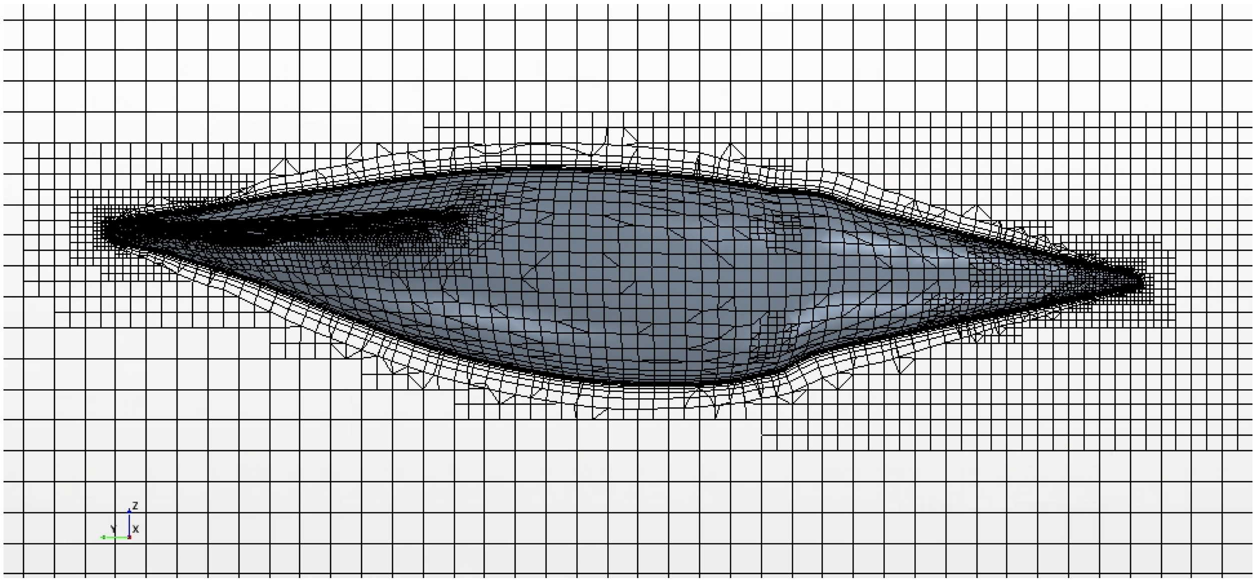


Figure 21. The mesh on the squid model, showing refinement around and on the squid, as well as in the wake of the squid on the right side.

The mesh is made up of cells of different sizes that reference a base size. Areas further from the squid are generally larger than the base size as there may not be anything happening there. Closer to the squid and in the wake behind the body, the cells are often smaller than the base size. To determine the optimal mesh, the simulation was run with base cell sizes of 13 mm, 10 mm, 7mm, 6mm, 4mm. The drag for each simulation was plotted against the total cell count for each base cell size, shown in Figure 22.

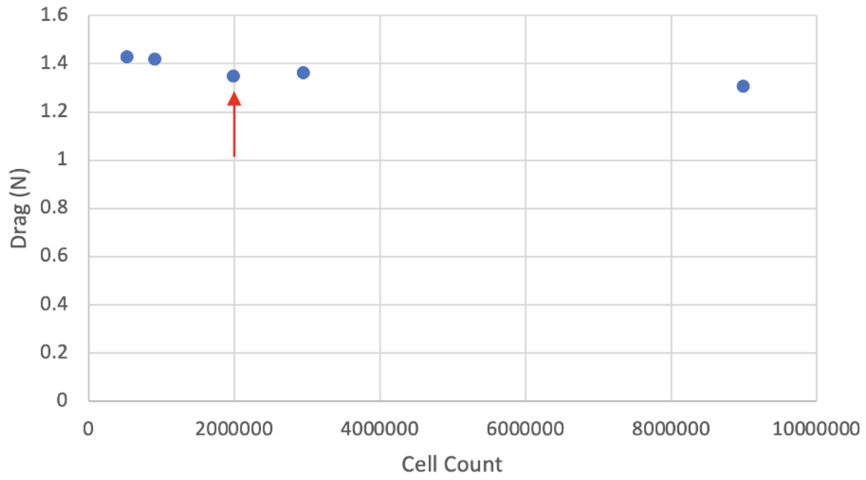


Figure 22. Drag on the squid plotted by total cell count of the model. As the cell count increases, the model should be more accurate.

Although the model is more accurate as the cell count increases, the time it takes to fun the simulation also drastically increases. Therefore, based on the plot above, a base cell size of 7 mm was chosen, pointed out by the red arrow. This simulation takes around 3 hours to run, much less than the approximately 8 hours that the 4mm simulation takes. There was just a 3.22% difference between the drag for the 7 mm and 4mm base sizes, and the 7 mm results were actually closer to the 4 mm results than the 6 mm results were.

Using the base cell size of 7mm, the mesh was found to be satisfactory due to the Y+ values. The Y+ value indicates how well the drag and skin friction, as well as the boundary layer, are captured by the model. For this mesh size, the Y+ values were all generally below 1, which is ideal. The flow velocity was also examined and can be seen in Figure 23 below.

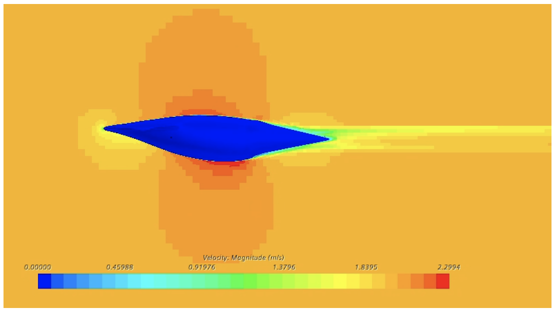


Figure 23. The flow velocity around the squid. Flow goes from left to right, and the scale on the bottom goes from 0 m/s at blue to 2.3 m/s at red.

8.2 Existing and New Tag Analysis

After refining the analysis on the baseline squid model, we moved forward with adding the tags to the model. The tags were modeled using simplified CAD of the base tag and impeller, which can be seen in Appendix D. These models were run using the selected 7 mm base cell size, and with flow speeds of 0.5 m/s, 1.0 m/s, and 1.5 m/s. The models were also analyzed with the squid moving both forwards and backwards. The goal of this analysis was to compare the results from the existing tag, particularly the drag, to the results of the new tag. The model and mesh for the squid with the existing tag can be seen below in Figure 24.

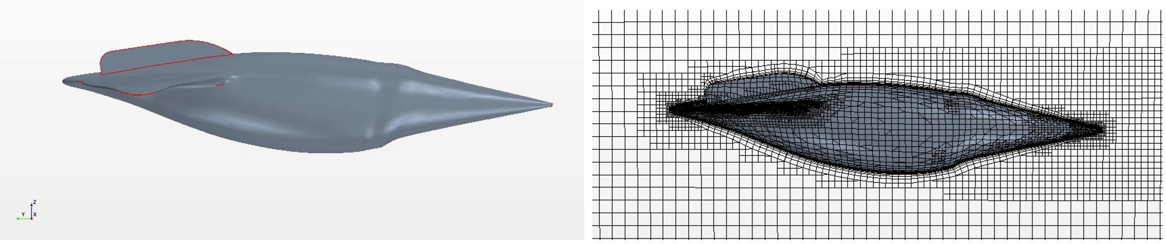


Figure 24. The model for the squid with the existing tag on the left with the mesh for that model on the right.

The model and mesh for the squid with the new tag can be seen below in Figure 25.

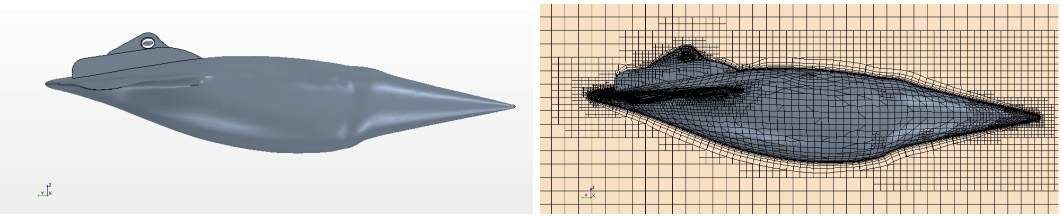


Figure 25. The model for the squid with the new tag on the left with the mesh for that model on the right.

8.3 CFD Results

The drag on the squid and tags was found through the simulations and used to calculate the increase in drag between the existing tag that does not have the impeller, and the new tag that does. These drag increases can be seen below in Table 5, while the full drag results can be seen in Appendix B. It is important to note that the increase in drag is ≤ 10%, so that engineering specification was satisfied.

Table 5. Drag increase between tags at different flow velocities in water using CFD simulation.

Flow Velocity (m/s)	% Increase in Drag with Forwards Flow	% Increase in Drag with Backwards Flow
0.5	1.63	3.51
1.0	2.16	1.92
1.5	2.54	1.13

9. VERIFICATION

9.1 CAD Verification

According to our calculations, if the current CAD redesign were to be elongated 1.1 inches, there shouldn’t be any magnetometer interfere beyond 5% error (Req / Spec. 2). With this suggested elongation, the overall length of the tag would contradict Requirement 5. This was confirmed an okay change by our stakeholder who believes the added length is still deemed appropriate size for the squid.

9.2 Sensor Verification

For sensor testing a Hall effect sensor was connected to an iTag PCB. The Hall effect sensor was powered by a separate battery so that the voltage and current being supplied to the PCB would be unchanged. The entire package was placed inside a shell of the CAD design. In this configuration the impeller was manually rotated and the change in Hall effect sensor output was confirmed by a voltmeter. This rotation is the method for measuring speed, and our tests showed the switches to be reliable. This implies that it will be able to accurately measure speed (Req / Spec. 1). Continuity between the chosen pin, PA19, and the Hall Effect Sensor output was also confirmed with a voltmeter. The distances between the impeller and the magnetometer and Hall effect sensor were verified in the testing procedure described in Section 7.2. These tests were used to verify the magnetic interference error that was used in CAD design (Req / Spec. 2).

9.3 CFD Verification

To try and verify the drag results from the CFD analysis, the squid and tags were 3D printed and tested in a wind tunnel. This setup can be seen in Appendix E. By connecting the squid to a load cell, the drag force on the squid and tags was found, and eventually compared to the drag found in the CFD. However, since this test was done in air while the simulations were done in water, the comparison was not so direct. Firstly, the Reynolds number of the flows were made constant between the tests and simulations. This made it so that the drag coefficient of the squid and tags were constant as well. To match the Reynolds number, the flow velocity in the wind tunnel needed to be considerably higher than that of the simulations. These calculated flow velocities can be seen below in Table 6.

Table 6. Velocity of water and velocity of air that will give equal Reynolds numbers.

Velocity of Water (m/s)	Velocity of Air (m/s)
0.5	8.8
1.0	17.6
1.0	26.4

Once the wind tunnel tests were run at the calculated flow velocities and the drag on the squid and tags was found, the drag coefficient could be calculated using Eq. 1 below.

$$c_d = \frac{2F_d}{\rho u^2 A} \qquad [1]$$

Where C_d is the drag coefficient, F_d is the drag force, ρ is the density of the air, u is the flow velocity, and A is the frontal area. As discussed earlier, this should be the same drag coefficient as it would be in water. Therefore, we could use this drag coefficient to calculate what the drag force would be in water using Eq. 2 below.

$$F_D = \frac{1}{2}\rho v^2 C_D A \qquad [2]$$

The variables are all the same as in Eq. 1, but this time the density of water was used, as well as the flow velocity of water from the simulations. Once we found the calculated drag in water, we could determine the percent increase in drag between the two tags. These results are shown in Table 7 below, while the full drag results and calculations can be seen in Appendix B.

Table 7. Calculated drag increase between tags at different flow velocities in water using wind tunnel data.

Flow Velocity (m/s)	% Increase in Drag with Forwards Flow	% Increase in Drag with Backwards Flow
0.5	-4.56	13.20
1.0	-0.36	11.45
1.5	12.27	4.41

The experimental results did not fully agree with the CFD. The full drag measurements can be seen in Appendix B. The drag values themselves were much higher than expected, but more important is the increase in drag between the two tag designs. Interestingly, the drag actually decreased between the tags at 0.5 m/s and 1.0 m/s forwards, though it increased by over 10% at 1.5 m/s. The fact that the drag decreased despite the addition of the impeller tells me that the inconsistency of this type of data collection is overwhelming compared to any increase in drag from new tag design. Everytime the tag was switched, the setup had to be taken out of the wind tunnel and reset, introducing many possible sources of error. Additionally, the velocity clearly has the largest impact on drag, but it could not be controlled precisely in the wind tunnel that was used. This would lead to large variations in drag between tags. Despite these sources of error, the maximum drag increase was only 13.20%, only 3.20% above our specification cut off.

10. RISK ASSESSMENT

As the scope of this project was adding functionality to an existing system, many of the main risks faced by the system were addressed by the previous team who worked on the project. Potential risks such as water damage and failure in the detachment procedure would have severe consequences, however our modifications to the tag wouldn't affect these aspects of the tag. Therefore, the focus of this risk assessment was on risks associated with the changes we implemented.

The main addition to the tag was the impeller. The main risk associated with the impeller is physical damage, such as the shaft getting bent or the impeller's rotation being impeded by particulates. This was determined to have low a probability of occurring, with a low to moderate impact if it did. The design of the impeller helps to mitigate the chances of physical damage occurring by having a sturdy triangular attachment to the rest of the tag, as well as a metal shaft for the impeller to spin on. Other minor risks, such as loose wiring, can largely be avoided by testing the iTag before deployment to ensure proper functionality.

11. DISCUSSION AND RECOMMENDATIONS

We made significant progress on the project this semester and our stakeholders are pleased with the results. That said, we wish we could have spent less on speed sensor concept generation and more time on the housing design of the tag, or potential configurations for sensor integration assuming a Hall sensor. Our package design is closed, meaning there are not too many external moving parts aside from the radio signal to the antenna for the catch and release mechanism. If given more time to iterate through designs, we would vertically move the Hall effect sensor cubby towards the impeller to better read the revolutions. Additionally, we would elongate the foam 1.1 inches (2.8 cm) to mitigate magnetic interference.

Looking into the future, our recommendations for our sponsors are the following. First, we suggest an update to our final CAD design based on the changes in the above paragraph. Second, for sensor integration we suggest to program the Hall effect sensor switch reading, calibrate it to water flow to account for squid directional independence, and to program the magnetometer to determine which direction the squid is swimming. Third, for CFD and wind tunnel testing, we also suggest waterproofing the sensors and testing the tag in water for more accurate readings than extrapolating air readings to water. Then we suggest using drag measurements from CFD simulations to inform future tag design.

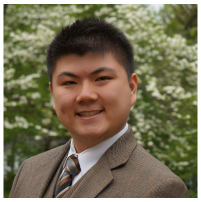
12. CONCLUSION

We were tasked with putting a speed sensor onto an existing bio-logging tag such that it doesn't interfere with the functionality of the existing sensors and nor the squid's natural behavior. This redesign must not create a magnetic interference with the preexisting magnetometer sensor on the tag. Additionally, this sensor must be programmed to account for the multi-directional swimming patterns that squid do. Last but not least, it must be able to last the full deployment and be reused for multiple deployments. An exhaustive list of requirements and specifications can be found in Sections 3 and 4 of this report.

We determined the best solution was to add an impeller plus bead and a Hall effect sensor. The revolutions on the bead can be converted to speed and measured by the Hall effect sensor. In the CAD, a cubby was added for the Hall effect sensor, though placed too far away from the impeller for accurate reading. It was also determined that the CAD design needs a 1.1 inch (2.8 cm) extension to mitigate an magnetometer interference. Sensor integration was able to measure the Hall effect sensor output with a voltmeter and confirmed continuity between the Hall effect sensor and pins on the Atmel. Sensor integration was not able to be verified in the wind tunnel or water tank due to time constraints. Computational fluid dynamics confirmed accurate drag readings on different designs which was informative in our final design decision. This was supported by wind tunnel testing and has yet to be confirmed in the water tank.

13. AUTHORS

Ethan Ames 	Ethan was the lead on working with the sensors in the existing iTag. He will be graduating next semester with a B.S.E. in Mechanical Engineering.
Will Binney 	Will took the lead on the CFD simulations and helped verify that with the wind tunnel testing. He will be graduating at the end of this semester with a B.S.E. in Mechanical Engineering, then returning in the fall to pursue an M.S.E in Mechanical Engineering.

Marissa Gabriel 	Marissa took lead on the CAD design and rendering. She will be graduating this term with a B.S.E. in Mechanical Engineering. This coming fall, she will begin graduate school here at UMich to pursue an M.S.E. in Materials Science & Engineering.
Blake Stoddard 	Blake worked on the integration of the Hall effect sensor to the iTag, and will be graduating this semester with B.S.E in Mechanical Engineering.
Kail Yuan 	Kail supported the iTag package design and wind tunnel testing of the prototype tag and squid. He will be graduating this semester with a B.S.E. in Mechanical Engineering and Aerospace Engineering, and will be pursuing an M.S.E. in Aerospace Engineering at Penn State in the fall.

14. ACKNOWLEDGEMENTS

Team 28 would like to acknowledge Seth Cones, Dr. Aran Mooney, and Professor K. Alex Shorter for their generous assistance and time investment on this project. We would not have been able to make the progress we did on this project without the knowledge and resources they provided to our team.

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16. APPENDIX

A. Potential Circuit Change

Currently the Hall Effect Sensor outputs a 1 bit digital signal. This requires measuring the number of times the signal switches between true and false per second. Depending on the number of operations that take place per loop of the arduino code, switches could be missed. If this ends up being a major source of error, a possible solution was developed. The Hall effect sensor would output an analog signal into the circuit shown on Figure 26.

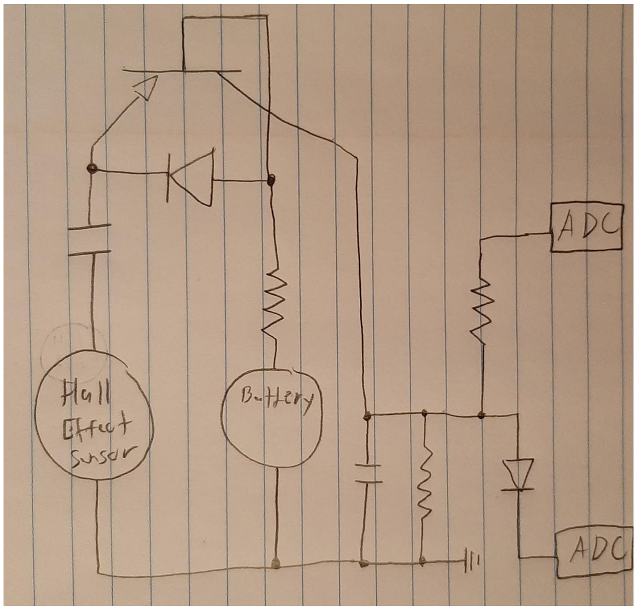
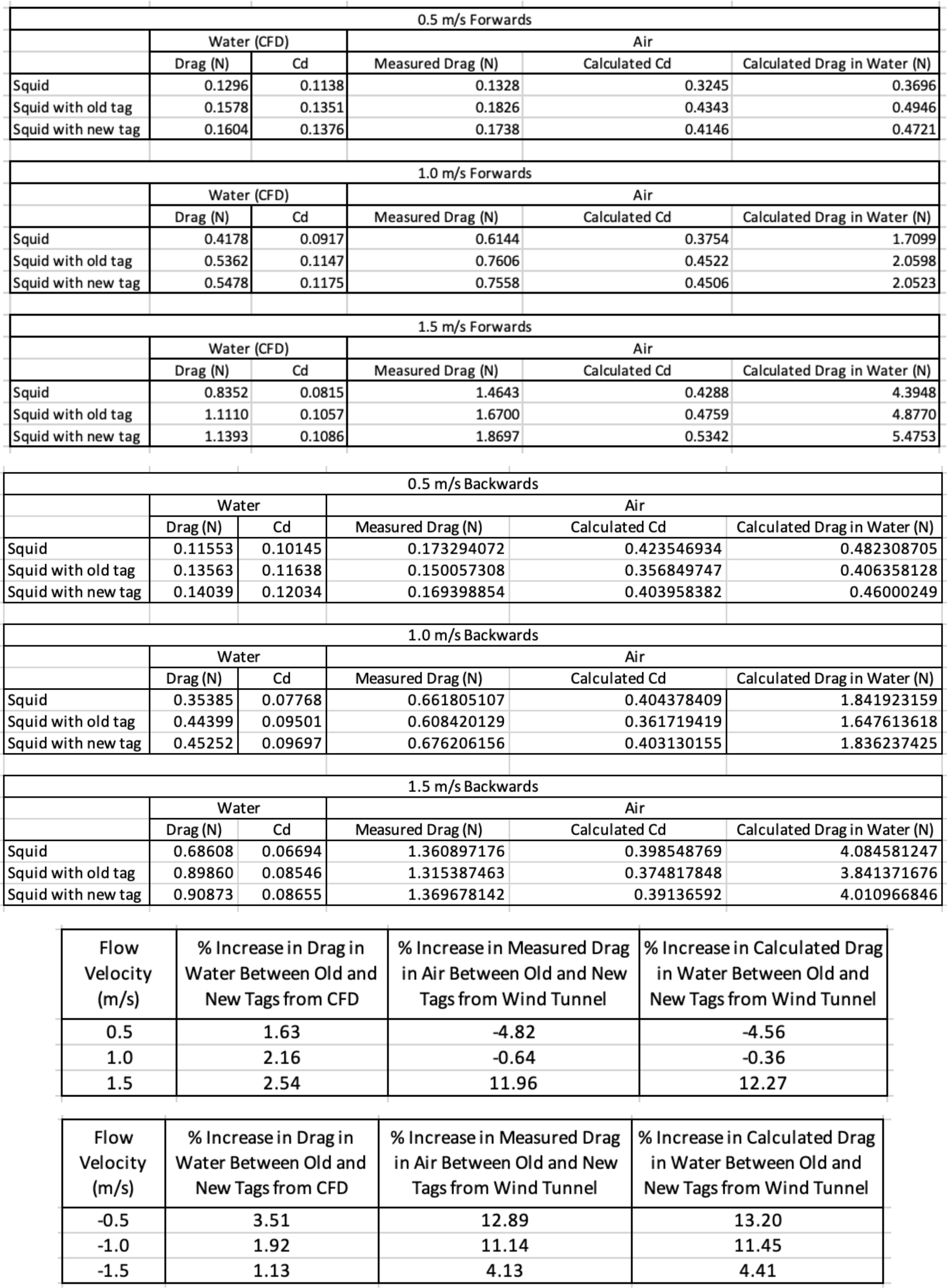


Figure 26. A circuit diagram to convert frequency to magnitude

This circuit converts the analog signal's frequency to magnitude, which can then be converted to a digital signal through one of two different ADCs. The upper ADC can be tuned for high speeds when jetting and the lower ADC can be tuned for low speeds when finning or flapping.

The advantage of this design is that it avoids any error resulting from potentially missing switches. This solution will have resolution error unlike the switch solution, and the number of bits should be chosen with the resolution error in mind. It will likely use up additional power, but if it's recorded infrequently enough it could be more efficient.

B. Full Drag Results



0.5 m/s Forwards					
	Water (CFD)		Air		
	Drag (N)	Cd	Measured Drag (N)	Calculated Cd	Calculated Drag in Water (N)
Squid	0.1296	0.1138	0.1328	0.3245	0.3696
Squid with old tag	0.1578	0.1351	0.1826	0.4343	0.4946
Squid with new tag	0.1604	0.1376	0.1738	0.4146	0.4721

1.0 m/s Forwards					
	Water (CFD)		Air		
	Drag (N)	Cd	Measured Drag (N)	Calculated Cd	Calculated Drag in Water (N)
Squid	0.4178	0.0917	0.6144	0.3754	1.7099
Squid with old tag	0.5362	0.1147	0.7606	0.4522	2.0598
Squid with new tag	0.5478	0.1175	0.7558	0.4506	2.0523

1.5 m/s Forwards					
	Water (CFD)		Air		
	Drag (N)	Cd	Measured Drag (N)	Calculated Cd	Calculated Drag in Water (N)
Squid	0.8352	0.0815	1.4643	0.4288	4.3948
Squid with old tag	1.1110	0.1057	1.6700	0.4759	4.8770
Squid with new tag	1.1393	0.1086	1.8697	0.5342	5.4753

0.5 m/s Backwards					
	Water		Air		
	Drag (N)	Cd	Measured Drag (N)	Calculated Cd	Calculated Drag in Water (N)
Squid	0.11553	0.10145	0.173294072	0.423546934	0.482308705
Squid with old tag	0.13563	0.11638	0.150057308	0.356849747	0.406358128
Squid with new tag	0.14039	0.12034	0.169398854	0.403958382	0.46000249

1.0 m/s Backwards					
	Water		Air		
	Drag (N)	Cd	Measured Drag (N)	Calculated Cd	Calculated Drag in Water (N)
Squid	0.35385	0.07768	0.661805107	0.404378409	1.841923159
Squid with old tag	0.44399	0.09501	0.608420129	0.361719419	1.647613618
Squid with new tag	0.45252	0.09697	0.676206156	0.403130155	1.836237425

1.5 m/s Backwards					
	Water		Air		
	Drag (N)	Cd	Measured Drag (N)	Calculated Cd	Calculated Drag in Water (N)
Squid	0.68608	0.06694	1.360897176	0.398548769	4.084581247
Squid with old tag	0.89860	0.08546	1.315387463	0.374817848	3.841371676
Squid with new tag	0.90873	0.08655	1.369678142	0.39136592	4.010966846

Flow Velocity (m/s)	% Increase in Drag in Water Between Old and New Tags from CFD	% Increase in Measured Drag in Air Between Old and New Tags from Wind Tunnel	% Increase in Calculated Drag in Water Between Old and New Tags from Wind Tunnel
0.5	1.63	-4.82	-4.56
1.0	2.16	-0.64	-0.36
1.5	2.54	11.96	12.27

Flow Velocity (m/s)	% Increase in Drag in Water Between Old and New Tags from CFD	% Increase in Measured Drag in Air Between Old and New Tags from Wind Tunnel	% Increase in Calculated Drag in Water Between Old and New Tags from Wind Tunnel
-0.5	3.51	12.89	13.20
-1.0	1.92	11.14	11.45
-1.5	1.13	4.13	4.41

Figure 27. Drag measurements and calculations.

C. Three View Drawing of CAD

All measurements are in inches.

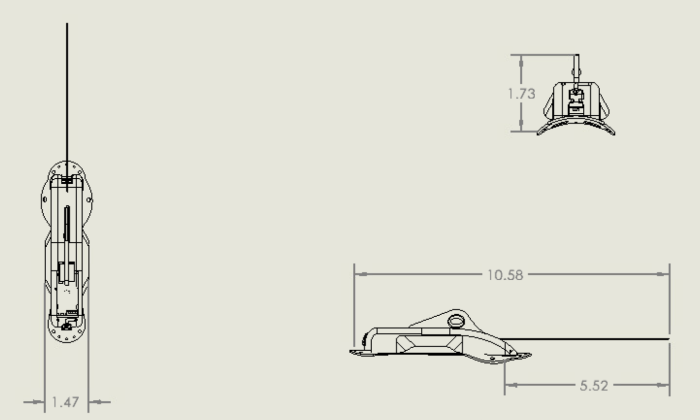


Figure 28. A Three View Drawing of the new CAD design.

Parts of the assembly include: foam body, catch and release latches, antenna, battery, 3d printed housing, Hall effect sensor, impeller, impeller bead.

D. Three View Drawing of Simplified CAD for CFD Testing

All Measurements are in inches.

Figure 29. A Three View Drawing of the simplified CAD design used in CFD testing.

E. Wind Tunnel Experimental Setup

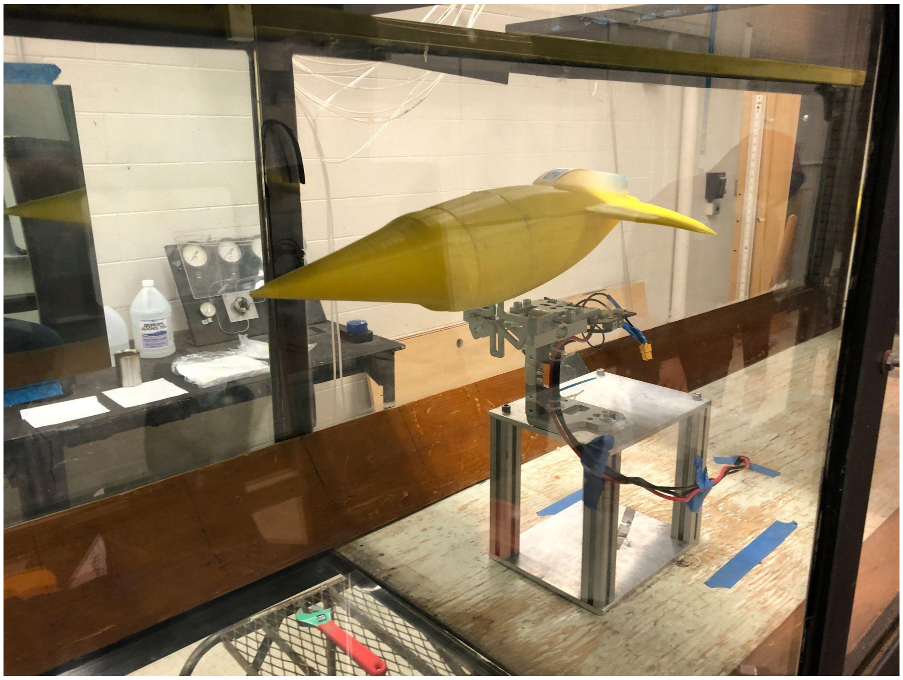


Figure 30. 3D printed squid and tag inside the wind tunnel with backwards-facing orientation (flow direction is from left-to-right).

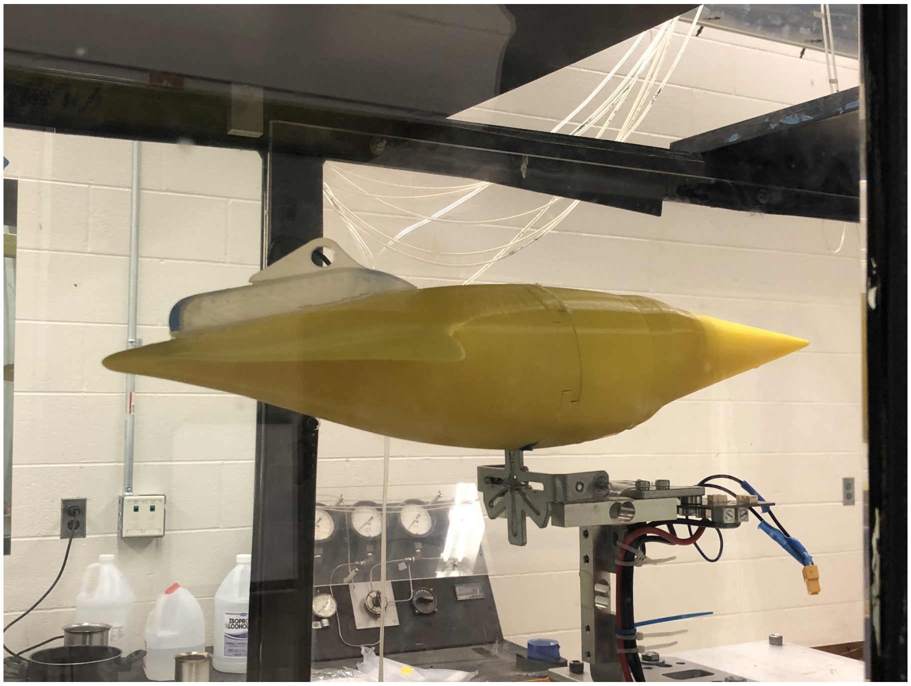


Figure 31. 3D printed squid, tag, and impeller inside the wind tunnel with forward-facing orientation (flow direction left-to-right)

F. Engineering Standards

Specific engineering standards were not used for our project. This is because our product is a redesign of an existing and active bio-logging project. Beyond ethical standards (see Ethical Decision Making), there were not standards put in place for our project as there aren't certain codes we had to follow. Our sponsors and stakeholders did not provide us with a list of codes to follow for best practice and our project's priority was ethical standards for squids over engineering standards for the design of the tag. The only standards we've found for bio-logging is from the International Bio-logging Society and exists in the realm of standardizing data collection and analyzation to be shared among countless biologists and scientists, which could be used when our project is in its deployment stages [24].

G. Engineering Inclusivity

Our team made efforts to be inclusive of our stakeholders throughout the duration of the project. However, as the scope of our product was relatively small, our stakeholder engagement process was limited primarily to our faculty advisor Dr. Alex Shorter as well as Seth Cones of WHOI, who was simultaneously our end user, external sponsor, and a technical expert. Our team regularly took input from regular meetings with both Dr. Shorter and Mr. Cones in our work, especially in the problem definition and concept exploration phases of the project. As Mr. Cones and Dr. Shorter were both familiar with previous iterations of the iTag, we were also able to incorporate changes in the prototype iTag based on their past user experiences and their technical knowledge of the device.

H. Environmental Context Assessment

Our design solution meets the two necessary conditions for sustainable technologies. The system makes significant progress towards an unmet and important environmental challenge. Our device contributes to the understanding of squid, a species that is thriving in the warming oceans. Learning about how squid are doing this can contribute to designing ways of keeping other species sustainable or in better utilizing the squid to supplement fisheries that are suffering from climate change.

The squid tag's negative environmental consequences don't overshadow its benefits. There are two sources of environmental damage from the iTag: the tag itself, and the baseplate. The tag has a very minimal environmental impact. It's designed to be reused until failure, dramatically reducing the environmental cost of production. Additionally, the battery is rechargeable and uses a small enough amount of power to make the CO_2 emissions from power generation negligible. The baseplate is sewn onto the squid and even after detaching isn't recovered. This means that for each dataset that is recorded a baseplate is added to the ocean. If the iTag was somehow adopted on a massive scale this could have negative rebound effects, but finding the behavior of a squid is a niche need. On the scale that the iTag will be used, the environmental benefit of the data is greater than the environmental harm of the baseplate.

I. Social Context Assessment

Our design meets two of the three remaining necessary conditions for sustainable technologies. There are listed here:

3. Is the system likely to be adopted and self sustaining in the market?
4. Is the system so likely to succeed economically that planetary or social systems will be worse off?
5. Is the sustainable technology resilient to disruptions in business as usual?

Looking at the third condition, our system fills a very niche market, and even if our stakeholders look to expand use outside of their institution, it would likely not be widespread or self-sustaining. This directly contributes to the fourth condition. It is not likely to be so successful that planetary or social systems will be worse off. In fact that seems nearly impossible. On the other hand, since the market is so niche, we believe the fifth condition is met: the technology is resilient to disruptions in business as usual. People who are interested in this product likely have a deep academic interest. This interest has lasted over the course of this pandemic already. Overall, the third condition was not met, but the fourth and fifth were.

The tag we have been working with will not have a large impact on society outside of our stakeholders. It is not likely to be manufactured more than a handful of times, and the tag itself is small and not composed of too many parts. Overall we believe the net impact will be positive due to the knowledge that can be gained by using the tag, but economically it is not meant to be successful.

J. Ethical Decision Making

The main ethical considerations with this project relate to the well-being of the squid, and ensuring that no undue stress is placed upon them. The tag should impede their normal behavior as little as possible, both to ensure that the data is reflective of an untagged squid and to preserve their well-being. These considerations were reflected in the specifications and requirements laid out at the beginning of the project, as well as throughout the design process.