DEVELOPMENT OF A DOLPHIN HORMONE SAMPLE COLLECTION DEVICE FOR UAS

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DEVELOPMENT OF A DOLPHIN HORMONE
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Abstract: Marine biologists are able to quantify the stress in dolphins through analysis of hormones in mucus samples released from the blowhole while breathing. This method provides a noninvasive approach compared to current methods used on wild dolphins to collect information on their stress levels. To capture the samples, a developed collection mechanism using Petri dishes attached to an Unmanned Aircraft System (UAS) can fly through the blow field of the dolphin's expelled breath. Analysis of the flow into the dish was performed with Particle Image Velocimetry and flow visualization. The resulting data were used to indicate key areas of flow across the Petri dish indicating both clean and separation areas. In preparation for UAS trials, the collection device is connected to the vehicle for flight-testing to measure significant changes in control, lift, and drag while the Petri dishes open and close. For the UAS trials, the system is flown through the "breath" of a simulator to emulate the flow rate of a dolphin's breath in a time frame of 0.26-0.31 seconds. The resulting data is used to provide validation of the systems capability for in flight sample collection.

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CHAPTER I

INTRODUCTION

1.1 Motivation

Determining the health of marine mammals in the wild is an important task in understanding how these animals behave and react to environmental changes and physical stimuli. Free-ranging, wild cetaceans can experience stress from numerous sources such as noise, predation, fisheries, ecotourism, climate change, declining food sources, diseases, social issues, pollution, and habitat degradation, among others[23]. Evaluating the hormone cortisol gives insight into the health of the dolphin by providing the relative stress level of the mammal. This hormone can often be biologically discerned from examination of the breath and/or mucus of the mammal. Biologists need a noninvasive method to be able to collect cortisol samples from wild dolphins. Current methods for collecting any biological information on dolphins involves using a large team of 30 to 60 members with 7 or more boats used [12]. This process involves using nets to trap dolphins in a giant loop. The team then works on slowly constraining the area inside the net to be able to capture individual dolphins in order to perform analysis on them. Figure 1 provides an illustration for this method on capturing dolphins for health assessment.

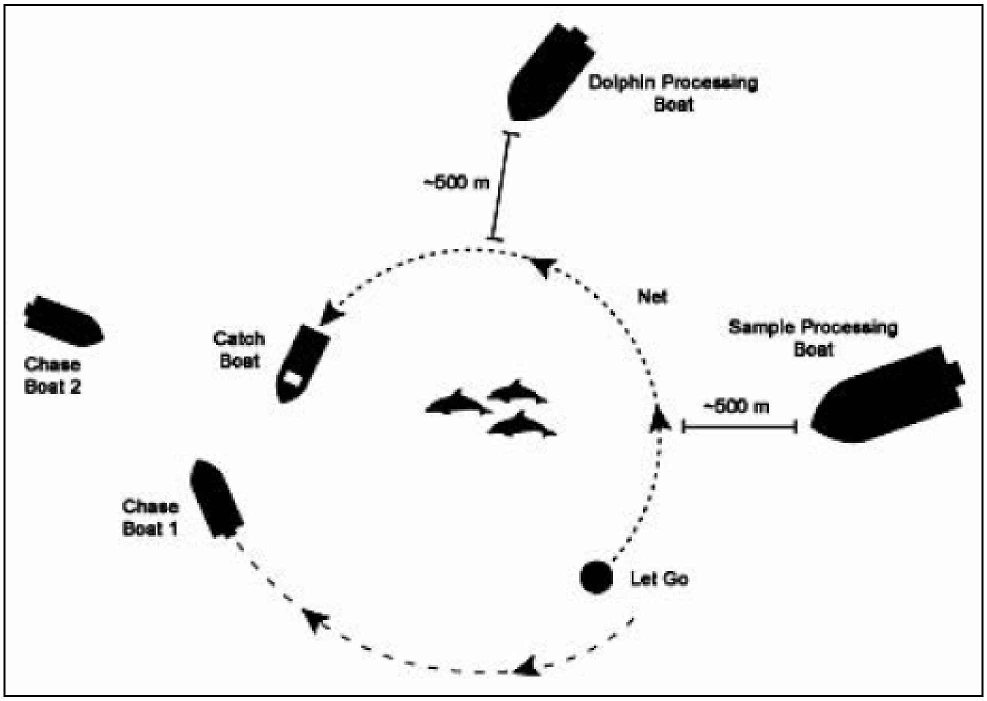

Figure 1: Boat positioning for live capture[12]

Additionally, remote biopsy darting is another current method being used to collect samples from dolphins. This method involves shooting modified darts into the side of dolphins to retrieve skin and blubber tissue samples. These samples can provide valuable information such pollutant concentrations, population health, and pregnancy status [16]. Both methods are invasive to dolphins, this leads to the need to develop a new method for sample collection from dolphins that is non-invasive.

Recently, work has been conducted attempting to capture cortisol from the breath of both whales and dolphins using multi-rotor unmanned aerial systems (UAS) as a non-invasive approach for sample collection. The process involves using the UAS to fly through the "blow" of the mammal as it breaks the surface of the water to breathe. There has been success with collection from whales as they are large, slow, and expel their breath many feet into the air. For the case of sample collection from dolphins, collection is a challenge as they have smaller expelled breath jets that do not travel far from the surface of the water. This leads to the need for developing a new unmanned aerial system that will be able to meet the constraints of cortisol collection from a dolphin.

Figure 2: Multi-rotor UAS collecting cortisol from whale.

1.2 Goals

The main goal of this project is to provide validation for the effectiveness of a UAS as a means for a noninvasive method of the collection of cortisol from the expelled breath of wild dolphins. The system will be compromised of subsystems to achieve the main goal. These subsystems include the vehicle used in collection and the sample collection mechanism. In order to achieve the main goal, the subsystems must be carefully selected to meet project constraints. A main constraint for the project is that the system needs to be non-invasive in order to not stress the dolphins. If the dolphins become stressed from the system, any samples collected from their blow will become invalid. At any point during the sample collection process on live dolphins, if the dolphins show any signs of stress or aggression toward the system, it is advised that the test collection be immediately stopped to not further harm them.

In order to minimize potential stress caused by the system, the vehicle must be carefully selected to not produce noise frequencies that induce stress. Additionally, the system cannot appear visually threatening to the dolphins. Ideally, the system will stay behind the dolphins in their blind spots in order to reduce chances of the system invoking a visual threat response.

The sample collection mechanism must be able to obtain a large enough sample to yield a valid result for cortisol testing. Additionally, the collection mechanism needs to be designed in a way that reduces the chances of cross contamination during flight to the dolphin pod and during handling before and after sample collection. The material used for the collection containers will be chosen to allow researchers to properly sanitize the containers before flight. Additionally, the material used will not contaminate the samples after collection.

The process for sample collection from the blow of dolphins is outlined in Figure 3. The aircraft would be launched from a small research vessel and flown toward a located dolphin pod. Once in the vicinity of the pod, the vehicle would be flown behind the last dolphin in the pod where it would wait for the dolphins to start exhaling. Once this is observed, the capture mechanism would be switched open and then the aircraft would be flown into the blow field produced by the dolphin. Once the sample is collected, the collection mechanism would be closed and the aircraft would fly back to the vessel for sample analysis. For an ideal case, the planned approach for the aircraft would be both from behind the dolphin and downwind.

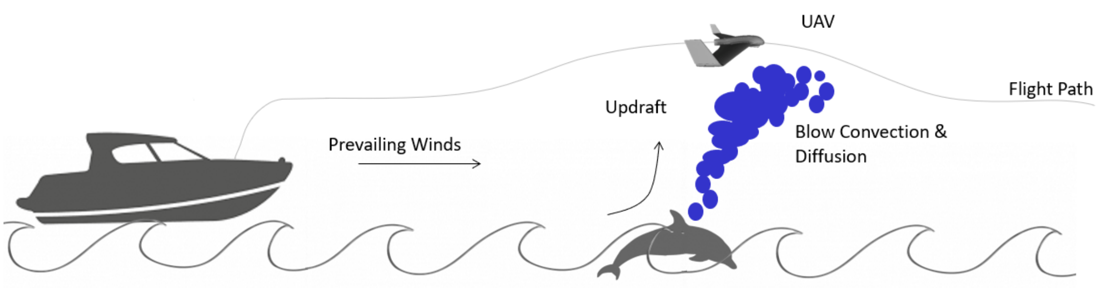

Figure 3: Mission concept of operation

1.3 Objectives

The project aims to prove that cortisol sample collection is possible from a UAS. In order to prove this, validation will be conducted utilizing specific objectives. The first objective is to evaluate different vehicle platforms to find the optimal vehicle for collection. Next is to evaluate different capture mechanisms to determine an optimal design for maximum sample collection and ease of use for sample analysis. The last objective is to evaluate the system through testing. The testing will be conducted with the system flying through a simulated breath plume from a dolphin lung simulator. The tests will be run at different configurations to test system performance. These configurations will involve a static test where the blow simulator remains stationary where the sample collection vehicle will be flown at different heights above the nozzle. Additionally, a multi rotor vehicle that is similar to what is typically used in cortisol sample collection from whales will be tested at the same heights as the fixed wing vehicle to provide a comparison.

1.4 Outline

This thesis aims to answer the question whether unmanned aerial vehicles are suitable for being able to perform a non-invasive capture of dolphin blow in order to determine their stress levels through cortisol test results. UAV behavioral effects on dolphins are discussed with an overview of previous attempts at collection of cortisol from cetaceans from a UAV. Additionally, an overview of suitable material for a collection container is discussed followed by a review of operation protocols of a UAV near dolphins. This thesis evaluates different vehicle platforms and capture mechanisms in order to find an ideal solution. A comparison of aircraft options is discussed with an aircraft selected using a down select process. An acoustics analysis is conducted to ensure that the chosen vehicle will not cause stress to the dolphins. Flow analysis results are discussed on the interaction of the flow inside and around the collection mechanism using both wind tunnel and water tunnel particle image velocimetry

(PIV) tests. Flight performance will be discussed on how the chosen vehicle performs with the collection mechanism. Test results from flights through a generated blowfield from a dolphin breath simulator are analyzed and discussed. The paper finishes with final thoughts with an overview for future work.

CHAPTER II

LITERATURE REVIEW

2.1 Previous Work: UAV Behavioral Effects on Dolphins

Recent studies have primarily focused on using UAV's to collect cortisol samples from whales. These studies incorporate multi-rotor UAV's for this task. Due to the size and nature of whales, collection is a relatively easy task that provides a minimal amount of danger to the mammal. Previous work has shown that flying multi-rotor UAV's within close proximity to whales has no effect on diving behaviors of the whales indicating that the presence of the UAV does not cause a disturbance [8]. However, using the same technique for dolphins proves to be problematic. There is the potential that frequencies emitted from the motors and propellers of multi-rotor UAV's could cause stress to the dolphins and could make them go underwater and disappear. In fact, there are studies that show conventional manned aircraft and helicopters elicit strong behavioral response from cetaceans [13]. Additionally, the breath plume from the dolphin is much lower compared to that of a whale and happens almost instantaneously at a respiratory expiration time of 0.26-0.31 seconds [11]. Due to the lower height of the breath plume, the vehicle used for sample collection will have to get much closer to the dolphin in order to collect cortisol samples from the expelled breath. A comparison of a whales breath height and dolphins can be seen in Figures 4 and 5 respectively.

Figure 4: Whale breath [8]

Figure 5: Dolphin breath

Most case studies that have been conducted for research on cetaceans have focused on using commercial off the shelf (COTS) UAV's. Typically these UAV's are small quad-copters outfitted with mission specific payloads such as cameras, sensors, and collection devices. For research on cetaceans with multi-rotor UAV's, noise emitted from the vehicles must be accounted for due to the high frequency from the motor speed. For this reason, research has been conducted to determine the effects that multi-rotor UAV's can have on cetaceans.

Previous work has shown that the effects of UAV's on dolphins can vary based on changing sea conditions. Christiansen conducted research that compared the noise emitted from two different multi-rotor UAV's to the ambient noise of the sea [7]. The results from this work indicates that when cetaceans are approximately a meter below the water surface level, they will have a difficult time discerning the noise emitted from UAV's compared to the ambient noise of the sea. However, their results also indicated that when at the surface level, the UAV's that were tested were capable of emitting sounds that could be distributing to certain species. A case by case study would need to be conducted in order to properly ascertain the exact effects of a UAV on a certain species of cetaceans[7]. Even so, the study indicates that UAV collection would remain a viable option especially for a vehicle that emits a lower frequency and sound level compared to the multi-rotors used in their testing.

Previous work has indicated that the dolphin behavior state before approach is crucial in order to avoid unnecessary disturbance. Dolphin behavioral states can differ based on their current activity. Table 1 serves as a reference for the different types of behaviors that are most commonly shown by dolphins[5].

Table 1: Definition of Behavioral States for Dolphins[5]

Behavioural State	Definition
Foraging	Searching for or consuming prey, as indicated by long, deep dives followed by loud forceful exhalations ("chuffs") and directionless movement; may include coordinated "burst swims" (rapid bursts of speed), "clean" noiseless headfirst re-entry leaps, coordinated clean leaps and tail slaps
Resting	Slow directionless movement at speeds of < 3 knots close to the surface with low activity level; often includes slow surfacing and floating near the surface
Socialising	Interacting with each other or inanimate objects; usually directionless movement and may include body and pectoral fin rubbing, rolling, belly-up swimming, spyhops, splashing at the surface, chasing, leaping, mating and playing with seaweed
Travelling slow	Steady movement in one direction at speeds of < 3 knots
Travelling average	Steady movement in one direction at speeds of 3 to 5 knots
Travelling fast	Steady movement in one direction at speeds of > 5 knots

There has been little research conducted on how UAS affects dolphins. The few existing studies indicate the importance of the behavioral state before flying UAS near any dolphins. Fettermann conducted a study that focused on flying a multi-rotor UAV above dolphins that were in a resting behavioral state [13]. The primary focus was to observe the response before and after exposure to the UAV to determine the effects of a multi-rotor UAV on resting dolphins. The results showed that flying at 10 meters above the water provokes negative disturbance for resting dolphins. In comparison, flying at 25 meters appeared to have no significant effect on resting dolphins for the vehicle used in in the study [13]. These results indicate that operating UAS at low altitudes has negative effects on resting dolphins and should be avoided.

Another study focused testing a multi-rotor UAV above dolphins that were either traveling or socializing [5]. The study was able to evaluate the immediate behavioural responses for both common and bottlenose dolphins to a UAV flown at different heights. The study was able to show that the UAV did not cause a significant change in diving behaviour or swimming speed for either species when they were traveling or socializing. For common dolphins (but not bottlenose dolphins), however, there were significant changes in direction when the UAV was flown at a height of 5 meters. This suggests that common dolphins may be more sensitive than bottlenose dolphins to the effects of a UAV flown at very low heights. Additionally, their results indicated that common dolphins also briefly responded to the UAV at heights of 20 and 30 meters. One potential explanation is that the dolphins detected some level of risk or disturbance from the UAV at these heights and responded briefly by changing direction before developing a short-term habituation to the UAV.

As mentioned before, initial behavior is an important aspect to understanding the response to the UAV being flown above. For the majority of the tests, both the common and bottlenose dolphins were initially either traveling or socialising before takeoff; however, there was a small case that was sampled for a pod of common bottlenose dolphins that were feeding before takeoff. From their tests, a lack of any significant response to the UAV was observed for all heights tested. This could be due to the fact that none of the dolphins were milling or resting before the UAV was launched. In a resting or milling state, dolphins tend to be more sensitive to UAV's. Despite not changing their behavior, it was observed during testing that several times the bottlenose dolphins exhibited a visual interest in the UAV by side swimming and side floating under the UAV during the tests.

Overall, however, the study indicated that UAVs do not induce immediate behavioural responses when flown at heights of 10 meters for common dolphins or 5 meters for bottlenose dolphins that are in a traveling or socializing behavioral state. The previous studies demonstrate the feasibility of using UAVs as a non-invasive research tool in dolphin research[5].

Finally, one study looked into behavioral states of the dolphins before exposure to a multirotor UAV and carefully monitored the responses after the UAV was noticed. They sampled dolphins that were either traveling, socializing, or milling. Their results showed either no change in behavioral state or a minor change in their behavioral state from pre-exposure to post-exposure[24]. From the dolphins they sampled, only a small subset seemed to respond to the presence of the UAV and that was when they were directly approached from the front and followed. The dolphins that did react only changed their behavior briefly, mainly to view the UAV, then returned to their previous activity. The strongest noted response that the dolphins had occurred when the UAV was directly or nearly flown above them. This indicates that dolphins may remain largely unaware of the presence of a UAV if it remained behind them. This could be due to the noise concentration from the UAV being the strongest when nearly overhead. Overall, the study was able to help identify behavioral responses that prove valuable for future work. They were able to determine an average height at which dolphins first noticed the UAV presence being at approximately 20 meters above the surface and were able to show that dolphins in a traveling, milling, or socializing behavioral state remain largely unaffected by a UAV[24].

Overall, the studies mentioned above are all subject to changing conditions such as wind speeds and sea conditions. UAV noise will travel farther when the see is calm with windless conditions than when there are ripples, and whitecaps[13]. However, the previous studies demonstrate the feasibility of using UAV's as a non-invasive research tool in dolphin research.

2.2 Previous Work: UAV Collection Methods

With UAS research on cetaceans becoming more popular, researchers are looking for ways to use these systems to collect data that was previously difficult or not possible. Recently few attempts have been made in order to try to collect cortisol samples from cetaceans. These attempts have all focused on extracting the cortisol from the exhaled breath of cetaceans.

The first attempt at blow sample collection from cetaceans focused on whales. The device used was a remote controlled helicopter that had petri dishes mounted to the landing gear for collecting blow samples[1]. This vehicle can be seen in figure 6. The design was able to capture blow samples from whales; however, it failed to account for airborne particle contamination resulting in contaminated samples that were inconclusive[22]. Despite the failed attempt, the design was able to demonstrate the feasibility of blow sample collection.

Figure 6: Blow collection from remote controlled helicopter[1]

One of the latest studies used for whale blow sample collection used a custom built multi-rotor UAV with a collection device incorporated into the design which can be seen in figure 7. The “flip lid” design that was used reduced contamination from aerosolized seawater bacteria. Additionally, the design proved effective in reducing contamination from the pilot and research team as well as the vapor fumes from the boat that the UAV was launched from[22]. Their design proved to be successful for blow sample collection from whales, proving that UAS is a valid approach for blow sample collection.

Figure 7: UAS multi-rotor design[22]

Figure 8: Whale blow sample collection[22]

The same custom built multi-rotor discussed previously and shown in figures 7 and 8 was used to attempt blow sample collection on dolphins. However, despite capturing a few blow samples, no quantifiable DNA could be determined from lab testing. The failure to obtain valid samples could be due to various factors. First, it could be due to lack of a sufficient sample size. Their study focused on collecting a single blow at a time, leaving the potential to not collect a large enough sample for DNA extraction from that dolphin. Second, the UAV remained between an altitude of 0.5 to 1 meter above the surface level resulting in the potential to miss the larger portion of the blow. Finally, dolphins exhale while their blow holes are still underwater leaving for the possibility that the collected samples were mainly seawater [26].

A few recommendations to aid in better sample collection lie within improvements to the system. A collision avoidance system could be installed to automatically maintain a set altitude above the surface level. Such a system could utilize a LIDAR, sonar, or optical flow image processing to maintain a set altitude while accounting for wave crests [26]. This would allow the vehicle to remain closer to the water surface level without additional strain to the pilot. To successfully capture dolphin blow, the pilot must be able to easily see it through the camera equipped on the UAV. Dolphin blow is closer to the surface, more transparent, and usually dissipates almost immediately compared to that of larger cetaceans such as whales. To ensure the best chance of collection, the live video camera and downlink on the UAV should be designed to allow for a high resolution. In addition, a large monitor would help aid the pilot in identifying samples.

Finally, the study notes that the success of blow sample capture is dependent on dolphin state. They determined that when the dolphins are socializing, they were not predictable in their patterns and surfacing, making it hard to position the UAV in an optimal place for blow collection. The ideal circumstance to capture blow was to track the dolphin from behind and then swoop low as the dolphins surfaced in range [26].

Another UAS blow collection method utilized a six well petri dish plate that was towed from a multi-rotor as seen in Figure 9.

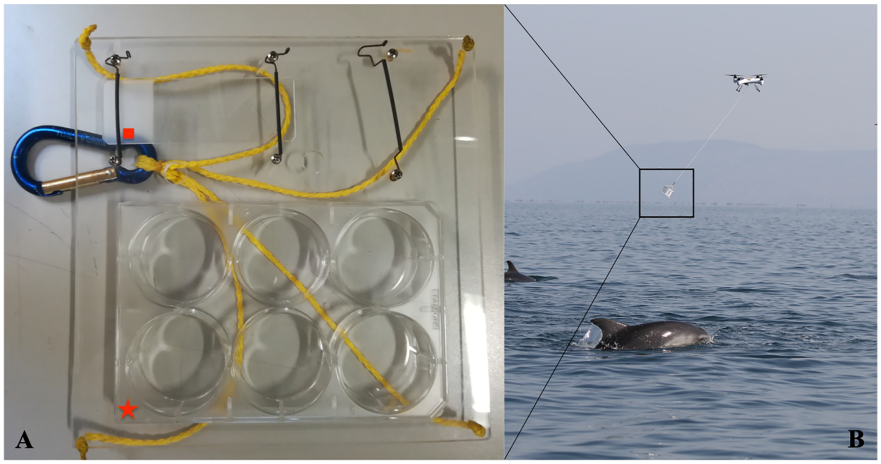

Figure 9: Multi-rotor UAS capture system.[6]

This design allows for the UAV to remain at a higher altitude above the water surface level to reduce the chance of stressing the dolphins when collecting blow samples. Their work showed that an optimal range was to keep the UAV 3 meters above the surface level while hanging the six well petri dish plate from a 2 meter long rope. This would ensure that the plate would remain 1 meter above the dolphin which was a height they determined to be optimal for blow collection. For blow sample results, they were able to capture blow samples from five wild dolphins. Their data analysis showed that they were able to collect valid DNA samples;however, there was evidence of potential human contamination, bacterial genera that are uncharacteristic of the seawater conditions, and one unclassified genus of Methylobacteriaceae strains[6]. The greatest success at blow sample collection occurred when they collected from dolphins that were engaged in feeding activities or in a traveling behavioural state.

For a fixed wing approach on cetaceans, little work has been done. One of the only studies that has been found related to research on cetaceans is the work SnotBot has conducted [31]. The primary focus of this vehicle is to provide an affordable, user friendly method for offshore research, monitoring, and mapping of whales while optimizing the endurance of the mission. With the ability to hand launch, the team is able to save battery power that is typically used for takeoff on VTOL fixed wing vehicles to increase their flight time. For recovery, the vehicle is landed in the water for retrieval by the team. This vehicle has an endurance up to two hours with a wind tolerance of 28 MPH making it ideal for tracking cetaceans. This would allow a research team to conduct long distance tracking of a pod to gather data on behavioral characteristics of the pod.

Figure 10: SnotBot Fixed Wing Vehicle [31]

For cortisol sample collection, there has been little to no research found on using a fixed wing approach. However, previous studies have used collection mechanisms on fixed wing vehicles for aerobiological sampling that are relevant to this study. Maldonado-Ramirez [20] created a design that used petri dishes mounted below the wings and near the center of the wing chord of a fixed wing UAV which can be seen in the figure below.

Figure 11: Fixed wing pore sampling UAV [20]

This design proved to be effective with a total of 12,858 flights completed [20]. However, there proved to be poor dynamic stability with the aircraft when the collection mechanism was opened and closed during flight. When the mechanism was switched into the open configuration, the aircraft would suddenly begin to pitch nose down due to the large amounts of drag introduced[27].

Schmale designed an improved version of this device by moving the collection mechanism to allow for the petri dishes to be centered along the leading edge of the aircraft. This design was able to solve the dynamic stability problems from the Maldonado-Ramirez design. However, this design slightly reduced the effective lifting force of the wings by causing turbulent flow over the airfoil where the collection device was positioned. In addition, this design Incorporated industrial strength Velcro where the dishes were mounted to allow for easy detachment.

Figure 12: Redesigned Fixed wing pore sampling UAV [27]

2.3 Collection Device Material Analysis

Due to the sensitive nature of retrieving valid DNA from the blow samples, careful analysis must be conducted in order to ensure that the samples remain free of contamination. If the proper material is not selected, sterilization may become difficult to achieve and result in further contamination of the samples. Additionally, the material itself may leave pieces in the blow sample causing interference.

There is limited work on materials that are suitable for the purpose of blow collection. However, the work done provides options for suitable material. The most common materials that have been evaluated are cotton, nylon mesh, nylon veil, nylon stocking, polypropylene containers, and petri dishes[4]. Hogg conducted a study on the effectiveness of some of these materials. The results indicate that cotton left behind material that could cause interference in testing thus making it unsuitable for blow collection. The Millipore net showed little interference, however; it was not effective in absorbing enough of the liquid thus making it unsuitable as well. Nylon stocking was able to absorb the liquid easily but interfering compounds were noted if the stocking was not cleaned. The recommend cleaning method was sonication with 100% acetonitrile[17].

Additional work was conducted on different materials to provide better insight into valid options. The materials used were commercial nylon veil, nitex nylon mesh, and a polystyrene dish[4]. The results indicate that each sampled material was capable of identifying key DNA characteristic traits proving that each material could be a viable option for blow collection. However, the polystyrene dish proved to be the most effective surface for sample accuracy and precision which produced measures close to absolute value[4]. In the end, there are numerous viable sample types that can be used to collect blow samples. The material that should be used must remain inert in order to not contaminant any blow samples that are collected. The material chosen for a design should factor in ease of use, sample extraction methods, and overall sample quality.

Figure 13: Whale material sample collection test[19]

2.4 Operational Protocol Review

For the deployment of a UAS for research on dolphins, protocols need to be developed to ensure the safety of the mammals during the collection process. There are no official protocols in place for conducting research on dolphins; however, based on previous studies there have been suggestions established for operational procedures to ensure the safety of the dolphins when flying UAS in their presence. Behavioral responses are a huge indicator for establishing protocols on dolphin research using UAS. To test behavioral responses, it is recommended to fly a UAV at different heights above the marine mammals being studied to observe if the UAV elicits a behavioral response from the mammals being studied [29]. In addition, other various factors should be accounted for such as ambient noise of the area, species and age class of the mammals being studied, behavioral state before and after UAV exposure, presence and type of other nearby anthropogenic activites, UAS acoutics and visual properties, and UAS approach angle and speed [29]. Currently the work that has been conducted in this area has been limited; however, based on existing studies, a few protocols can be developed. Vehicles should not be flown below 30m for drones that are 2kg or under unless necessary for specific research requiring the vehicle to fly in close proximity to dolphins [25]. This would be ideal for cases such as research on pods where long distance travel is being tracked.

For close proximity research on cases such as biological sample collection and morphometric measurements where the vehicle has to be flown in close proximity to gather good data. General principles to minimize impact would be to avoid flying over mother and calf pairs, minimising flight time over the same group, avoiding close approaches in socializing groups, and to stop data collection in the observance of strong behavioral responses [25]. Overall, careful evaluation should be conducted before subjecting marine wildlife to UAV based research. The above listed protocols should help to ensure the safety and well being of marine mammals that are being sampled from using UAV's. A general overview of operational protocols used for drone research on marine mammals can be found in Figure

14.

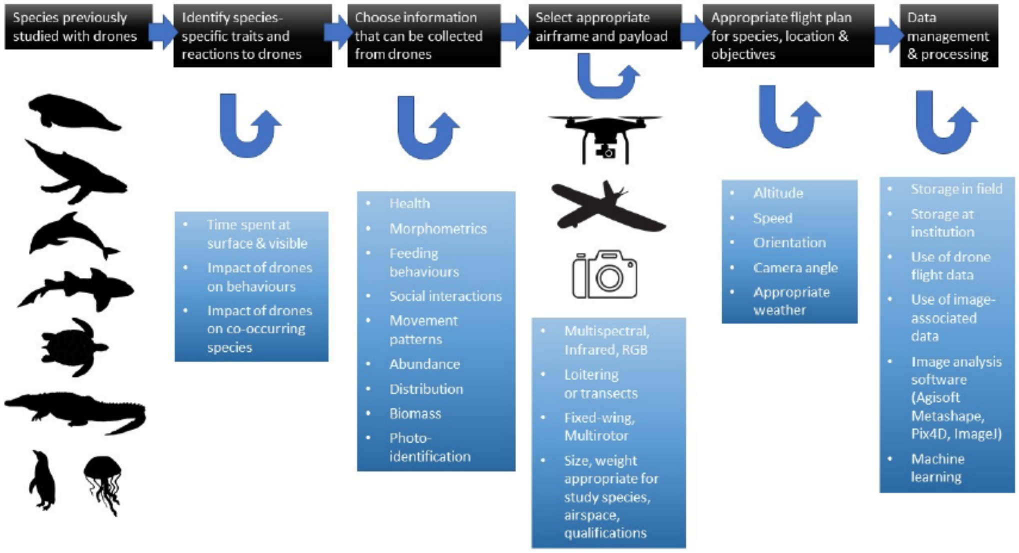

Figure 14: Operational protocol overview[25]

CHAPTER III

METHODOLOGY

3.1 Vehicle Selection

3.1.1 Airframe Selection

The selection of the airframe is an important aspect to this project. In this section, different airframes will be evaluated and down selected for the optimal design choice. The airframe must meet various criteria in order to be selected. These criteria are as follows.

- Capable of taking off and landing from small ship or boat
- System have a minimum range of 15 miles
- System have a minimum endurance of 1 hour
- Propulsion system that does not cause stress to dolphins

In order to best meet these criteria, a few different airframes were considered for this project. The first airframe that was explored was the Foxtech Nimbus. This vehicle is a fixed wing VTOL hybrid allowing for easy takeoff and landing without a runway. This configuration makes the Nimbus an ideal system for meeting the requirement that the vehicle must takeoff and land from a small boat or ship. A first person view (FPV) camera can be installed which is essential to allow the pilot to see and collect the cortisol samples. This system can be upgraded to include a Pixhawk autopilot bringing the total cost to around $3,000.

Another airframe that was evaluated was the DJI M600 Pro. This vehicle is capable of VTOL which would make it excellent for takeoff from a small ship or boat. Additionally the vehicle has the ability to carry a large payload up to 12 lbs. The vehicle comes with a camera from the manufacturer allowing for the pilot to more easily control the vehicle into the exhaled dolphin breath from a distance. Lastly, the vehicle is capable of way point missions allowing for easy flight to and from the launch point. The total cost with controller is around $7,300.

Another airframe that was evaluated was the ZOHD nano talon evo. The nano talon is a fixed wing vehicle that is hand launched making it easy to deploy in the field. This would allow easy takeoff from a small research ship or boat. The nano talon provides an excellent endurance range of over an hour on a single battery. The nano talon is a small lightweight vehicle that can easily be packed and setup in the field. The wings and v-tails are easily attached and detached allowing for installation with no tools required. Additionally, the front of the plane is designed to accept an FPV pilot camera and is designed to be modular with most FPV cameras on the market. The downside to the nano talon is the low communication range. With an X8R receiver, the range is limited to 1.5 km (0.93 miles). The range can be increased using a ground control station to boost the signal. An example of a component that can be used is the RFD 900+ which can increase range up to 40 km (24.8 miles). The cost of the vehicle with an ardupilot compatible autopilot, FPV camera, and airspeed sensor is $700. A plug and play (PNP) version can be purchased for $120 making the airframe easily replaceable in the event of a crash or damage occuring to the body. The PNP version comes equipped with motor, ESC, and servos installed but is missing the transmitter receiver, and battery. The total cost of the vehicle with autopilot, FPV, RFD 900+, and controller is around $1100.

Another airframe that was evaluated was the WingtraOne. The WingtraOne is a fixed wing, tail-sitter UAV that is capable of VTOL. This vehicle utilizes two rotors on each wing to power the system and works to lift the vehicle from the ground for vertical takeoff. The endurance of this vehicle is greater than multi rotor vehicles while still being able to preform VTOL. This vehicle is specifically designed for mapping purposes and has an integrated camera bay. This would serve well for searching and tracking dolphin pods. The total cost of this vehicle with ground station,batteries, and camera is around $21,100.

The following table contains an overview of airframes considered for this project.

Table 2: List of Airframes

Airframe	Range	Endurance	Takeoff Method
WingtraOne 	13 miles	0.98 hrs	VTOL
 ZOHD Nano Talon EVO	15 miles	1 hrs	Hand Launch
FoxTech Nimbus 	18 miles	0.75 hrs	VTOL
DJI M600 Pro 	3 miles	0.58 hrs	VTOL

The ZOHD Nano Talon was chosen due to a few reasons. First, the nano talon is a small lightweight vehicle that can be easily packed and transported. Additionally, assembly and breakdown of the vehicle is very simple with no tools required to assemble the wings and tail to the main body making the nano talon ideal for research on a small boat. Despite not being capable of VTOL like the other options, the nano talon can still takeoff in a very small space. The vehicle is hand launched capable making it easy to deploy from a small research ship or boat. Due to the nano talon being lightweight and relatively small in size and with the propeller located in the back behind a small skid guard, it is possible to hand catch the nano talon but not advised. Another solution to landing would be to catch the vehicle in a small net setup after takeoff or belly landing if there is enough space on the vessel.

Second, the nano talon provides the longest endurance out of all the vehicles selected meaning that the vehicle will be able to search larger areas for dolphin pods to sample from.

Utilizing a system to increase the telemetry range can be easily achieved without drastically increasing the price of the system which would further aid in operating in larger areas. The vehicle has a minimum speed of 6.5 kts according to the manufacturer which is slightly higher than a dolphins minimum cruise speed at 6.35 kts making it capable of being able to loiter behind the dolphin in most conditions.

Next, the nano talon remains the cheapest option out of all the other airframes considered even with upgrading the communication range making it ideal for incorporating into research of small cetaceans such as dolphins.

Furthermore, a fixed wing vehicle is ideal for this project in terms of acoustic effects. In general, fixed wing UAV's produce a less noise at a lower frequency level compared to that of multi-rotor vehicles that have to spin propellers at high RPM for flight. Another reason is due to the material used for the body of the nano talon. The body and wings are almost entirely made out of EPP foam making it lightweight. In the worst case of a potential crash into the dolphins, having a lighter aircraft made out of foam would be safer in terms of reducing the severity of an impact. Additionally, the nano talon uses a pusher propeller configuration for propulsion decreasing the chances of the propeller hitting a dolphin in the event of the vehicle colliding with the mammal. Last, the airframe is readily available at the lab through USRI making it an ideal platform for testing.

The Foxtech Nimbus will also be evaluated to test how a fixed wing VTOL hybrid performs for collection. A vehicle like the nimbus allows for the best option to increase the range and endurance of a fixed wing vehicle while still being able to take off and land vertically from the boat compared to multi-rotor vehicles. Therefore flight performance testing will be conducted with a nimbus as well.

3.1.2 Acoustics

With noise being a large factor in causing stress to dolphins, careful analysis must be conducted on the noise produced by the vehicle used for sample collection. In order to account for this, hearing characteristics of dolphins need to be known. The hearing frequency range of bottle nose dolphins can range from 75 to 150,000 Hz [28]. Research has shown that a frequency of around 1,000 Hz at 60 to 80 dB [14],[21] invokes a strong behavioral response from dolphins. The figures below show both an audiogram for a bottlenose dolphin and a Fourier transform of response amplitude of Rissso's Dolphin. Both these figures give a range of dolphin hearing while Figure 16 gives information on how dB at that frequency generates a response from a dolphin. The higher response amplitude indicates a stronger reaction to the noise generated at a higher dB.

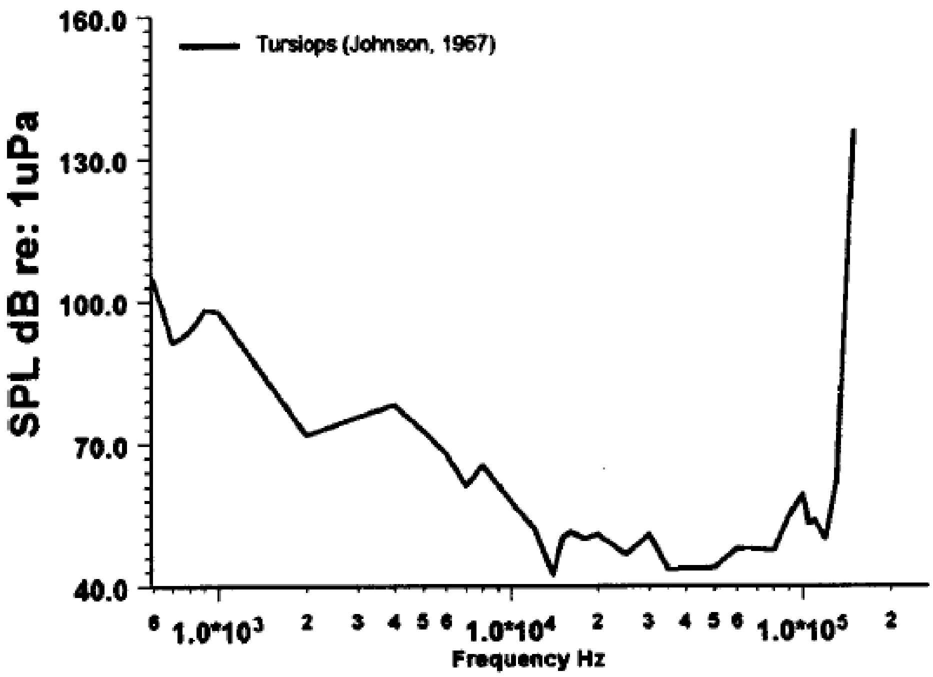

Figure 15: Bottlenose dolphin audiogram [3]

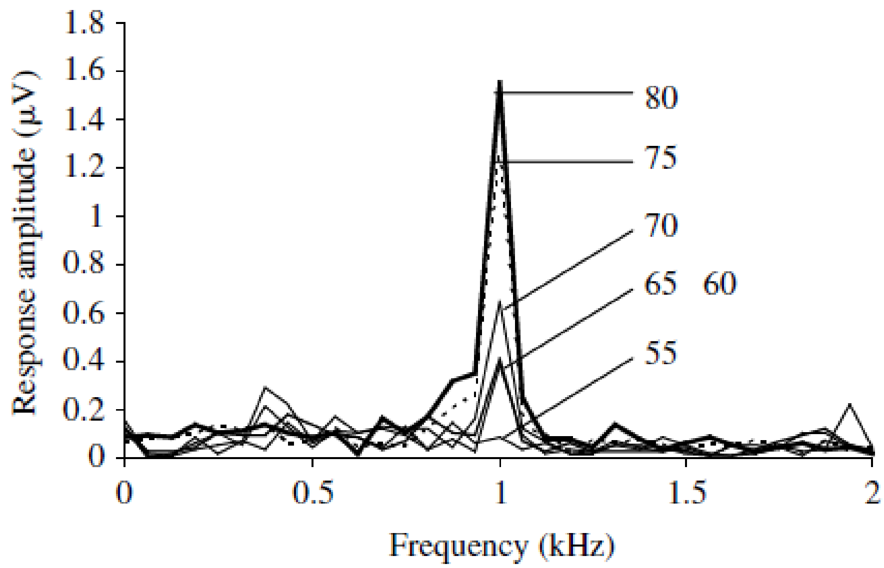

Figure 16: Response amplitude of Rissso's Dolphin[21]

The nano talon utilizes a ZOHD 2204-1870KV with a two bladed 6x3 inch propeller. Knowing the KV and number of blades on the propeller, an estimate of the produced frequency can be achieved using an RPM calculation and the blade passing frequency equation shown below.

$$RPM = KV * V$$

$$BPF = \frac{RPM * n}{60}$$

Where KV represents the motor KV, V represnets the voltage supplied to the motors from the onboard batteries, RPM is the rotation velocity, and n is the number of blades. Using the above equations and the specifications from the nano talon, an estimation of the frequency produced by the vehicle at max speed can be calculated. The nano talon can use both a 3S and 4S lipo battery which effects the power produced and the blade passing frequency. Table 3 shows the maximum values produced by the 3S and 4S batteries.

Table 3: BPF calculation

	3S	4S
KV	1870	1870
V	11.1 $volts$	14.8 $volts$
RPM_{max}	20,757 $\frac{rev}{min}$	27,676 $\frac{rev}{min}$
n	2	2
BPF_{max}	691.9 Hz	922.5 Hz

With the maximum RPM calculated, a plot can be generated to show how the BPF responds as RPM increases. Estimates for BPF at low speed to high speeds can be determined based on correlating max speed with max RPM to estimate RPM at a lower speed. The following equation can be used to estimate RPM at a desired velocity using the minimum and maximum RPM and velocities.

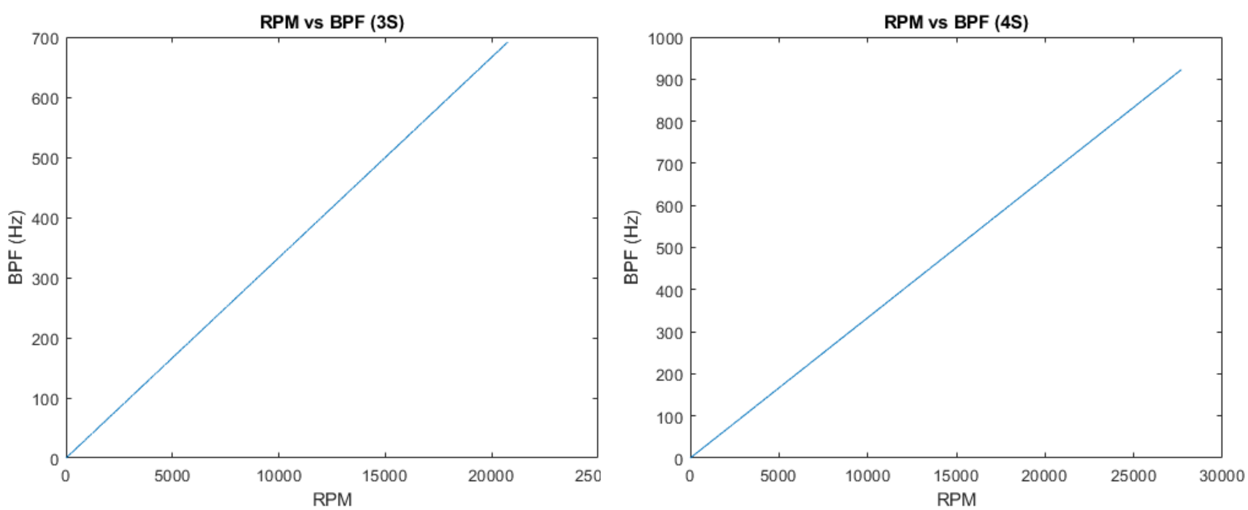

Figure 17: RPM vs BPF

$$RPM_{desired} = RPM_{min} + \frac{RPM_{max} - RPM_{min}}{v_{max} - v_{min}}(v_{desired} - v_{min})$$

To provide a more accurate estimation on the frequency that will be generated during most of the mission, cruise speed of the nano talon at 13 kts can be plugged into the above equation to provide a closer approximation of the blade passing frequency. Using the equation and the figure with a minimum speed of 6.5 kts knots and a max speed of 48 knots for the talon, the resulting RPM from the 3S battery is 3,251 $\frac{rev}{min}$ and from the 4S battery 4,335 $\frac{rev}{min}$ which results in a frequencies of 108.4 Hz and 144.5 Hz for the 3S and 4S batteries respectively. Both the maximum and cruise speed frequencies for both the 3S and 4S batteries are below that of the 1kHz that has been shown to elicit strong behavioral reactions from dolphins. The vehicle selected can perform the mission without causing harm in regards to induced stress from noise. Typical small fixed wing UAVs produce around 50 dB at 100 ft AGL[15]. Dolphins have a strong reaction to noise levels from 60 to 80 dB at 1,000 Hz indicating that a small fixed wing UAV would be under the noise level that would scare them at 100 ft AGL.

XROTOR was used to provide a replication of the noise level generated by the nano talon at a height of 3 ft above the water surface level to ensure that the noise generated by the vehicle will not cause stress to the dolphins being sampled on. XROTOR uses the propeller's geometry combined with the vehicle velocity, RPM, and motor power to be able to generate the dB footprint seen in Figure 18. The conditions were modeled for the nano talon's cruise speed of 13 knots providing the dB range for a from 5 ft behind the nano talon to 10 ft in front of the vehicle. The results indicate that the max noise is around 51.63 dB at 3 ft above the water surface level. These results indicate that the vehicle would be able to be used for sample collection without causing stress to the dolphins being sampled.

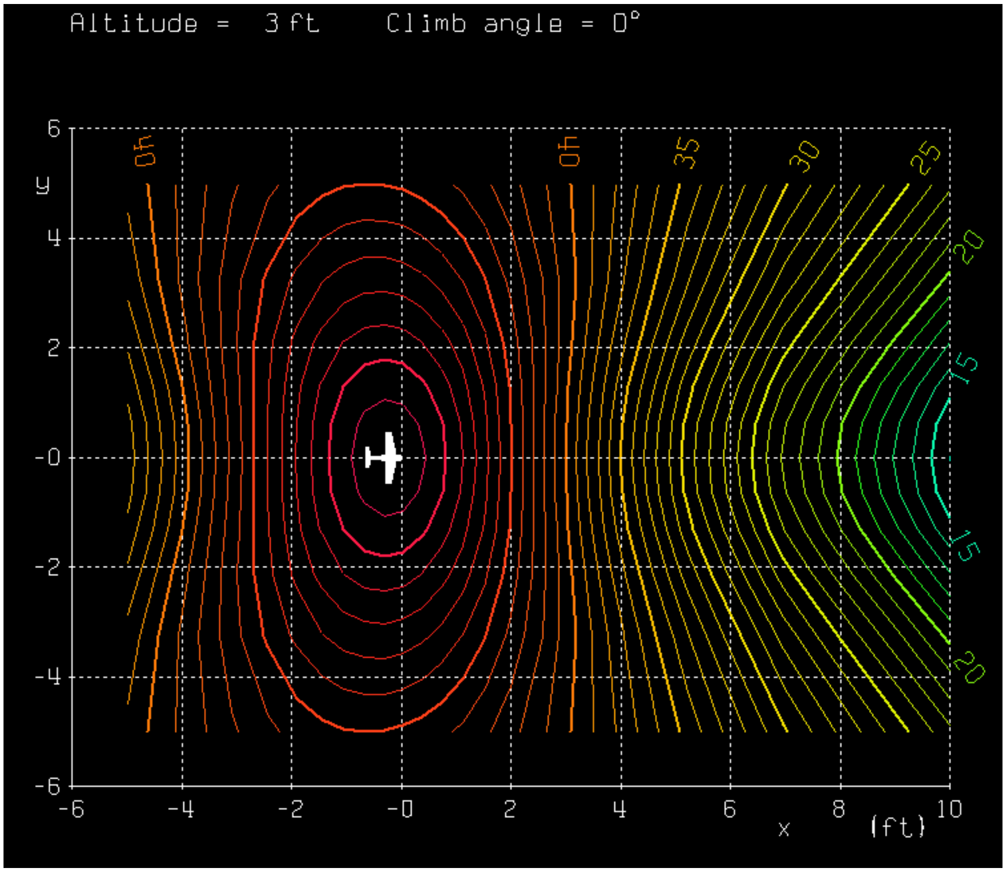

Figure 18: dB Footprint at 3ft

3.2 Sample Collection Mechanism Integration

With the vehicle selected, the capture mechanism will be designed and integrated with the vehicle. Based on the material analysis from the literature review, petri dishes have been chosen to be used for sample collection. The design must be able to keep potential contaminates out before and after sample collection. Therefore,the mechanism will use servos to operate the petri dish to be able to open and close during flight. Due to the large amount of drag produced by the petri dishes, careful selection on a high torque servo was conducted. First, the drag created by the petri dishes when opened to the freestream flow is estimated to help determine how much torque will be needed to open and close the servos. The following equations were used to determine both drag force and torque respectively.

$$F_D = C_D A \rho \frac{v^2}{2}$$

$$\tau = r F_D$$

Tables 4 and 5 contain both the input parameters and the resulting torque values corresponding to velocity. For the parameters, the coefficient of drag was estimated for a circular plate perpendicular to a freestream flow; the area, A, is the inside area of the petri dish; the velocity,v, is the freestream velocity acting on the petri dish; and the length of the arm, r, that rotates the servo.

Table 4: Parameters

C_D	1.12
ρ	$4.427 \times 10^{-5}\ \frac{lb}{in^3}$
A	$9\ in^2$
r	$4.8\ in$

Table 5: Torque range

Velocity ($knots$)	Force (lbs)	Torque ($Oz - in$)
9.72	0.022	1.72
19.43	0.0.089	6.87
29.15	0.201	15.456
38.87	0.358	27.478
48.59	0.559	42.935
58.30	0.805	58.304
68.02	1.096	68.022

Based on the calculations, high torque servos are necessary for operation of the collection mechanism. The servos that were selected were based on torque produced as well as size and weight. The servos that were selected were the SAVOX SV1250MG high voltage servos for the wing mounts. Additionally, industrial-strength Velcro is used to hold both the bottom and the lid of the petri dish in place to allow for easy removal for biological testing of the collected breath.

The collection mechanism will be integrated on the wings of the nano talon. For the design of the wing mounts, the airfoil shape of the nano talon was modeled using SOLIDWORKS. A clamp was designed to form around this airfoil shape with a panel to allow a servo to be attached to. These clamps will be located on each wing and will allow for the servos to open and close when installed. Each petri dish and lid is held on using industrial strength velcro to allow for the dishes to be removed after sample collection for analysis of cortisol levels. The servos that open and close the petri dishes use metal servo horns to keep the arms attached to the dishes stable when operating. The servos are powered and controlled through the autopilot which has different output ports that provide 5 volts.

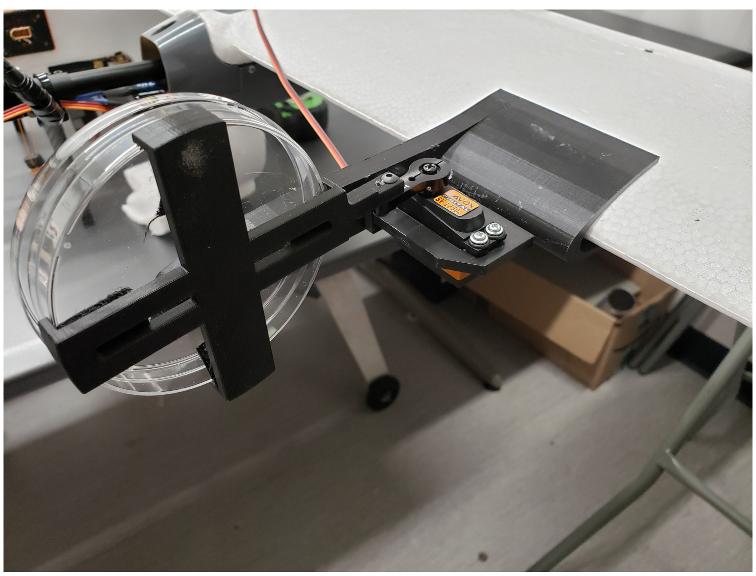

Figure 19: Leading Edge Collection Mechanism

3.3 Chuffsim Experimental Setup

To test the effectiveness of sample collection from a UAS, an experimental method is needed to replicate the characteristics of the blowfield emitted from a dolphin before testing is performed on a live dolphin. A device has been created by Barton at Oklahoma State University [2] to be able to replicate the dolphin blowfield. This device that was created will be referred to as Chuffsim from this point on. Chuffsim is capable of of producing an impulse at flow rates of approximately 44 to 84 $\frac{liters}{sec}$ for a duration of 0.25 to 0.35 seconds which is dependent on the nozzle geometry. Chuffsim produces flow rates that are within the range of flow rates measured from live dolphins; however, Chuffsim is not capable of producing the max range measured from wild dolphins. Flow rates measured from dolphins have been found to range from 20 to 140 $\frac{liters}{sec}$. A diagram of the components used to create Chuffsim can be seen in Figure 20.

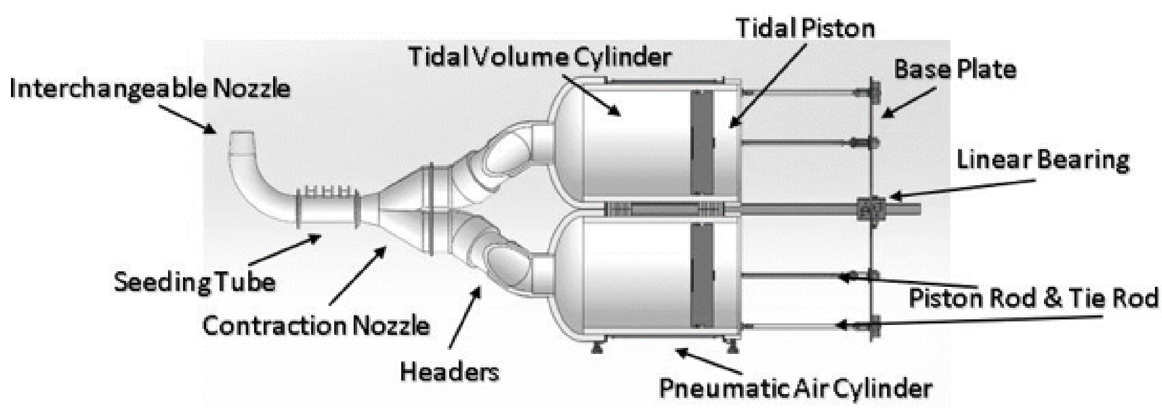

Figure 20: Chuffsim Diagram[2]

Chuffsim operates by using a linear piston cylinder setup where the pistons are driven from top dead center (TDC) to bottom dead center (BDC) through the use of four solenoid-valve actuated air cylinders. The device requires approximately 120 psi of compressed air @10 SCFM to power the hydraulics that compress the air in the cylinders of the apparatus. Chuffsim initiates the impulse at the press of a button. The total volume cylinder capacity is oversized (47.2 liters) to compensate for fluid leaks in the system. The volume expelled is controlled by adjusting the stroke length or by-passing cylinders in the system via the contraction nozzle. The cylinder's exhausts join into one contraction nozzle that attaches to a 3D printed geometry of a dolphin nasal passage which can be seen in Figure 21.

The nasal passage geometry was obtained through a CT scan taken of a one-year old cadaver dolphin by the Integrative Biology department. The original CT scan went through an iterative design and modification process to get the geometry into a useable format. The geometry was scaled-up to an adult sized nasal-passage using a 20/13 ratio based on the relative head size of the cadaver dolphin[2].

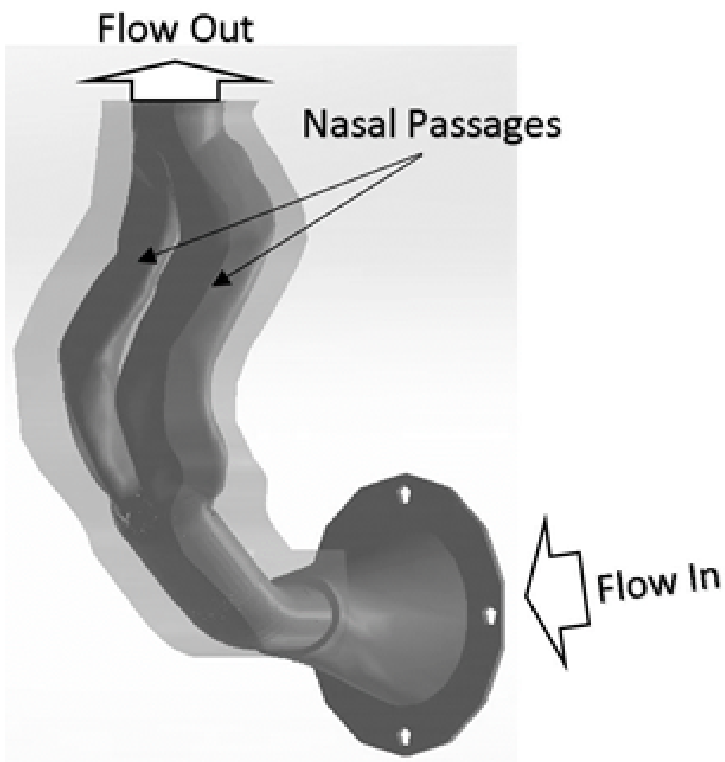

Figure 21: Dolphin Nozzle Nasal Passages[2]

For implementation of this system for use in testing the effectiveness of UAS collection, seeding must be selected to attempt to provide a replication of the blowfield that will be sampled. In order to seed the system, a tube section was developed to allow for testing of liquid based seeding. The seeding tube that was developed for this purpose can be seen in Figure 22.

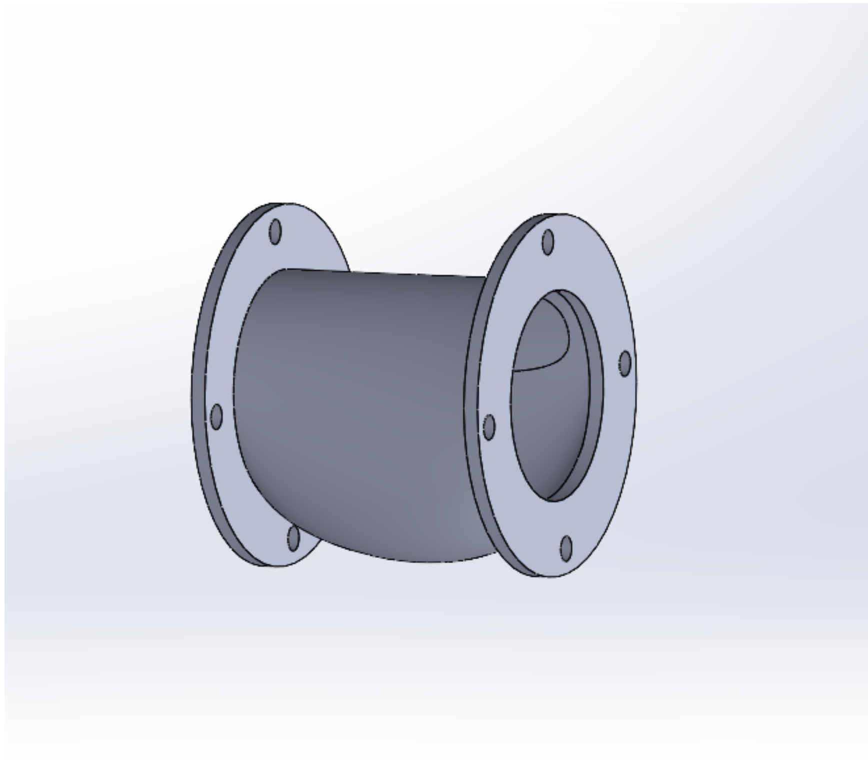

Figure 22: Seeding Tube

This tube has a bottom bowl that will allow for the liquid based seeding to sit in. When the Chuffsim is fired, the flow will cause the liquid to be sprayed out with the flow. Various types of seeding will be evaluated in order to find what will work best for flight tests. The seeding types can be categorized into two groups. The first is liquid based seeding and the next is powder based seeding. For the liquid based seeding, the various types that will be tested are colored water, a 50/50 glycerin water mix, glycerin, and cornstarch and water mixed together. The goal for these tests is to test from a low viscosity fluid to a higher viscosity fluid.

For the powder based, the seeding types that will be tested are climbing chalk, a chalk/glycerin mix, and a chalk/sprinkle mix. The goal for these tests is to provide a better visual image of the spread of the blowfield for field tests. Two different exhaust nozzles will be tested to evaluate the spread of the seeding amongst the different seeding types. These nozzles can be found in the below images. The first that will be tested can be seen in Figure 23 and will be referred to as the open nozzle. This nozzle has a gradual incline in from base to tip to create a jet flow out of the tube. The next nozzle that will be tested can be seen in Figure 25 and will be referred to as the dolphin nozzle. This nozzle is a replicated dolphin nasal passage that was 3D printed and will provide the most realistic case for field tests.

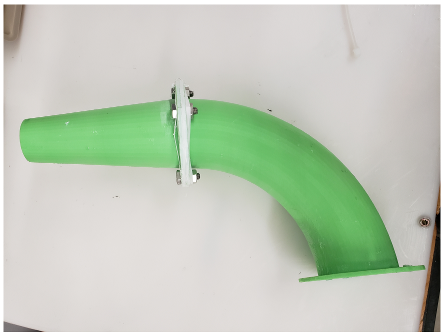

Figure 23: Chuffsim Open Nozzle

Figure 24: Open Nozzle Opening

Figure 25: Chuffsim Dolphin Nozzle

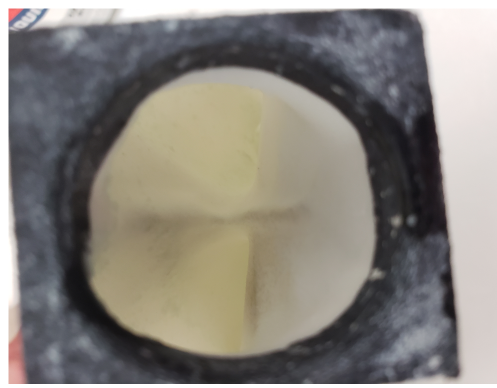

Figure 26: Dolphin Nozzle Opening

For testing, a certain procedure will be followed to maintain consistency. First, the 30 gallon air tank used to provide air to the pneumatic cylinders on Chuffsim will be filled with a small air compressor to 120 *psi*. Once filled, the regulator on Chuffsim will be set to 90 *psi*. After, the base plate will be pulled all the way back and then pushed in approximately a quarter inch. This will set the pistons from TDC to BDC at a similar volume of a dolphins lung capacity. The seeding will then be applied through the nozzle where it will collect in the seeding bowl. Once the seeding is added Chuffsim is ready to fire. To fire, a switch is pressed causing the pneumatic cylinders to actuate the pistons from BDC to TDC.

In order to validate chuffsim, flow meter testing was conducted to measure the exhaled flow rate at different pressures. This data will prove crucial in comparing flow rates generated by chuffsim to actual flow rates from dolphins. In order to do this, flow meters developed by Andreas Fahlman were placed over the opening of the nozzle. Figures 27 and 28 are the flow meters that will be used for testing.

Figure 27: Dolphin flow meter

Figure 28: Killer whale flow meter

For experimental testing, chuffsim will be setup for numerous test runs. First a mounting surface will be placed at the opening of the nozzle to create a flat plane to ensure a good seal with the flow meter. The purpose of this is to make sure that the flow exiting the nozzle travels into the flow meter and does not leak into the surrounding area. A gasket will be placed between the mounting surface and the tip of the nozzle to provide a better seal. Additionally, the flow meter will be pressed down into the mounting surface to keep flow from exiting around the seal of the flow meter. Once the table is setup, the tank will be filled to 120 psi. From here, the pressure to the pneumatic air actuators will be changed throughout the duration of the testing. These ranges will be from 30 psi to 110 psi to create a profile for volumetric flow rates. Testing will start at 110 psi and will be worked down to 30 psi in increments of 10 psi. Once at 30 psi, an additional 30 psi test will be conducted and then test runs will be increased by 10 psi until reaching 110 psi to create a full test profile. All tests will be conducted using the dolphin nozzle to obtain the flow rates that chuffsim produces for a comparison to measured flow rates from a dolphin. Additionally, this will provide key information on what set pressure values will produce a corresponding flow rate to allow for precision controlling of the flow rates produced by chuffsim.

Figure 29: Flow meter test setup

3.4 Flight Test Techniques

In this section, the flight tests techniques will be detailed. The tests will consist of using a multi-rotor UAV to replicate current methods of testing with whales and dolphins and compare that with fixed wing flights. This will provide information on the effectiveness of the design of the capture mechanism based from replicated current designs with the multi-rotor UAV used. Testing will be done with the fixed wing vehicle to determine the overall spread on the body of the aircraft. A petri dish will be mounted to the nose to help aid in the observation of sample collection. The final test will be to use the designed capture mechanism to collect samples generated from the Chuffsim. For all tests, both liquid and powder based seeding will be used. First, liquid based seeding will be tested followed by powder based seeding. For the nozzle, the dolphin nozzle will be used for each test due to the higher volumetric flow rate achieved with this nozzle. Additionally, this nozzle will provide better replication of the blowfield that would be seen from a wild dolphin.

The first test that will be conducted is to use a multi-rotor vehicle to fly into the replicated blow of the Chuffsim. This is to provide a comparison of current work being conducted on whales and dolphins that utilize multi-rotors. The multi-rotor being used is a 3DR solo that is equipped with petri dishes that are attached using industrial strength velcro. The operational procedure is as follows. The petri dishes will be cleaned using isopropyl alcohol and a non-abrasive cloth to wipe it down. This serves to clean out any contaminates that may hinder test results. Once the petri dishes are cleaned and installed to the bottom of the solo, the propellers will be installed in the correct manner as indicated by the 3DR solo guidelines.

Once the propellers are installed, the 3DR solo will be powered on and connected to the flight controller by the pilot. After the flight controller is connected and the aircraft is verified by the pilot to be flight ready, Chuffsim will be setup. In order to replicate the blowfield, Chuffsim will be placed near the runway at the flight field with the seeding loaded in. Once Chuffsim has been armed and ready to fire, the multi-rotor will take off and loiter in the blowfield generated by the Chuffsim.

Figure 30: Multi-Rotor Setup

After the replicated chuff has been collected, the vehicle will land and analysis will be conducted on how effective the the multi-rotor approach was in collecting samples. Wind direction and speeds will be accounted for during each test. Different runs will be conducted at different heights above the nozzle. These heights will be at 1 ft and 3 ft above the nozzle. This will help determine the optimal range for collection heights above the nozzle for the next set of tests and help determine a maximum range for chuff collection.

The next set of testing will be to use a fixed wing vehicle with a pertri dish taped to the nose to fly through the plume. As with the multi-rotor setup, Chuffsim will be set up near the runway and primed to fire. Once setup, the fixed wing vehicle will be prepared for take off. Preflight procedures will be conducted by the pilot to ensure the vehicle is flight ready. This will include connecting the battery, checking the center of gravity, connecting the vehicle to the flight controller, and the checking input with the control surfaces of the vehicle. The vehicle body will be checked and cleaned of any debris to ensure that there is no interference for the test results.

Once the vehicle is ready for flight, the pilot will initiate takeoff and fly toward Chuffsim. After takeoff, the vehicle will attempt to fly through the generated blowfield from Chuffsim. After flying through the blowfield, the vehicle will land where an analysis will be conducted on the spread of the seeding on the fuselage and the inside of the dish. This will identify the overall spread on the vehicle to highlight key areas of collection. The vehicle will be flown at approximately 3 to 4 feet above the nozzle for the tests. The vehicle that will be used for the fixed wing flights is the nano talon which can be seen in Figure 31.

Figure 31: Fixed Wing Vehicle

For the final test, the modified nano talon with the sample collection devices will be used to fly through the generated blowfield of Chuffsim. In this test, the collection mechanisms will be evaluated to determine how effective they are at sample collection. As with the other tests, Chuffsim will be placed near the runway and primed to fire. The 30 gallon air tank will be maintained at 120 *psi* to ensure consistency during the testing. For the preflight procedures, the petri dishes will be attached to the wing mounts. Once attached, they will be cleaned of any debris using isopropyl alcohol and a non-abrasive cloth. The pilot will then perform tests on the sample collection mechanisms by actuating the servos to ensure that all sample collection mechanism operate as they should before flight. The pilot will also verify that all the control surfaces on the nano talon are operational before flight.

After the pilot verifies that the vehicle is flight ready,the nano talon will take off and fly towards Chuffsim. At this time all the sample collection mechanism will remain in the closed position as they would in actual sampling. The nano talon will fly towards Chuffsim and will attempt to fly through the generated blowfield. Right before reaching the blowfield, the pilot will operate the sample collection mechanism into the open position to allow for the petri dishes to be exposed to the incoming airflow and blowfield. After flying through the blowfield, the sample collection mechanisms will be closed by the pilot and the vehicle will land. Once landed, an analysis will be conducted on how much seeding is located within the sample collection devices. The vehicle will be flown at approximately 3 to 4 feet above the nozzle for the tests. This will determine the spread characteristics at this height and will provide information on the ideal sample range for future work with sample collection from live dolphins.

Figure 32: Nano Talon with Sample Collection Mechanisms

CHAPTER IV

EXPERIMENTAL RESULTS

4.1 Collection Mechanism Flow Analysis

4.1.1 Wind Tunnel Tests

Before flight tests with the capture mechanism, preliminary ground testing was done in order to provide validation for the system. This is done in order to resolve potential issues that could occur before equipping the system onto a vehicle. Additionally, this is done to provide support to validate that the capture system could obtain samples during flight tests. The designed wing mounts were tested in a wind tunnel to determine if the servos could operate the collection mechanism under flight speeds for collection. The collection mechanism was placed inside a small wind tunnel attached to an airfoil section and was tested at various speeds from 5 to 25 $\frac{m}{s}$. It was found that the servos could operate under all conditions up to 25$\frac{m}{s}$ which is the max speed of the wind tunnel. Due to the dolphins max speed of approximately 8 $\frac{m}{s}$, the servos used in the collection mechanism are capable of completing the mission.

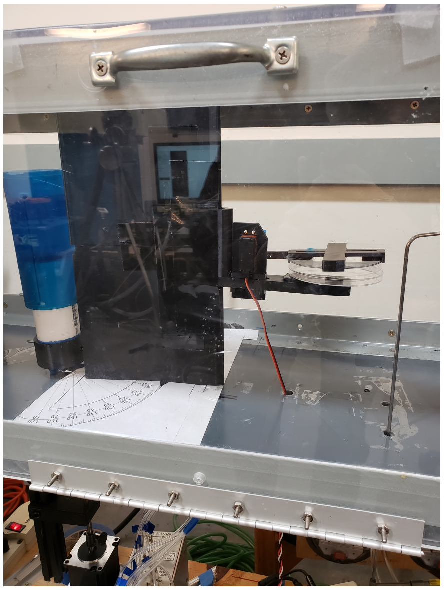

Figure 33: Closed configuration

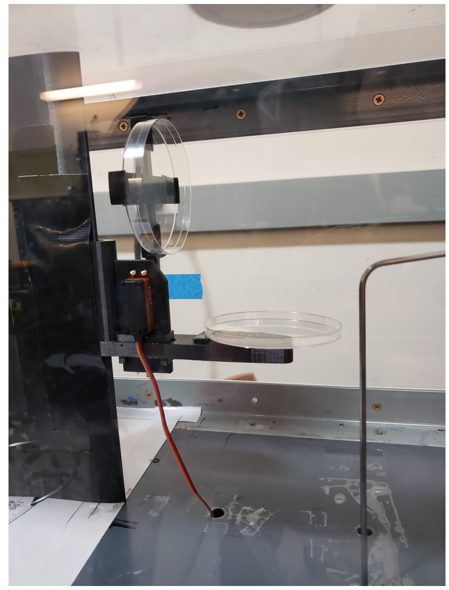

Figure 34: Open configuration

In order to determine the flow interaction with the inside of the petri dish, flow visualization was conducted. For the flow visualization, all tests were conducted in a wind tunnel setup in an open configuration at 6 m/s. Fog was inserted into the flow for seeding. Results from the test can be seen in the images below. These images clearly indicate that the flow enters the center of the dish and collects inside the dish with minimal flow escaping from the sides. There is minimal flow exiting the sides. Figure 36 shows how the flow separates behind the dish when the dish is opened into the flow. It can be seen that there is a fair amount of flow separation behind the dish.

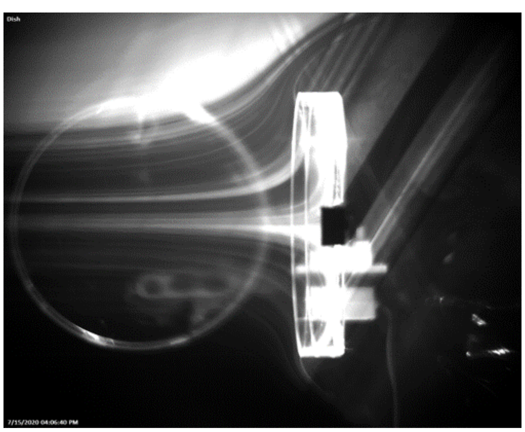

Figure 35: Flow visualization inside dish

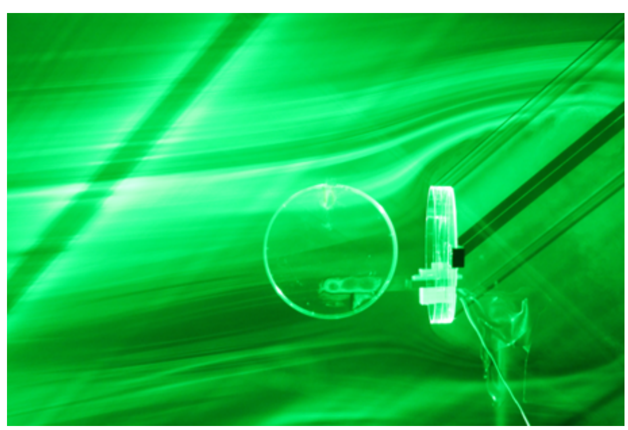

Figure 36: Flow visualization around dish

4.1.2 PIV Results

Further testing was done to determine greater detail on the flow interaction inside the dish. These tests were conducted in a water tunnel at various speeds to determine flow interaction with particle image velocimetry (PIV) used for evaluation. Water tunnel speeds were related to dolphin speeds at low cruise, high cruise, and max speed. The first being at a water speed of 0.2 m/s which is the equivalent of 3.27 m/s for dolphin speed. This was accomplished using Reynolds number calculation which can be seen in the below equations.

$$Re = \frac{\rho V c}{\mu}$$

$$Re_{air} = Re_{water}$$

$$\frac{\rho_{air} V_{air} c}{\mu_{air}} = \frac{\rho_{water} V_{water} c}{\mu_{water}}$$

Where Re represents Reynolds number, ρ is the densities of air and water, V is the velocities for air and water, c is a constant, and μ is the dynamic viscosity of the fluid. Using these equations, the velocity of water in the water tunnel can be related to what the perti dish will see in the air when in flight. Rearranging the last equation above to solve for water velocity yields the the below equation.

$$V_{water} = \frac{\mu_{water}}{\mu_{air}} \frac{\rho_{air}}{\rho_{water}} V_{air}$$

This equation relates the water velocity inside the water tunnel to the air velocity the petri dish will see when trying to match the different dolphin speeds. The below table shows the relation between air speeds and water speeds for dolphin low cruise speed, high cruise speed, and max speed.

Table 6: Water Tunnel Speeds

$V_{water}(\frac{m}{s})$	$V_{air}(\frac{m}{s})$	$V_{air}(MPH)$
0.2	3.27	7.31
0.3	4.90	10.96
0.5	8.18	18.30

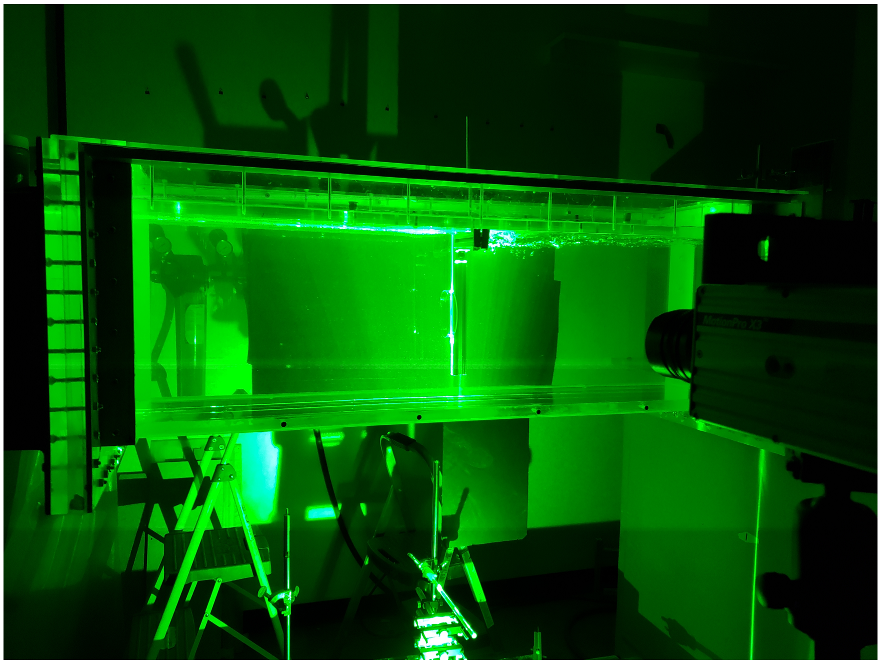

Figure 37: Water Tunnel Setup

Each water tunnel velocity was tested inside the water tunnel with PIV computed using a software called DaVis. The results of the tests can be seen in the images below. It can be seen in each case that the flow collects inside the dish. The blue areas are the flow at the water tunnel speed. The black areas are places were the flow is practically zero. The images show that the flow enters the inside area of the dish where it begins to decrease in speed and practically stops by the time it hits the back of the dish indicating that the blowfield would collect once hitting the inside of the dish with minimal flow separation around the outside edges of the dish.

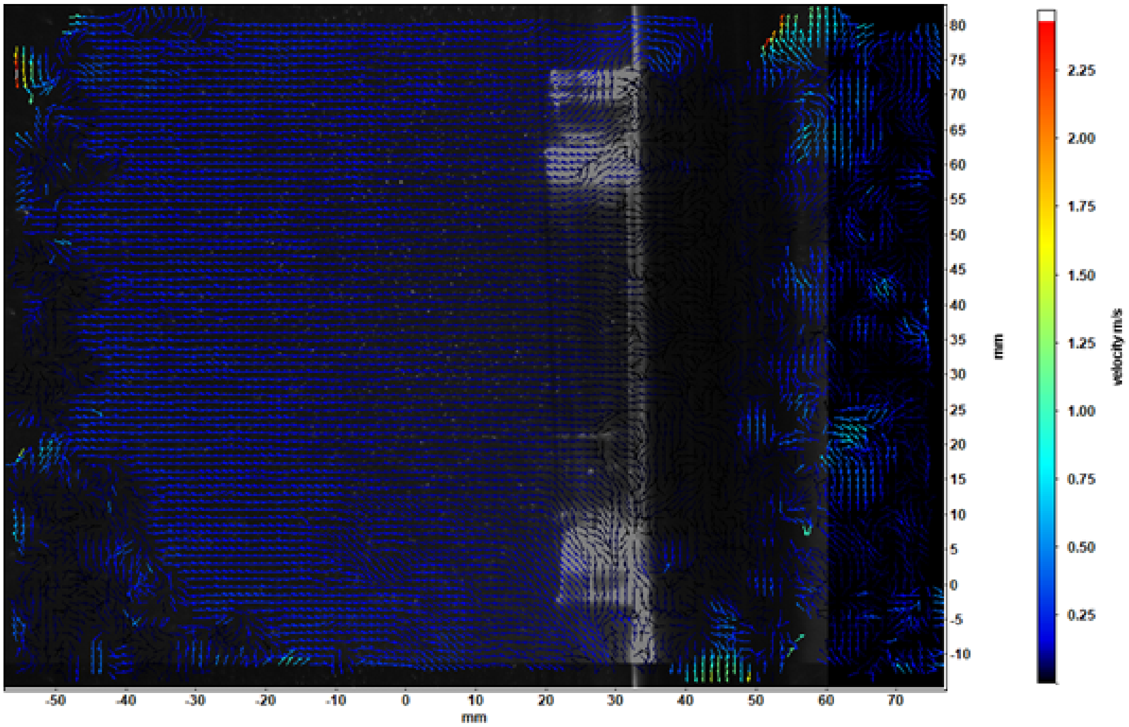

Figure 38: PIV at 0.2 $\frac{m}{s}$

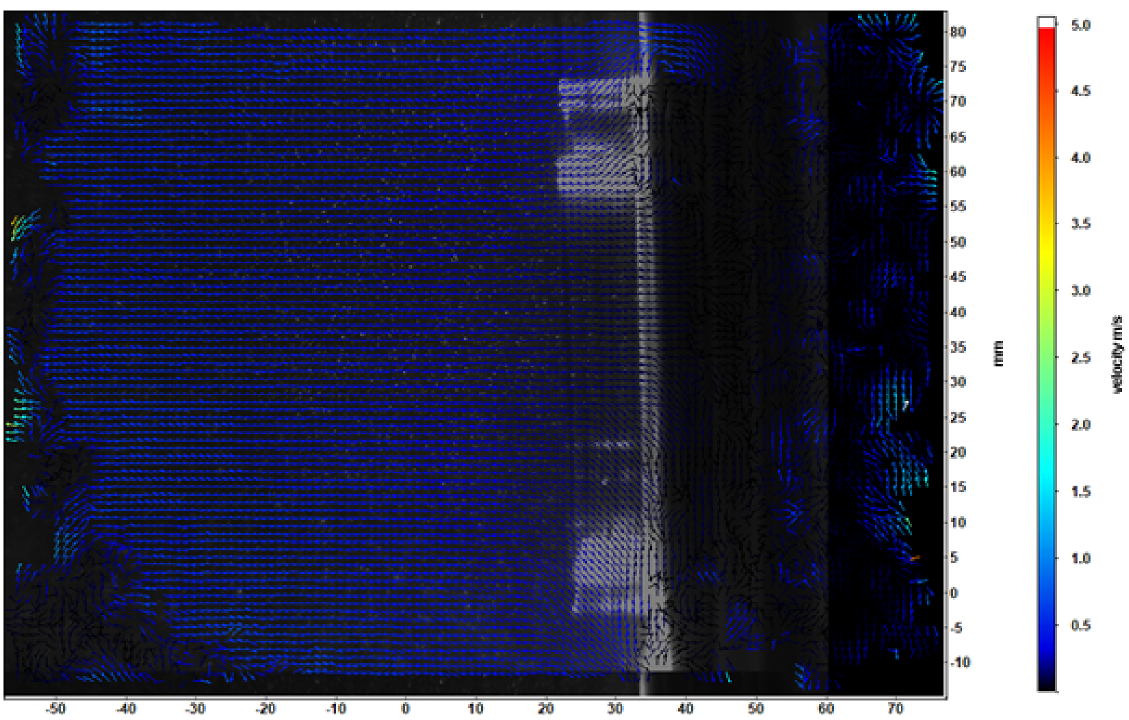

Figure 39: PIV at 0.5 $\frac{m}{s}$

4.2 Chuffsim Seeding Tests

As mentioned before, Chuffsim will be a key part for testing the capture mechanisms. Preliminary testing was done to test the seeding that will be used in the flight tests to ensure consistent results. Each test consisted of loading Chuffsim with the seeding and shooting it on to a piece of white foam board. Different seeding was tested to find an ideal solution for testing. The seeding types are split between liquid based and powder based. For the liquid based, the seeding types were colored water,glycerin, a 50/50 glycerin water mix, and a cornstarch/water mixture. For the powder based, the seeding types were climbing chalk and a chalk/glycerin mix.

Initial testing was done with all mixtures listed above with a piece of foam board placed at 3 feet above with the open nozzle used. For the glycerin testing, the glycerin remained within the seeding tube when Chuffsim was fired producing little to no results on the foam board. For the 50/50 glycerin water mix, the seeding was able to be fired out of the nozzle; however, the majority of the seeding remained within the seeding tube which lead to a minimal visible spread on the foam board. For the cornstarch/water mixture, when Chuffsim was fired the mixture inside the seeding tube hardens under the pressure resulting in little to no seeding produced from the nozzle. The most successful liquid based case came from colored water.

From here both the open nozzle and the dolphin nozzle were tested with water as the seeding. The previous cases were not tested with the dolphin nozzle because of the problems faced with getting good results. For the open nozzle results, testing was conducted at both 3 feet and 6 feet above the nozzle to determine the overall spread. The results of the open nozzle water seeding tests can be found in the figures below.

Figure 40: Open nozzle water test (3ft)

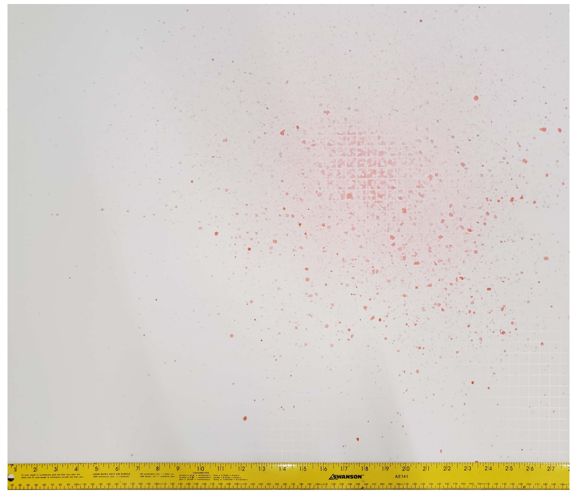

Figure 41: Open nozzle water test (6ft)

As can be seen from the images, the seeding begins to spread further and does not remain as uniform as it doubles in distance. The concentration from the 3ft test remains within a relatively tight group with a large part of the seeding staying in the middle with smaller particles spreading past the middle area. For the 6 ft test, the heavy concentration in the middle begins to spread out further and does not remain as uniform like the 3ft case. Additionally with the 6 ft case, the smaller particle droplets are spread further away from the middle of the concentrated center.

Testing was done next with the open nozzle swapped with the dolphin nozzle on Chuffsim. The dolphin nozzle will provide a more accurate representation of what will be seen in the wild with live dolphins providing for the best case for replication for field tests with Chuffsim. The results from the water based seeding tests with the dolphin nozzle can be seen below.

Figure 42: Dolphin nozzle water test (3ft)

Figure 43: Dolphin nozzle water test (6ft)

As can be seen from the images, the seeding begins to spread when the distance is increased. The spread area is much larger for the 3 ft test compared to the 6 ft test. There are a large number of particle droplets that extend past the middle section of the spread for the 3ft case while still remaining relatively close to the middle section of the spread.

For the 6ft case, the spread does not cover as large of an area. This was in part due to the middle section of the spread shifting lower on the foam board causing the particle droplets to be located further from the middle section and resulted in partial seeding loss of the outer diameter that is greater than the coverage area of the foam board. Additionally, the spread of the seeding from the 3 foot case to the 6 foot case begins to move more from the left side to the right side. In terms of relating to the dolphin nozzle geometry, this shift occurs from the port side to the starboard side of the dolphin. This shift is due to the structure of the dolphin nasal passage. Specifically, the port side of the nasal passage is effected by the shape of blowhole due to a lip at the top of the nasal passage on the port side. This lip causes interference and obstructs part of the exit flow causing a shift in the spread of the seeding [2]. Figure 44 provides a representation on the orientation of the nozzle in regards to port and starboard side of the dolphin nozzle.

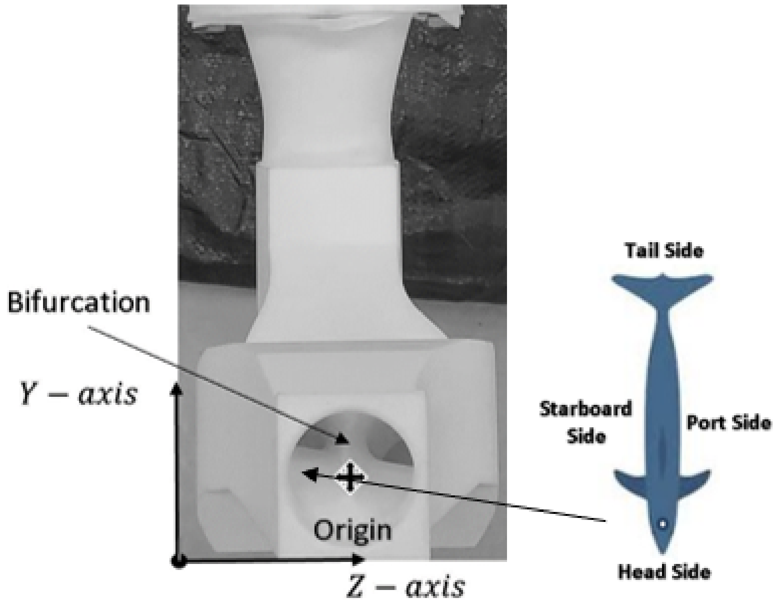

Figure 44: Dolphin nozzle coordinate system[2]

Testing was next conducted with powder based seeding. Previous tests have been conducted by Barton [2] that showed the spread from the nozzle using both chalk and glitter. Barton's results were similar to those derived from the water seeding tests where the open nozzle has a more concentrated spread compared to that of the dolphin nozzle. A mixture of glycerin and chalk was tested next to attempt to replicate a blowfield with more of a mucous like spread.

These tests were conducted with a petri dish placed in the center of the foam board to observe the interaction of the seeding with the actual dish and to observe the spread of the seeding across distance. To start, all tests were conducted with the foam board at 3 feet above the nozzle. The first nozzle that was tested was the open nozzle configuration.The results of the tests can be seen in the below images showing the spread of the seeding.

Figure 45: Open Nozzle Results

Figure 46: Open Nozzle Petri Dish Results

As can be seen in the above images, the seeding stays within a fairly concentrated area with larger particles not spreading far from the center and the overall spread can be found within a 15x17 inch area in the foam board. The image below shows a close up of the petri dish. There are numerous small particles from the chalk that can be seen in the center of the dish. A few of the larger particles made it inside the dish as well. These results indicate that the chances of collecting large samples may very case by case and will prove difficult to replicate consistent results. Additionally, due to the low amount of particles that were found on the foam board and inside the dish, testing at 6 feet above the nozzle was not conducted.

Figure 47: Open Nozzle Petri Dish Close Up

The dolphin nozzle was tested next to compare with the open nozzle tests and to try to replicate a more realistic scenario that will be seen with dolphins in the wild. This nozzle showed a further spread in the overall area of the seeding. The seeding area increased to approximately 16x29 inches which shows that the width nearly doubles with the different nozzle. The results from the tests can be seen below. As with the open nozzle tests, this nozzle was only tested at 3 feet above the nozzle due to low count of seeding picked up on the foam board and inside the dish.

Figure 48: Dolphin Nozzle Results

Figure 49: Dolphin Nozzle Petri Dish Results

Next, chalk was tested for seeding. These results were focused on testing the overall collection of seeding inside the dish. Like the other cases, both the open nozzle and dolphin nozzle were tested for a comparison. For each test, $\frac{1}{4}$ cup of chalk was placed inside chuffsim for the simulated chuff. For the open nozzle, the 3ft case had a uniform spread like what was exhibited in the water tests. A large amount of seeding remained was able to be collected inside the dish. With the 6ft case for the open nozzle, the spread of the blowfield was greater at this distance. Additionally, the chalk become finer at this distance and had a much smaller particles as compared to the 3ft test. Particles were still captured inside the dish; however, the particles that were collected were smaller in size and fewer in quantity. Both Figures 50 and 51 show the collection results inside the dish for both the 3ft and 6ft case respectively.

Figure 50: Open Nozzle chalk test (3ft)

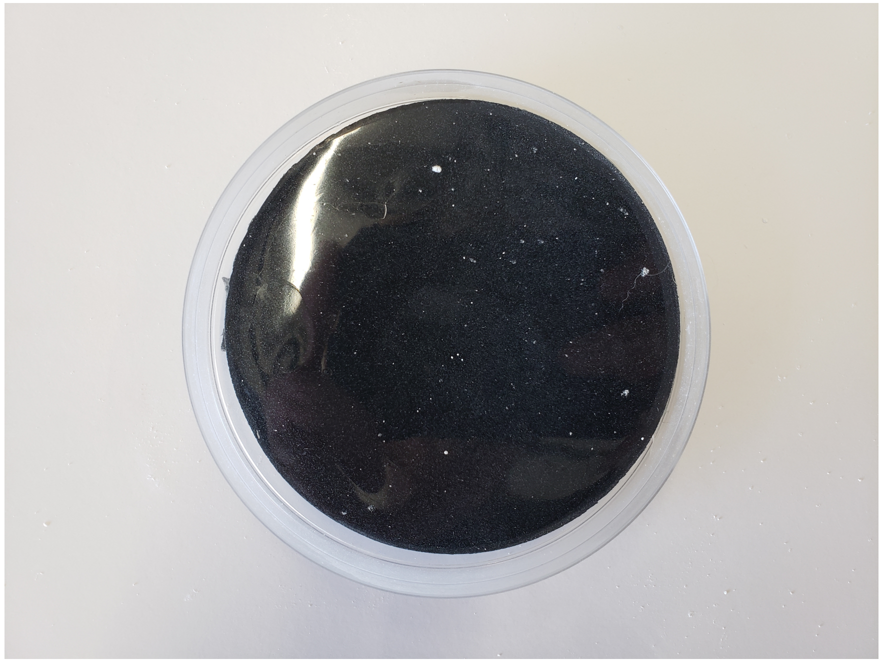

Figure 51: Open Nozzle chalk test (6ft)

Testing was conducted next with the dolphin nozzle at both 3ft and 6ft above the nozzle. Like with the open nozle test, $\frac{1}{4}$ cup of chalk was loaded into the chuffsim for each test run. For the 3ft case, a large amount of chalk was collected inside the dish. Additionally, there was further spread outside the dish area with a heavy concentration being produced corresponding to the head side of the nozzle. For the 6ft case, the accumulation of chalk was reduced compared to the 3ft case. This was due to the chalk becoming finer with the increase in distance. The results produced are greater in particle size and quantity compared to the open nozzle case. Due to the concentration of chalk at both 3ft and 6ft from the dolphin nozzle tests, the dolphin nozzle will be used for field testing.

Figure 52: Dolphin Nozzle chalk test (3ft)

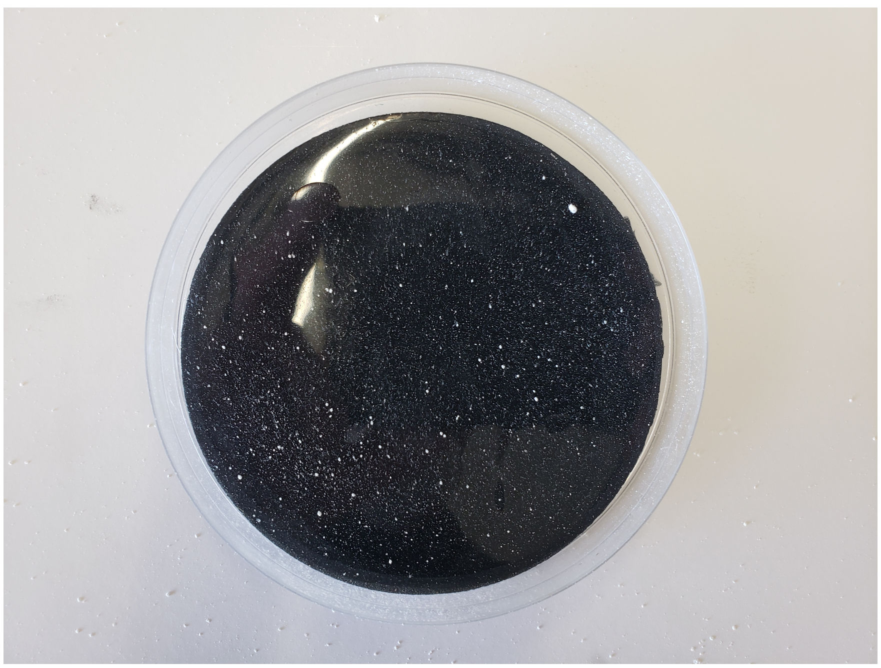

Figure 53: Dolphin Nozzle chalk test (6ft)

Additional testing was done for flow visualization of the blowfield using fog for the seeding. The purpose of this testing was to get visual results of the blowfield as it spread with distance. Both the dolphin replica nozzle and the open nozzle were tested. For these tests, the open nozzle top section was separated to allow for a larger exit diameter. Fog was placed at the inlet of the nozzle where the back plate on chuffsim was pulled back to pull the fog into the cylinders. The surrounding fog was cleared from the test area and then chuffsim was fired to release the fog inside the cylinders. This provided a visual replication of the blowfield. The results for the dolphin nozzle and open nozzle can be found in Figures 54 and 55 respectively. These figures show the spread characteristics of the blowfield with the lines approximating the mean radius of the blowfield as it spreads. It can be seen that the blowfield for the dolphin nozzle begins to spread further with increasing distance compared to the open nozzle where the flow stays relatively close in a tighter concentration. This confirms the results found from the seeding tests were the blowfield diameter increased with increasing distance.

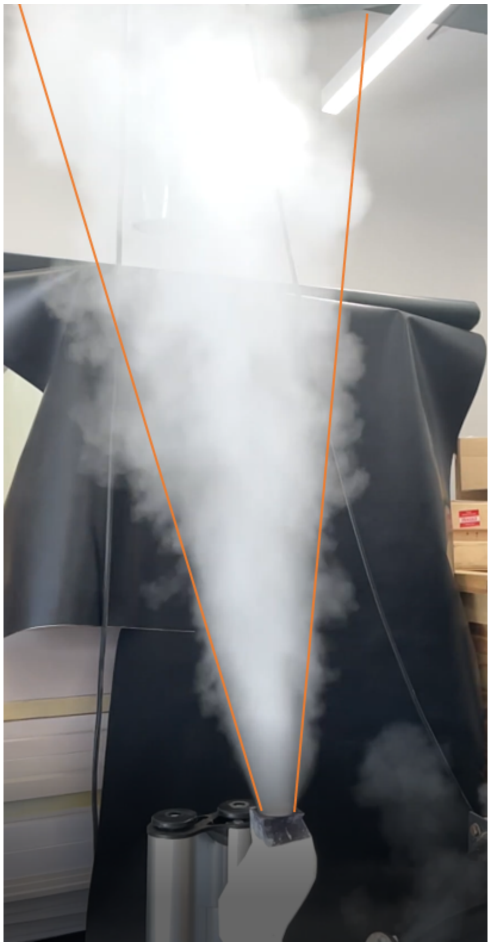

Figure 54: Dolphin nozzle flow visualization

Figure 55: Open nozzle visualization

4.3 Flow Rate Testing

For flow rate testing, a flow meter was attached to the end of the dolphin nozzle to measure the flow rates produced to ensure that chuffsim could replicate similar flow rates exhibited by dolphins. There were three test runs conducted for each trial run. These three runs were compiled and the results are shown in Figure 56. It was found that the resulting flow rate matched well with previous tests conducted by Barton. Additionally, this data falls within in the 20 to 140 L/s that has been found to be exhibited by dolphins in the wild [10]. This data proves critical for being able to replicate different flow rates for testing at different set pressures from chuffsim. Sealing to provide accurate results proved to be a challenge during data collection. This could result in the lower flow rate measurement at 90 psi. This is also demonstrated by the larger deviations seen in the 90, 100, and 110 psi test runs.

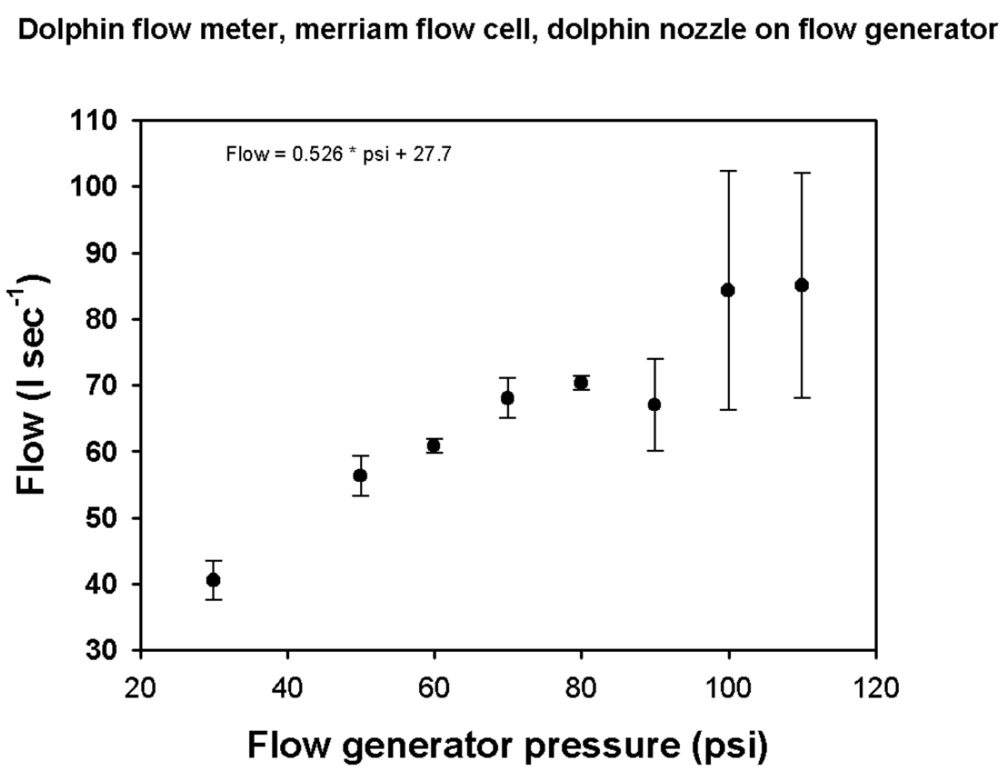

Figure 56: Flow meter results: dolphin nozzle

4.4 Flight Tests

4.4.1 Collection Mechanism Vehicle Performance Testing

Vehicle performance is an important factor to the design of the capture mechanism and sample collection process. A stock ZOHD nano talon EVO is the vehicle being used for collection. With specifications from the manufacturer, an evaluation of the performance of the vehicle can be estimated using an online program eCalc. Range was calculated based from the cruise speed of the talon and the maximum flight time using the below equation.

$$R = t_{max} * V_{cruise}$$

The specifications for the stock nano talon can be found in Table 7 and will serve as a base comparison for seeing the change in specifications when the capture mechanism is installed to the stock nano talon. For both tables, a speed of 30 MPH is used.

Table 7: COTS Nano Talon Vehicle Specifications

Endurance	Range	Weight
1.15 hrs	34.5 miles	1.29 lbs

With the capture mechanism installed, the overall weight increases. Due to this weight increase, endurance and range will decrease. Using eCalc and the range equation provides an estimation for how the endurance and range are effected with the change in weight due to the capture mechanism which can be seen in Table 8.

Table 8: Modified Nano Talon Vehicle Specifications

Endurance	Range	Weight
0.93 hrs	27.9 miles	1.92 lbs

In addition to endurance effects, handling and flight performance is also important to the integration of the capture mechanism to the stock nano talon. Two primary designs were made to be integrated on to the nano talon for the capture mechanism. The first used a wing mount were the collection petri dishes opened perpendicular to the leading edge of the wing. This design proved to be ineffective due to the large amount of flow separation over the wings. Initially, it was thought that the collection mechanism was too heavy for the aircraft; however, further testing was done where just the petri dishes were taped perpendicular to the leading edge of the wing to reduce weight from not including the entire capture mechanism and to concentrate on performance of the aircraft from just the dishes being open along the leading edge themselves. This test proved that the petri dishes mounted to the leading edge cause a large amount of drag and flow separation that the vehicle is not capable of generating enough lift for takeoff.

Figure 57: Leading Edge Wing Mount

Another wing mount was developed for testing. This wing mount has the collection petri dish mounted to the bottom of the wing. The servos open the lids of the petri dish as can be seen in Figure 59. This orientation reduces the drag experienced from the leading edge mount in the previous design.


Figure 58: Bottom Wing Mount


Figure 59: Open Dish Configuration

The vehicle was able to fly with the bottom wing mounts. Weight proved to be a slight issue with the aircraft with a larger 5200 mAh 4s battery. With this heavier battery, the vehicle had a difficult time elevating up. Additionally due to the weight tighter turns in the air were not possible. Regardless of the weight issue, the vehicle was still able to successfully fly. The collection mechanism was successfully operated into the open configuration during flight and produced no stability issues or change in performance of the aircraft at high cruise speeds. To achieve better flight control performance, a lighter 2200 mAh 4s battery was used which reduced the weight of the vehicle. This change to a smaller battery reduces the endurance of the aircraft; however, due to the control issues with the heavier battery, a lighter battery was more effective. With this reduction in weight, the vehicle was able to reduce some of the elevating issues as seen with the heavier 5200 mAh 4s battery. Flight performance changed when the dishes were opened. During a simulated approach with the aircraft flying slow with the dishes open, winds could cause the aircraft to slightly sway in the direction of the wind. Despite this, the vehicle was able to maintain its path in wind speeds from 6 to 20 MPH. The heavier the winds, the more difficult the vehicle had to maintain the flight path.

4.4.2 Spray Flight Testing

For the multi-rotor test, a 3DR solo was used as a control on what is currently being used for cortisol collection. The vehicle was flown directly above the nozzle in hover with water being used for the seeding. The vehicle was flown about 2 ft above the nozzle of chuffsim to attempt to collect some of the seeding. No water droplets were discovered inside the dish after the test. This was suspected to be due to the down wash produced from the rotors and wind conditions.

An additional test was conducted were chalk was used for the seeding to better visualize the seeding. A petri dish with a sticky pad placed inside the dish was mounted to the bottom of the 3DR solo and flown directly above the dolphin nozzle. The 3DR solo was flown directly above the nozzle in hover at approximately 3 ft above the nozzle. No chalk particles were detected inside the petri dish despite being directly in the blowfield. An additional test was conducted next where the solo was lowered to approximately 1 foot above the nozzle. From this test it was obvious that the rotor down wash had a major effect on the chalk seeding. When the chuffsim was fired, it was observed that the majority of the chalk blowfield quickly traveled down and never reached the petri dish. Figure 60 shows how the rotors effect the blowfield generated from the chuffsim.

Figure 60: 3DR Solo Collection Test

Despite the majority of the flow traveling around the dish, traces of chalk were found on 3 of the 4 propellers and on one of the arms of the landing gear. Figures 61 and 62 show the traces of chalk discovered after testing.


Figure 61: Chalk traces on propellers


Figure 62: Chalk particles on landing gear

These results show that using a multi rotor vehicle to collect for cortisol would be relatively ineffective depending on the location of the collection unit. It is possible to collect from underneath the drone; however, the petri dish was positioned directly above the nozzle and resulted in no chalk collected. A sweeping option would be better where the vehicle either flies through the blow field or where the vehicle remains behind and the blowfield travels into the vehicles path.

Additional testing was conducted with chalk and sprinkles used for the seeding. This was to see if the denser sprinkles would be significantly effected like the chalk was in the previous tests. For the first tests, the 3DR solo was flown at approximately 3ft above the nozzle. Three test runs were conducted at this height. The results produced are found in the Table 9. For the first run no particles were collected. This matched results found in the chalk only seeding case. For the second test run, 4 sprinkles were collected with one small chalk particle. Figure 63 shows the collected particles from this test run. For the third run, only 2 particles were collected which consisted of 1 sprinkle and 1 chalk particle.

Table 9: Chalk Multi Rotor Tests (3ft)

Flights:	Run 1	Run 2	Run 3
Number of particles:	0	5	2

Figure 63: Multi rotor sample collection results 3ft

Due to the low particle count at 3ft, the height was lowered to 1 ft above the nozzle. This was tested primarily to observe the interaction of the blowfield at this point where the blowfield is more concentrated. Three tests were run at a height of 1ft above the nozzle. The first run produced a greater amount of particles compared to the 3ft tests with 9 sprinkles collected and 5 small chalk particles. The second run yielded a high amount of particles collected inside the dish. The results were 18 sprinkles and approximately 31 chalk particles. The high quantity could be due to overloading chuffsim with seeding compared to other runs. In this run a higher quantity was loaded in compared to the normal $\frac{1}{4}$ cup of chalk and $\frac{1}{8}$ cup of sprinkles. The amount of sprinkles was around $\frac{1}{4}$ cup. There was also numerous particle marks found on the body of the 3DR solo. For the third test run, $\frac{1}{4}$ cup of chalk and $\frac{1}{8}$ cup of sprinkles was added. This run produced a lower amount compared to the second run with 3 sprinkles and two chalk particles collected.

Table 10: Chalk Multi Rotor Tests (1ft)

Flights:	Run 1	Run 2	Run 3
Number of particles:	14	49	5

For the first fixed wing flight test, a nano talon was used to determine overall spread over the body, the vehicle was flown through a simulated blowfield generated by Chuffsim. This run used colored water for the seeding to determine what the spread over the body of the nano talon would be. A petri dish was mounted to the front of the vehicle in order to help determine how effective sampling would be in the dishes.

Timing proved to be a challenging issue when collecting. The chuffsim was either fired too soon resulting in the vehicle not flying through the blowfield or the chuffsim was fired too late causing the vehicle to be in at the end of the blowfield or not in the field at all. After numerous attempts, the timing was achieved and proved that sampling was possible. Figure 64 shows that the petri dish was able to collect the colored water from the blowfield.

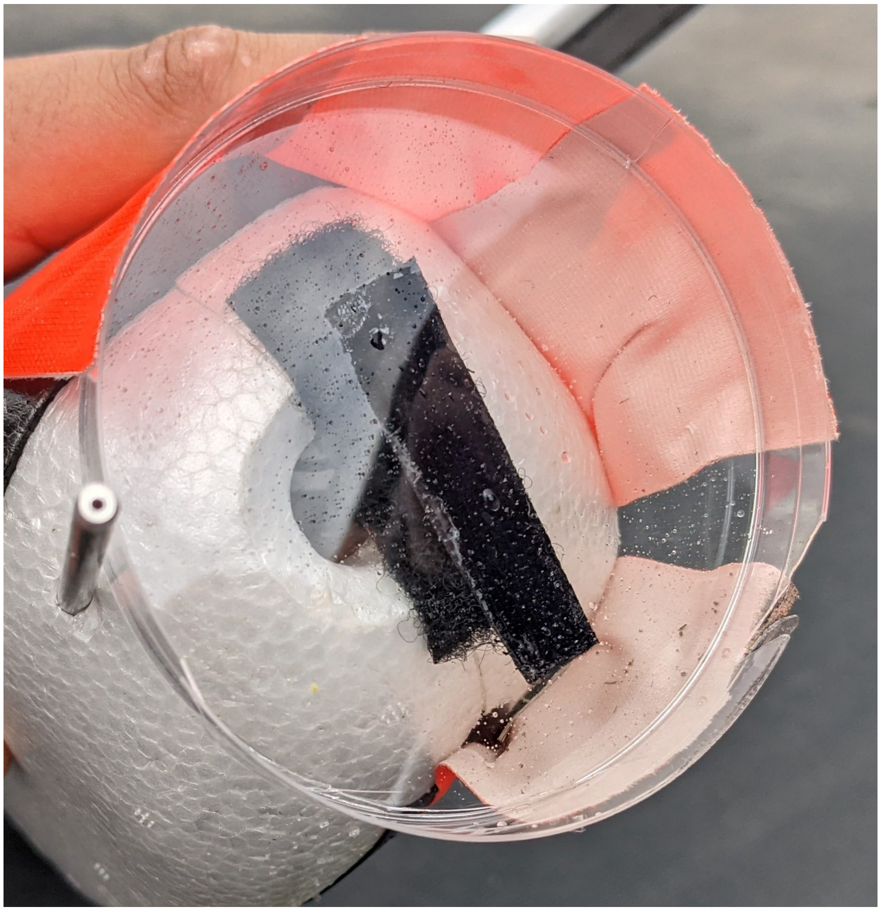

Figure 64: Sample collection test

The body of the vehicle was inspected for water droplets; however, the droplets were not detectable on the body either due to the droplet size being too small or because the droplets dried out before landing. For this reason, chalk was tested next.

For the chalk tests, $\frac{1}{4}$ cup of climbing chalk was loaded into the chuffsim for each run. As with the water tests, timing proved to be a challenging issue. Wind speeds were monitored during the test and were recorded at around 5 kts in the SSW direction. The chalk plume was effected by the wind direction adding to the complexity of the collection. It was noted that during wind gusts, that the plume would shift with the wind direction making it difficult when lining the vehicle up with the center of the nozzle to attempt to collect samples. Predicting the direction of the plume was difficult at times due to the travel of the plume even in relatively light winds. Sudden gusts would occur when lined up with the nozzle causing the plume to miss the vehicle when it was lined up with the front of the nozzle. Additionally, at times when the vehicle was lined up with the area the plume had shifted to, the wind would die down causing the plume to remain in the area above the nozzle. In order to capture the chalk, a sticky pad was placed inside the petri dish as seen in the figure 65.

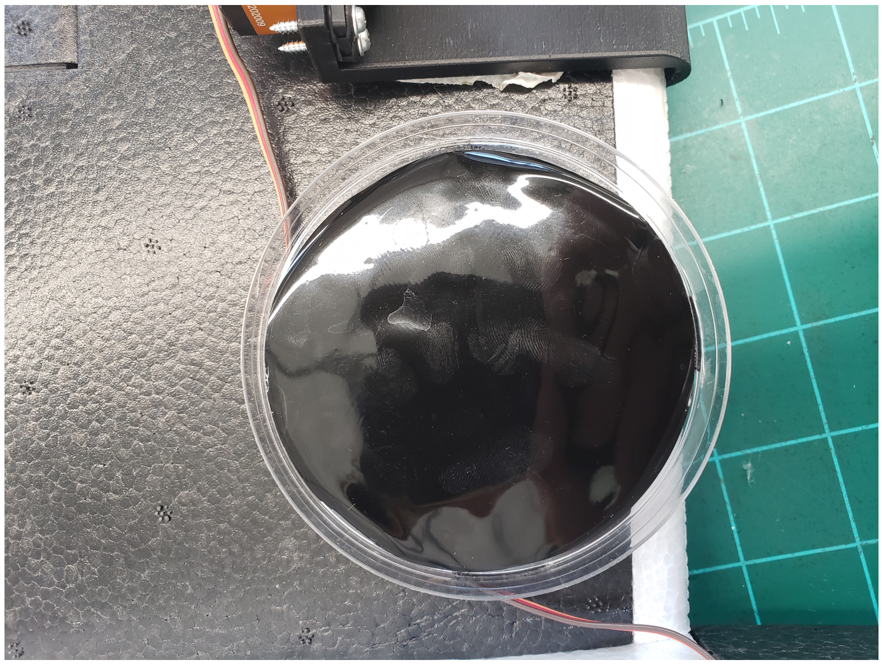

Figure 65: Chalk collection dish

Despite the issues faced with lining up with the plume, the vehicle was able to make it through the plume successfully three times. After each pass through, the vehicle was landed and the dishes were inspected for particles of chalk. The results from all three runs can be found in Table 14. The number of particles accounts for the total found in both dishes after flying through. In the second run, the port side wing mount contained the majority of the small particles compared to the starboard side wing mount. In addition, pieces of glitter were found inside the dish from previous tests where glitter was used for seeding. Because of the relatively small amounts of seeding located within the dish, a heavier particle seeding was used next.

Table 11: Chalk Fixed Wing Tests

Flights:	Run 1	Run 2	Run 3
Number of particles:	2	6	4

Figure 66: Chalk Flight Test

For heavier seeding and an attempt to replicate "chuff", nonpareil sprinkles were used next combined with chalk. This was to provide a denser seeding that maintained a larger particle size to attempt to replicate the mucus found in dolphin's chuff and to alleviate the difficulties from the chalk seeding runs tested previously. Chuff is defined as a mixture of water particles, air, and mucus; therefore, for these tests, the nonpareil sprinkles were used to represent the large segments of mucus that can be found in a dolphin's chuff. Initial testing proved difficult to capture any samples; however, this was primarily due to high wind conditions from 15 to 20 kts averaging wind gusts of 16 kts. The seeding was either spreading too quickly or the flow over the wings was causing the samples to miss the dish mounted to the bottom of the wing. Testing was done in lower wind conditions with wind speeds of 8 to 10 kts. For these tests, the bottom wing mounts were used to test the effectiveness with the sprinkle/chalk mix. Additionally double sided tape was put on the leading edge of the wings to determine if there was any seeding hitting the edge of the wings. Separate tests were conducted after the primary testing of the bottom wing mounts where a single petri dish was attached to the nose of the nano talon to determine the effects of flying through the plume versus flying above the plume. The complete setup with the front petri dish and double sided tape attached can be seen in Figure 67.

Figure 67: Collection Test Setup

Three separate test runs were conducted with just the double sided tape on the wings and the bottom wing mounts. These tests consisted of flying the vehicle at a height approximately 2 to 3 ft above the nozzle. The timing for firing chuffsim focused on attempting to fire once the vehicle was almost directly above the nozzle for optimal collection. Each test run proved successful in capturing some particles. The particles that were collected varied in each case. For the first case run, one sprinkle was collected inside the starboard side petri dish and one sprinkle was found on the tape on the starboard wing.

For the second test run, 5 sprinkles were found in the starboard petri dish with some larger particles of chalk as well which can be seen in Figure 68. In addition, the wing mount that was on the starboard side had traces of chalk located on the servo arm, servo, and the mount itself. Figure 69 shows the petri dish with sprinkles collected, the splatter located on the bottom wing mount and a single sprinkle collected by the double sided tape. For the port side, only one chalk particle smear was recovered.

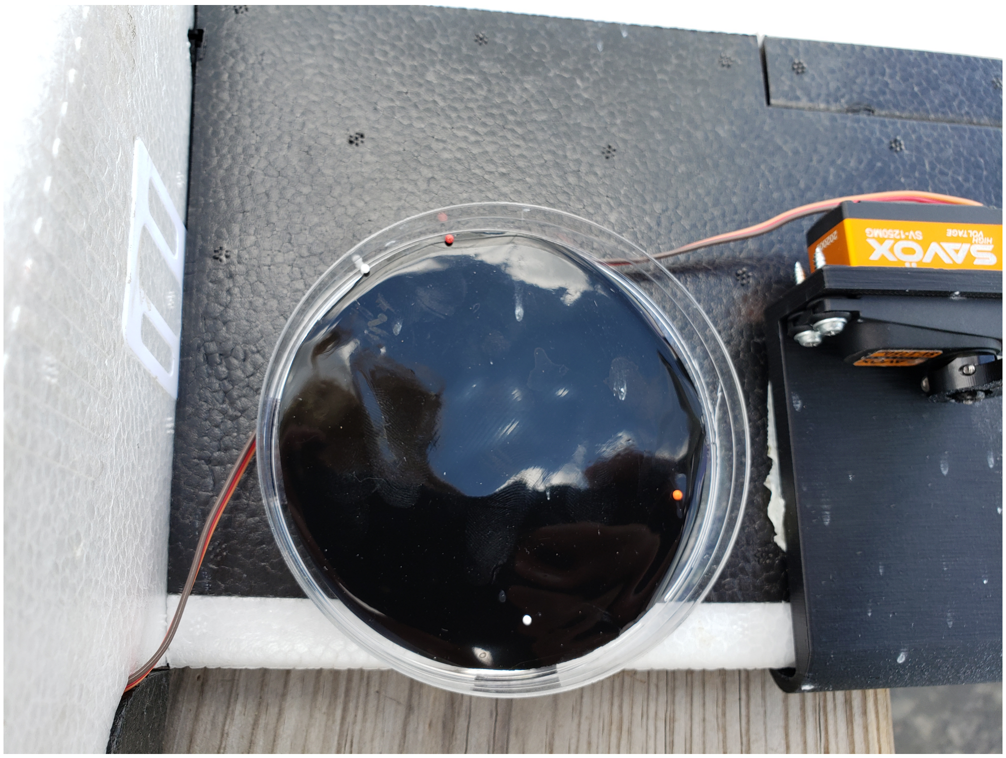

Figure 68: Bottom mount best run

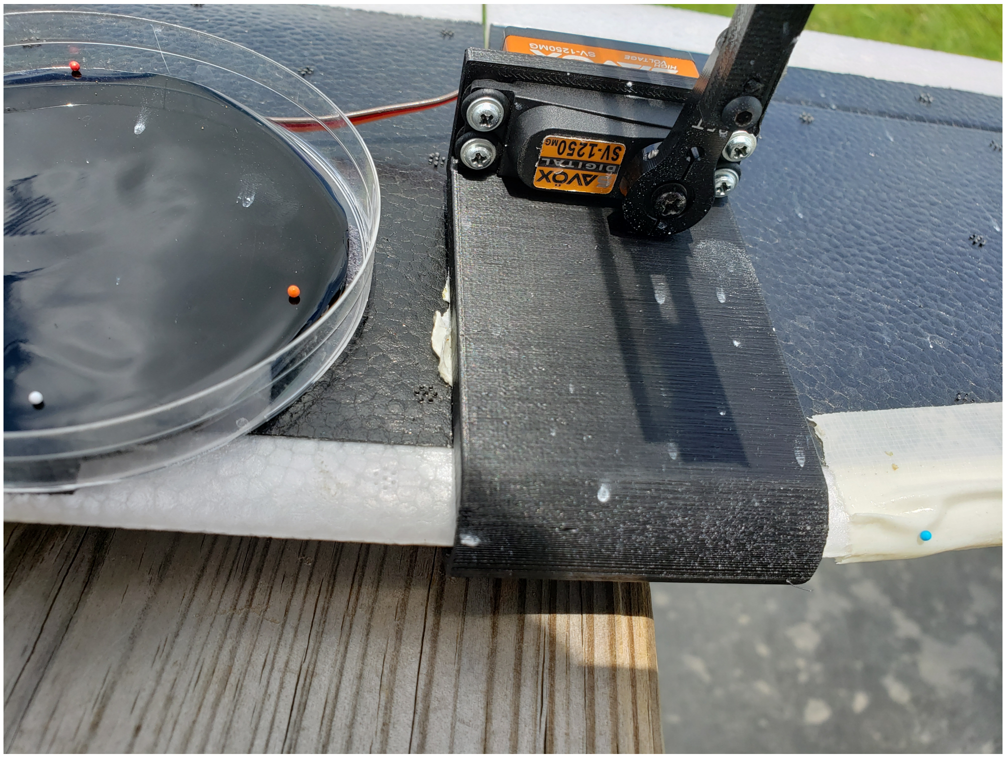

Figure 69: Bottom mount spread

For the third test run, one sprinkle and one chalk particle smear was found inside the port side petri dish. On the starboard side, there was one sprinkle found with two chalk particle smears found inside the petri dish. No sprinkles were detected on the tape located on the wings for this test run. Results from each test run are summarized in Tables 12 and 13. Table 12 pertains to the total number of sprinkles collected inside just the petri dishes without accounting for the chalk particles and the sprinkles that were collected from the tape on the wings and Table 13 is the total number of particles of sprinkles and chalk smears that were collected from both petri dishes and the tape on the wing mounts.

Table 12: Bottom Mount Collection Results

Flights:	Run 1	Run 2	Run 3
Number of sprinkles:	1	5	2

Table 13: Sprinkle/Chalk Seeding Collection Results

Flights:	Run 1	Run 2	Run 3
Number of particles:	2	11	5

The next set of testing consisted on determining how the blowfield interacts with a petri dish that is perpendicular to the flow. In order to accomplish this, a petri dish like the ones mounted beneath the wings was mounted to the nose of the nano talon. The petri dishes that were attached to the bottom of the wing as a part of the bottom wing mount collection mechanism were left on the wings to see if there was still any collection in those dishes during the testing. The arms from the capture mechanism that open and close the dish were removed making the bottom dishes always open. Testing was focused on firing chuffsim slightly before the vehicle got there in order to allow the vehicle to fly through the blowfield instead of focusing on firing the chuffsim when the vehicle is underneath. Two test runs were conducted with this vehicle configuration. Wind speeds picked up for these test and remained around 13 kts for both test runs.

For the first test run, 13 sprinkles were collected inside the dish. There were also 8 marks left on the inside of the dish indicating that sprinkles were attached but fell off either during flight back to the runway or during landing. Furthermore, there were also chalk particles that were recovered in the front dish. The bottom dishes both had two sprinkles located inside the dishes with the starboard side collecting an additional chalk particle smear. Additionally, during this test it was observed that a large chalk smear was collected on the bottom of the wing which can be seen in Figure 71.

Figure 70: Run 1: Front Dish Collection Results

Figure 71: Wing chalk smear

For the second run, only 4 chalk particles were collected inside the front petri dish; however, there was a large amount of chalk particles that were left inside the dish which can be seen in Figure 72. No sprinkles or chalk was collected inside the petri dishes on the bottom of the wings. Despite this, there was signs that the blowfield was in this area due to visible impacts left on the outside edges of the petri dishes and on the bottom wing mounts as can be seen in Figure 73.

Figure 72: Run 2: Front Dish Collection Results

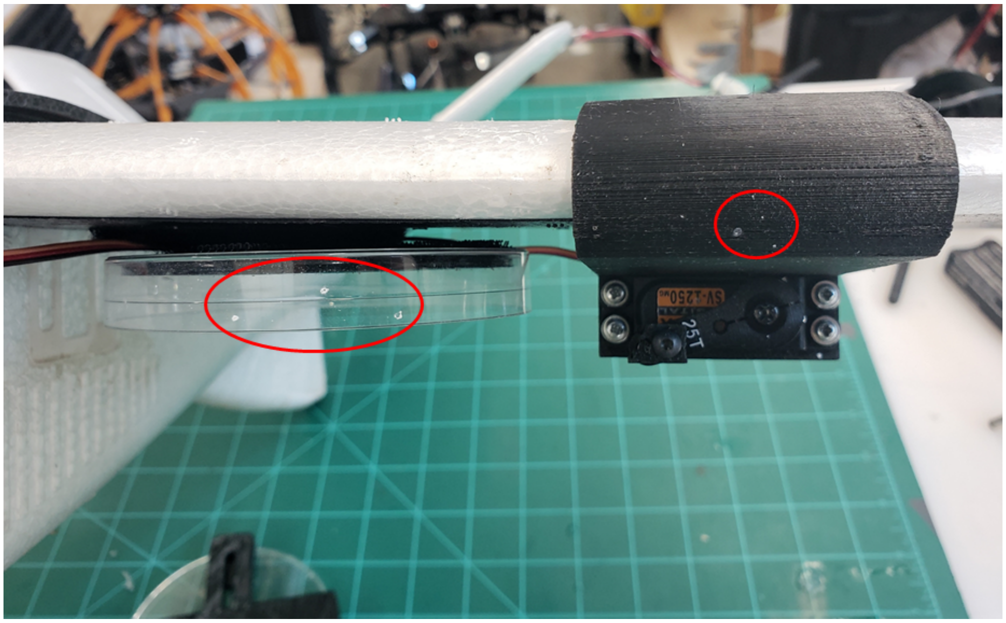

Figure 73: Seeding Impact

The results from the runs with the front dish test are summarized in both Tables 14 and 15 where Table 14 is the breakdown of sprinkles found in all dishes and Table 15 focuses on the total number of particles from the sprinkle/chalk mix. From these results it can be seen that utilizing a capture mechanism on the front or one that is perpendicular to the free stream flow produces better results compared to that of sample collection from the bottom of the wings. These results indicate that the leading edge mounts that were first developed should be implemented on an aircraft that has a larger wingspan or new collection mechanism should be developed to be mounted to the front of the aircraft. Implementing a system like this could prove beneficial to alleviate the controllability issues of the bottom wing mount mechanism on approach when the lids of the dishes are open which act as rudders that can push the vehicle in high wind speeds.

Table 14: Front Dish System Sprinkle Results

Flights:	Run 1	Run 2
Front Dish Number of sprinkles:	13	4
Bottom Dishes Number of sprinkles :	4	0
Total Number of sprinkles:	17	4

Table 15: Front Dish System Total Results

Flights:	Run 1	Run 2
Front Dish Number of particles:	22	20-30
Bottom Dishes Number of particles :	5	0
Total Number of particles:	27	20-30

4.4.3 Nimbus Testing

Additional testing was conducted with the Foxtech Nimbus with the leading edge mounts incorporated onto the wings of the vehicle. This was done to test if the leading edge mounts could operate on an aircraft with a larger wing area compared to the nano talon. Early flight tests used a dual wing mount system with two servos operating petri dishes on each wing that were attached to the leading edge of the wing. This provided four collection areas instead of the two that were integrated on the nano talon. These collection mechanisms were located near the edge of the wings in order to reduce propeller interaction with the sample collection mechanism when the dishes were opened in flight. Flight testing of the system was successful; however, the vehicle showed characteristics of slight lateral and directional instability during flight. This was due to the location of the sample collection mechanisms being near the wing tips. Additionally due to a failure of a servo, the collection mechanisms were only tested in flight when the Nimbus was in hover in VTOL mode. Due to the scope of time of the project, no further testing was conducted on this platform. However, flight testing with this configuration proved successful. Further testing would require the collection mechanisms to be moved further inboard to reduce the instability issues faced during the initial flight. To incorporate moving the sample collection mechanism inboard, the design would have to be changed to use a single petri dish that opens toward each wing tip. This would allow the mechanism to be moved further inboard while ensuring no propeller interaction with the mechanism.

Figure 74: Foxtech Nimbus Setup

CHAPTER V

CONCLUSION

5.1 Conclusions

This thesis focused on testing the effectiveness of an unmanned aerial vehicle to be able to collect cortisol samples from the breath of a dolphin for evaluation of health. Tests were conducted using both a fixed wing and a multi-rotor vehicle. Different test cases were conducted using a pneumatic dolphin lung simulator to replicate the blowfield of the dolphin. This simulator, chuffsim, was tested with various types of seeding in attempts to replicate what would be seen from a dolphin. These seeding types ranged from both liquid and powder based.

5.1.1 Multi-Rotor Evaluation

For the multi-rotor tests, water, chalk, and a chalk/sprinkle mix were tested for the seeding used to generate the blowfield. The multi-rotor was flown directly above the nozzle where the vehicle loitered. From these tests it was clear that the down wash produced by the rotors had a major effect on the blowfield causing the blowfield to be pushed down with minimal to no sample collection occurring. Sample collection tests were initially conducted at 3ft above chuffsim. The only successful sample collection occurred with the chalk/sprinkle mix; however, the sample collection quantity was relatively low especially compared to fixed wing vehicle tests. Further testing was conducted were the vehicle was lowered to approximately 1 ft above chuffsim. These test results proved better for collection; however, at this height there is the chance for increased danger to the dolphin being sampled. The potential for this system to crash is increased due to the lower altitude. Additionally, the frequency produced from the rotors of a multi-rotor vehicle could cause a negative reaction from the dolphins being sampled when at this low altitude. An additional method could be used for collection that utilizes a sweep approach; however, this system would still have to fly relatively low to the water surface level due to the nature of the blowfield physics. The ideal range for collection remains between 1.1 and 4.5 ft [2]. A low flying system like this would have a higher chance of collision with the dolphin being sampled and would have a higher chance of being detected from the dolphin being sampled which could cause it to dive and swim away.

5.1.2 Fixed-Wing Evaluation

For the fixed wing sample collection tests, testing was done with a ZOHD nano talon EVO. Different capture mechanisms were developed and tested to determine an ideal mounting system. Additionally, two collection methods were tested. The first was to attempt to collect samples when directly above the nozzle. The process for this was to attempt to fire chuffsim when the vehicle was directly above the nozzle. This method can be seen in Figure 75 and will be referred to as the above sample collection method. The next configuration that was evaluated was attempting to collect by flying into the plume. This method involved firing chuffsim right before the vehicle reached chuffsim to collect the blow suspended in the air. This method can be seen in Figure 76 and will be referred to as the behind collection method.

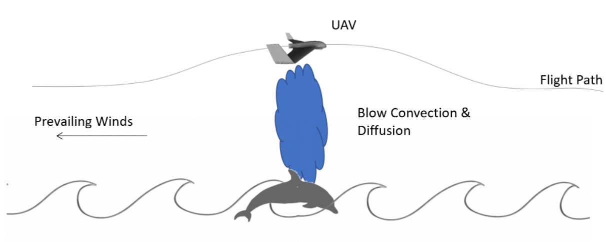

Figure 75: Above sample collection

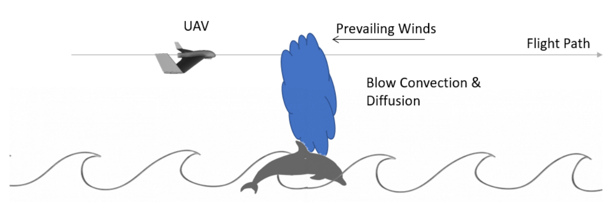

Figure 76: Behind sample collection

To confirm the possibility of sample collection, early testing was conducted with dyed water that was used for the seeding. This test confirmed the concept of collection with particle droplets being collected in a petri dish mounted to the nose of the nano talon. Further testing was done in order to obtain sample sustainability. These tests focused on using a capture mechanism for collection. Initial testing with the sample collection mechanism revealed that the leading edge mounts that were developed for the nano talon caused a large amount of drag and flow separation over the wings making the aircraft unable to generate enough lift for flight. New wing mounts were developed that positioned the petri dishes below the wings. This bottom wing mount was tested using both chalk and a mixture of nonpareil sprinkles and chalk for the seeding. Tests with the chalk seeding proved to be inconclusive and hard to determine exact particles due to the small size and different shapes of the chalk particles. The sprinkle/chalk mix was tested next to obtain consistent quantifiable results. The sprinkles proved to be a good indicator for consistent results due to the same size of particles. Chalk was also used in order to help identify the blowfield and whether the vehicle was in the blowfield during testing.

Flight test results proved that collection was possible using the chalk sprinkle mix with the bottom wing sample collection mechanism. Numerous runs were conducted with this seeding configuration resulting in sample collection occurring during each run. Sample amounts varied in each run due to the fire timing of chuffsim in proximity to the vehicle location above the nozzle. The best results with the bottom wing mounts occurred when chuffsim was fired as the vehicle was directly above the nozzle. This allowed for the majority of the blowfield to hit the vehicle as it passed over the nozzle. Lower particle counts occurred if the timing did not match this instance such as if chuffsim was fired before the vehicle was over the nozzle or the vehicle being slightly after chuffsim was fired. This indicates that sample collection remains effective with the bottom wing mounts for the above sample collection method despite timing issues due to the success of sample capture from each run. To better aid the controllability of the aircraft using the bottom wing mounts, 360° programmable servos should replace the existing servos. This would reduce the yaw issues faced during flight testing when the control mechanism was opened. The increased yaw in the system was due to the lids acting as rudders causing the vehicle to sway in high wind conditions. Therefore, 360° servos would allow the lids to open at a greater angle than 90° which would reduce the yaw instability with the lids open.

To test collection from flying into a plume as seen with the behind collection method, a single petri dish was attached to the nose of the nano talon and flown through the generated blowfield. The chalk/sprinkle mix was used for the seeding for these tests with the system flown at 3 to 4 ft above the nozzle. Collection results were high for the two test runs conducted with this setup. The results indicate that collecting with a collection plate that is perpendicular to the free stream flow produces a higher sample collection count compared to collection from the bottom wing mounts. Additionally, this method proved to be more effective than the above collection method. Samples were collected on each run indicating a high success rate with this collection setup. Timing was still an issue as with the above collection method; however, there is room for greater error in timing due to the nature of the blowfield lingering in the air for a couple of seconds after firing. For collection to be successful with this method, the vehicle would have to cruise behind the dolphin being sampled and would fly through the blowfield after the dolphin chuffs. An additional scenario would require the sample collection vehicle to cruise behind the dolphin and let wind push the blowfield into the vehicle. This scenario would require the vehicle to be flying into the wind during sample collection which may not always be feasible for sample collection.

5.2 Future Work

For future work on a fixed wing vehicle, a system should be developed to make the vehicle autonomous to reduce work load of a pilot. Breath jets from a dolphin would be hard to detect for an autonomous system; however, systems can be developed to aid the pilot in sample collection. A system should be developed to help keep the vehicle in a set height above the water surface level to ensure that the pilot does not accidentally pitch the vehicle down into the water or dolphin. Additionally, this would allow for the pilot to focus on the difficult task of flying through the blowfield without worrying about maintaining a set height above the water. LIDAR or ultrasonic sensors could be used with a system to calculate wave crests in order to aid in keeping the vehicle at a desired height above the water.

A tracking system should be setup and developed to locate and track dolphins autonomously. This would allow for a research team to fly the vehicle in a grid pattern to search for the dolphin pods. Once the system could identify a pod, the system would track and up date coordinates to allow the research team to move closer to the pod for visual observation during sample collection. This would be crucial especially during early testing to ensure that the vehicle is not causing harm to the dolphins. This would require a camera system with image recognition software to be able to work. OpenCV could be used for image recognition and tracking. Additionally, the cameras should record the sample collection in order to aid researchers in being able to determine which dolphin is being sampled from and potentially help identify the sampled dolphin from catalog records.

Also, thermal image targeting could prove useful to implement in the future for tracking and location purposes. There has been research conducted on whales and dolphins to determine the effectiveness of such systems for detection. Currently, infrared (IR) technology can be used to measure the difference between the water temperature and the cetacean's skin or breath providing a new method for location and tracking [9],[18],[30]. A system could be developed and integrated on board a UAS with an IR camera that could be used to locate and track dolphin pods in the future. Additionally, this system could be used to identify dolphin blowfields to aid in the sample capture process.

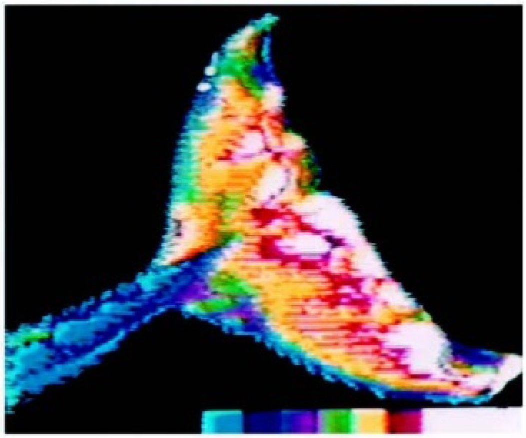

Figure 77: IR of bottlenose dolphin fluke[9]

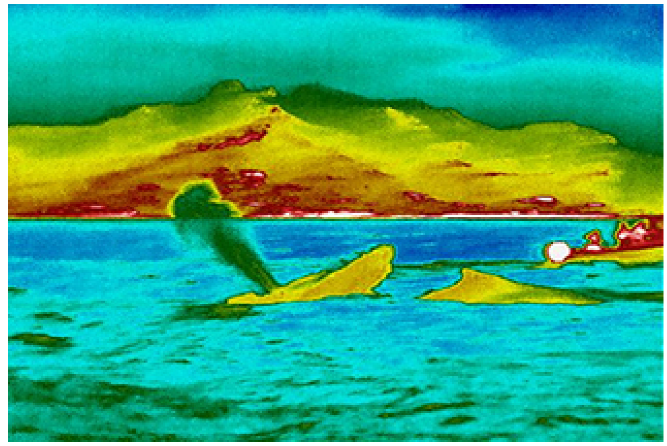

Figure 78: IR whale breath[18]

For suggestions for future work, a controlled towed vehicle (CTV) should be designed and tested. This vehicle should be designed as a glider with control surfaces and sample collection mechanisms on board. Quick preliminary testing was done in order to validate the concept of using a towed vehicle for sample collection. This involved using a custom built multi-rotor to tow a simple foam kit, fixed wing airplane that served as a glider. The airplane was towed behind the multi-rotor using an 18 ft long tether. To ensure tether clearance, a carbon fiber rod was mounted to the multi-rotor. This setup was to keep the tether under the propellers in order to prevent entanglement. The vehicle setup can be seen in Figure 79.

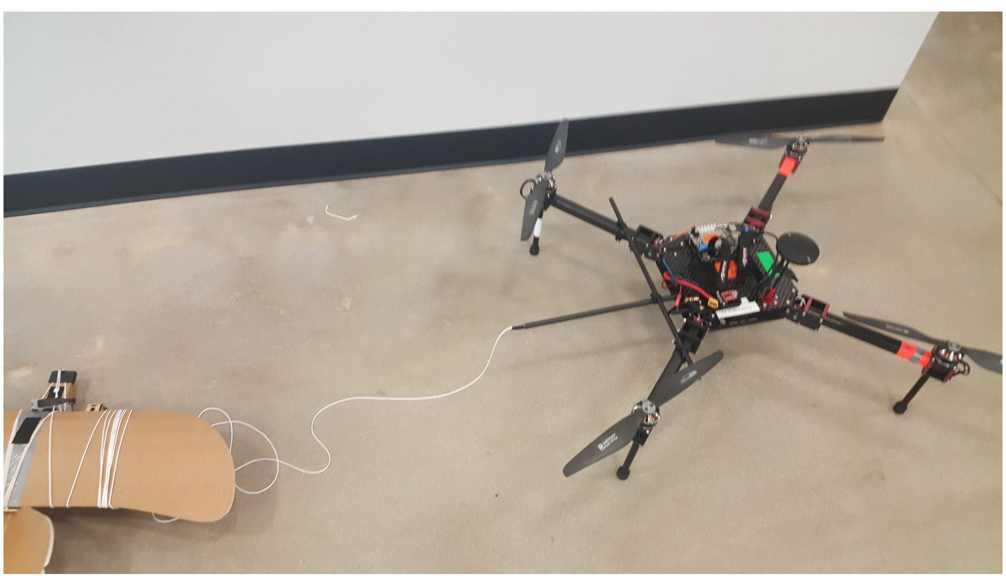

Figure 79: Tow vehicle concept setup

The tow system setup was tested out in an open field to determine if a towed vehicle concept would be successful. This involved starting the multi-rotor and tethered vehicle on the ground at the full tether length apart. The multi-rotor was launched and flown in a straight line to get the fixed wing vehicle in steady level flight. Steady level flight was achieved by the towed vehicle during testing; however, the vehicle generated enough lift to pitch up raising above the multi-rotor vehicle. This resulted in the tether getting entangled in the propellers of the multi-rotor vehicle causing a crash. Despite this issue, the concept of towing a vehicle from a UAV was proven successful. A system would need to be developed in order to make sure that the tether does not get entangled with the vehicle that is towing. One method would be to add control surfaces on the towed vehicle to control the pitch to ensure that the vehicle could not rise above the parent vehicle.

Figure 80: Flight concept testing

In order for this system to work, careful consideration needs to be accounted for when deploying the CTV. With this configuration, the vehicle needs to be tethered to the main vehicle that deploys the system. In order to achieve this, a winch mechanism needs to be developed that allows for the deployment of the CTV from the parent vehicle. The winch system needs to be developed to account for tension on the cable that attaches the CTV to the parent vehicle. Too much tension could case strain on the system and break the tow cable. Additionally, if there is not enough tension, the CTV could potentially lift above the parent vehicle causing the cable to strike the parent vehicle. If the parent vehicle is a multi-rotor UAV, the cable could get entangled in the propellers causing the parent vehicle to crash. A proposed design for the winch mechanism and CTV is shown in Figures 81 and 82 respectively.

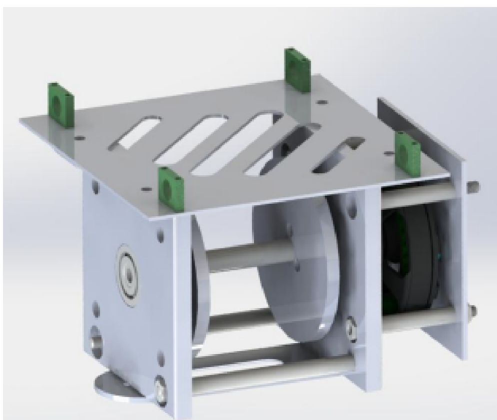

Figure 81: Winch Mechanism

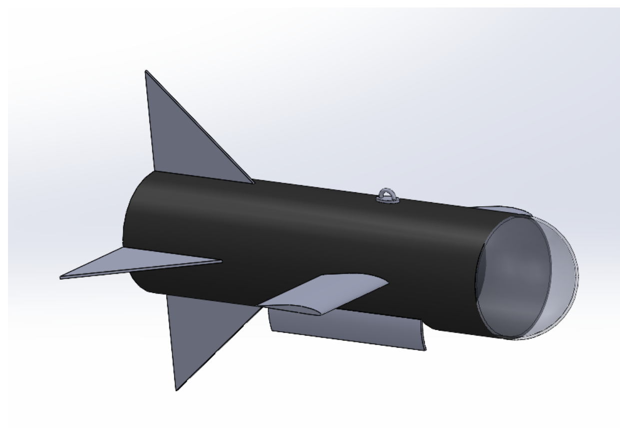

Figure 82: Sample Collection CTV

The winch mechanism would utilize a DC motor that controls a cable spool. This motor would be controlled to allow the cable to be spooled in or out depending on whether the CTV is being deployed or recovered. Additionally, this system should be autonomously controlled in order to prevent the cable connecting the CTV to the parent vehicle to cause damage to the parent vehicle. The sample collection CTV concept consists of a tube design with control surfaces. The front of the vehicle would house the camera system consisting of both an IR and FPV cameras. These cameras would be used for dolphin identification, tracking, and plume detection. Figure 83 provides a reference to the location of the components of the vehicle.

The bottom of the vehicle has a sample collection bay that uses two doors to open and close the bay. This functions as a seal between the surrounding air and the petri dishes that are mounted inside the bay. The bay is designed to hold two 3 inch petri dishes. The petri dishes would be held in place with velcro to ensure that they can be removed after flights for lab testing of the collected samples. Figure 84 shows the sample collection bay.

The vehicle is 18.25 inches in length with a main body being 4.5 inches in diameter. The wing control surfaces are 4 inches in length on each side and are designed to be rotated to control the angle of attack of the vehicle when in tow. The total width of the vehicle including wings is 12.5 inches. The sample collection bay is 6.9 inches in length and roughly 3.94 inches wide in order to allow two petri dishes to be placed inside.

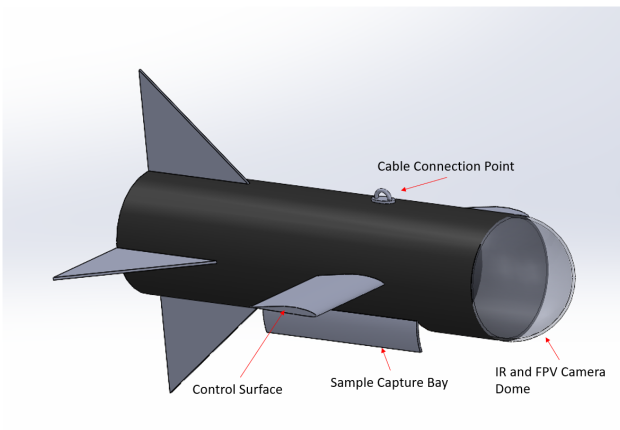

Figure 83: CTV

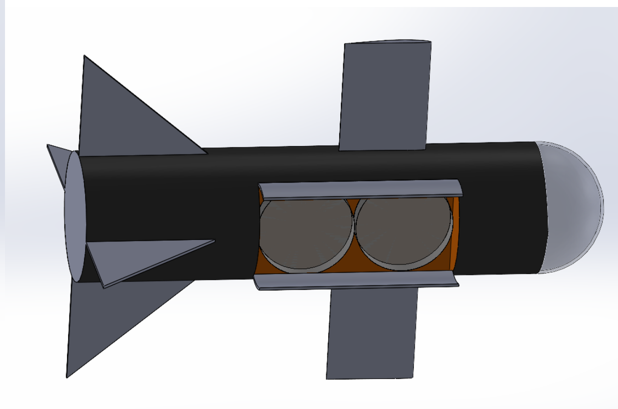

Figure 84: CTV Sample Capture Bay

REFERENCES

[1] Karina Acevedo-Whitehouse, A. Rocha-Gosselin, and Diane Gendron, *A novel non-invasive tool for disease surveillance of free-ranging whales and its relevance to conservation programs*, Animal Conservation **13** (2009), 217 – 225.

[2] CJ Barton, *Characterization of the impulsive jet produced from a dolphin's blowhole*, 2020.

[3] Randall L. Brill, Patrick W. Moore, and Lois A. Dankiewicz, *Assessment of dolphin (tursiops truncatus) auditory sensitivity and hearing loss using jawphones*, The Journal of the Acoustical Society of America **109** (2001), no. 4, 1717–1722.

[4] Elizabeth A. Burgess, Kathleen E. Hunt, Scott D. Kraus, and Rosalind M. Rolland, *Get the most out of blow hormones: validation of sampling materials, field storage and extraction techniques for whale respiratory vapour samples*, Conservation Physiology **4** (2016), no. 1, cow024.

[5] Joana Castro, Francisco O. Borges, André Cid, Marina I. Laborde, Rui Rosa, and Heidi C. Pearson, *Assessing the behavioural responses of small cetaceans to unmanned aerial vehicles*, Remote Sensing **13** (2021), no. 1, 1.

[6] Cinzia Centelleghe, Lisa Carraro, Joan Gonzalvo, Massimiliano Rosso, Erika Esposti, Claudia Gili, Marco Bonato, Davide Pedrotti, Barbara Cardazzo, Michele Povinelli, and Sandro Mazzariol, *The use of unmanned aerial vehicles (uavs) to sample the blow microbiome of small cetaceans*, PLOS ONE **15** (2020), 1–14.

[7] Fredrik Christiansen, Laia Rojano-Doñate, Peter T. Madsen, and Lars Bejder, *Noise levels of multi-rotor unmanned aerial vehicles with implications for potential underwater impacts on marine mammals*, Frontiers in Marine Science **3** (2016), 277.

[8] Carlos Domínguez-Sánchez, Karina Acevedo-Whitehouse, and Diane Gendron, *Effect of drone-based blow sampling on blue whale (balaenoptera musculus) behavior*, Marine Mammal Science **34** (2018).

[9] Niru Dorrian, *Marine fauna mitigation using thermal imaging.*

[10] Andreas Fahlman, Stephen H. Loring, Gregg Levine, Julie Rocho-Levine, Trevor Austin, and Micah Brodsky, *Lung mechanics and pulmonary function testing in cetaceans*, Journal of Experimental Biology **218** (2015), no. 13, 2030–2038.

[11] Andreas Fahlman, Michael J. Moore, and Daniel Garcia-Parraga, *Respiratory function and mechanics in pinnipeds and cetaceans*, Journal of Experimental Biology **220** (2017), no. 10, 1761–1773.

[12] Patricia A Fair, *Protocols for conducting dolphin capture-release health assessment studies*, (2006).

[13] Ticiana Fettermann, Lorenzo Fiori, Martin Bader, Ashray Doshi, Dan Breen, Karen A. Stockin, and Barbara Bollard, *Behaviour reactions of bottlenose dolphins (tursiops truncatus) to multirotor unmanned aerial vehicles (uavs)*, Scientific Reports **9** (2019), no. 1, 8558.

[14] James Finneran, Dorian Houser, Dave Blasko, Christie Hicks, Jim Hudson, and Mike Osborn, *Estimating bottlenose dolphin (tursiops truncatus) hearing thresholds from single and multiple simultaneous auditory evoked potentials*, The Journal of the Acoustical Society of America **123** (2008), 542–51.

[15] Joseph Flynt, *Drone noise levels and how to keep them quiet*, Sep 2020.

[16] Pedro Friedrich Fruet, Luciano Dalla Rosa, Rodrigo C. Genoves, Victor H. Valiati, Thales R.O. De Freitas, and Luciana M. Möller, *Biopsy darting of common bottlenose dolphins (tursiops truncatus) in southern brazil: evaluating effectiveness, short-term responses and wound healing*, Latin American Journal of Aquatic Mammals **11** (2017), no. 1-2, 121–132.

[17] C. J. Hogg, T. L. Rogers, A. Shorter, K. Barton, P. J. O. Miller, and D. Nowacek, *Determination of steroid hormones in whale blow: It is possible*, Marine Mammal Science **25** (2009), no. 3, 605–618.

[18] Travis W. Horton, Alice Oline, Nan Hauser, Tasnuva Ming Khan, Amelie Laute, Alyssa Stoller, Katherine Tison, and Peyman Zawar-Reza, *Thermal imaging and biometrical thermography of humpback whales*, Frontiers in Marine Science **4** (2017), 424.

[19] Kathleen E. Hunt, Rosalind M. Rolland, and Scott D. Kraus, *Detection of steroid and thyroid hormones via immunoassay of north atlantic right whale (eubalaena glacialis) respiratory vapor*, Marine Mammal Science **30** (2014), no. 2, 796–809.

[20] Sandra Lee Maldonado-Ramirez, David G. Schmale, Elson J. Shields, and Gary C. Bergstrom, *The relative abundance of viable spores of gibberella zeae in the planetary boundary layer suggests the role of long-distance transport in regional epidemics of fusarium head blight*, Agricultural and Forest Meteorology **132** (2005), no. 1, 20–27.

[21] Paul E. Nachtigall, Michelle M. Yuen, T. Aran Mooney, and Kristen A. Taylor, *Hearing measurements from a stranded infant risso's dolphin, grampus griseus*, Journal of Experimental Biology **208** (2005), no. 21, 4181–4188.

[22] Vanessa Pirotta, Alastair Smith, Martin Ostrowski, Dylan Russell, Ian D. Jonsen, Alana Grech, and Robert Harcourt, *An economical custom-built drone for assessing whale health*, Frontiers in Marine Science **4** (2017), 425.

[23] Shelby Proie, *A Systematic Review of Cortisol Levels in Wild and Captive Atlantic Bottlenose Dolphin (Tursiops truncatus), Killer Whale, (Orcinus orca), and Beluga Whale (Delphinapterus leucas).*, Master's thesis, The Evergreen State College, Olympia, WA, 2013.

[24] Eric A. Ramos, Brigid Maloney, Marcelo O. Magnasco, and Diana Reiss, *Bottlenose dolphins and antillean manatees respond to small multi-rotor unmanned aerial systems*, Frontiers in Marine Science **5** (2018), 316.

[25] Vincent Raoult, Andrew P Colefax, Blake M. Allan, Daniele Cagnazzi, Nataly Castelblanco-Martínez, Daniel Ierodiaconou, David W. Johnston, Sarah Landeo-Yauri, Mitchell Lyons, Vanessa Pirotta, Gail Schofield, and Paul A Butcher, *Operational protocols for the use of drones in marine animal research*, Drones **4** (2020), no. 4.

[26] Holly C. Raudino, Julian A. Tyne, Alastair Smith, Kym Ottewell, Shelley McArthur, Anna M. Kopps, Delphine Chabanne, Robert G. Harcourt, Vanessa Pirotta, and Kelly Waples, *Challenges of collecting blow from small cetaceans*, Ecosphere **10** (2019), no. 10, e02901.

[27] David G. Schmale III, Benjamin R. Dingus, and Charles Reinholtz, *Development and application of an autonomous unmanned aerial vehicle for precise aerobiological sampling above agricultural fields*, Journal of Field Robotics **25** (2008), no. 3, 133–147.

[28] SeaWorld, *Senses*.

[29] Courtney Smith, Seth Sykora-Bodie, Shalynn Pack, Brian Bloodworth, Trevor Spradlin, and Nicole LeBoeuf, *Assessment of known impacts of unmanned aerial systems (uas) on marine mammals: data gaps and recommendations for researchers in the united states*, Journal of Unmanned Vehicle Systems **4** (2016), 1–14.

[30] Heather R. Smith, Daniel P. Zitterbart, Thomas F. Norris, Michael Flau, Elizabeth L. Ferguson, Colin G. Jones, Olaf Boebel, and Valerie D. Moulton, *A field comparison of marine mammal detections via visual, acoustic, and infrared (ir) imaging methods offshore atlantic canada*, Marine Pollution Bulletin **154** (2020), 111026.

[31] UASweekly, *Aeromapper talon amphibious being used for whale research*, Mar 2021.

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Master of Science

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