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Dolphin Behavioral Responses to Uncrewed Aerial Systems as a Function of Exposure, Height, and Type

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Height, and Exposure

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ABSTRACT

Uncrewed aerial systems (UAS) are becoming a standard tool in the study of cetaceans, however, a comparative assessment of animal responses to UAS has not been established to gauge the most effective systems for cetacean study. We utilized Dolphin Quest Bermuda's eleven bottlenose dolphins as subjects for such an investigation taking place over five weeks in 2022 and five weeks in 2023. The dolphins were evaluated for investigative behavioral responses to six off-the-shelf UAS types and a custom fixed wing system. Each UAS was flown in decreasing height vertically above the main dolphin lagoon to evaluate dolphin behavioral responses in terms of number of looks and duration of submersion. We evaluated dolphin responses to UASs as a function of UAS type, height, and flight number. Results indicated that UASs with a large visual and noise profile generated high behavioral responses from the dolphins. In terms of UAS height, dolphin submersion duration decreases as height decreases, but that individual subject seems to be a strong overall predictor of responses. Also, we found evidence for habituation to the UASs over successive flights. Together these data support the idea that dolphins are best studied with small rotary UAS consistently in a population over time to allow for habituation.

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INTRODUCTION

The widespread use and subsequent rapid advancement of uncrewed aerial systems (UAS, colloquially referred to as drones) in society has led to opportunities to apply this technology to wildlife applications. Perhaps nowhere in wildlife ecology has the adoption of these tools been so rapid as in the study and management of marine mammals, whose often cryptic existence has been illuminated by this technology. This thesis will explore an aspect of UAS integration with cetaceans, specifically bottlenose dolphins, *Tursiops truncatus* (Montagu, 1821), in service of a larger joint Stephen F. Austin State University/Oklahoma State University project (Passive Hormone Assessment in Sea Mammals, PHASM) of a behavioral assessment of animal responses to common UAS types as compared with PHASM's experimental platform.

Cetaceans and Conservation Threats

Marine mammals are a diverse group of mammals with unique adaptations, i.e., respiratory adaptations (Kooyman, 1973), thermoregulatory adaptations (Whittow, 1987), and increased breath holding for diving (Davis, 2014)) that allows them to occupy marine ecosystems worldwide (Kaschner et al., 2006). Marine mammals can be divided into four taxonomic groups: cetaceans (whales, dolphins, and porpoises), sirenians (manatees and dugongs), pinnipeds (seals, sea lions, and walruses), and fissipeds (polar bears and sea otters). The infraorder Cetacea is categorized into two groups: mysticetes (baleen whales) (i.e., blue whales, humpback whales) and odontocetes (toothed whales) (i.e., dolphins, porpoises) (Fordyce & de Muizon, 2001).

One of the most common cetaceans world-wide is the bottlenose dolphin, *Tursiops truncatus* who is a member of the mammalian order Artiodactyla (Rosel et al., 2022). Bottlenose dolphins are a highly adaptable species commonly seen in temperate, subtropical, and tropical oceans around the world (Chivers, 2012). Bottlenose dolphins, like all marine mammals, are protected under the Marine Mammal Protection Act (MMPA) of 1972 which prohibits the importation of marine mammals and marine mammal products into the United States or the take of marine mammals (harassment, hunting, capturing, collecting, or killing) without permit or special authorization. This act was created in response to concerns among scientists and the public regarding large declines in some marine mammal species in relation to human activities (Rizzardi, 2014). The goal of the MMPA is to maintain the health and stability of marine ecosystems, as marine mammals play an extensive role in the food web (Rizzardi, 2014). To help maintain health and stability of cetaceans, sound conservation practices and research is needed. Technology has become an important tool in marine mammal conservation (Dutton et al., 2019). Technology being utilized includes remote sensing, bioacoustics, telemetry, molecular technology, and UAS (Dutton et al., 2019). UAS has been particularly impactful for the study of cetacean behavior and for measuring the effects of human impacts on cetaceans.

History and Effectiveness of UAS in Wildlife Research

The use and development of UAS has evolved rapidly over the past two decades (Watts et al., 2012). Within recent years, there has been an increased interest in UAS by ecologists because of the tool's ability to carry remote sensing instruments and collect pertinent ecological data at large scales. This technology is being utilized to study various aspects of terrestrial and marine species' ecology, behavior, health, movement, and distribution (Raoult et al., 2020; Wich & Koh, 2018). Studying wild marine mammals presents unique challenges. Terrestrial mammals can be observed continuously in environments often accessible to humans. Conversely, wild marine mammals are elusive, spending much or most of their time underwater. Historically, marine mammal research in the wild has been restricted to what can be seen from shore or a boat (Figure 1A), which poses a variety of difficulties for animals who surface for a limited time (i.e., dwarf sperm whales, beaked whales). UAS provides an aerial, top-down perspective (Figure 1B) that is relatively low cost, discrete, less risky than boat approaches, easily maneuverable and can provide up to three times more observational capacity than boat surveys (Torres et al., 2018).

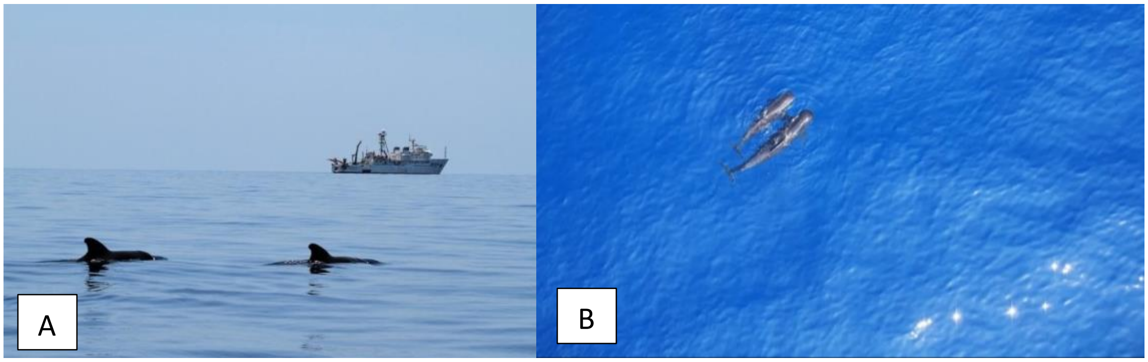


Figure 1. A) Two Gulf of Mexico pilot whales' surface near the NOAA Ship Gordon Gunter on a boat-based survey near Pascagoula Mississippi. Credit: NOAA Fisheries/Melody Baran (Permit # 14450) (Southeast Fisheries Science Center, 2023). B) Two Hawaiian pilot whales filmed northeast of Kauai using a UAS in July 2017 as part of the HICEAS Cetacean Study. Note the increased visibility especially regarding body size and condition (DeSchryver, 2017).

When compared to traditional research methods (i.e., boat surveys) UAS usage results in a reduction of animal disturbance (Ramos et al., 2018). This technology provides the ability to observe wildlife at safe distances and in areas that are hard to reach by boat or piloted aircraft. Successful uses of UAS based wildlife monitoring in marine mammals include abundance data (Hodgson et al., 2013; Sweeney et al., 2015), photo-identification (Koski et al., 2015; Pomeroy et al., 2015), photogrammetry (Christiansen et al., 2022; Currie et al., 2021) behavioral research and health assessments (Acevedo-Whitehouse et al., 2010; Pirotta et al., 2017).

UAS Platforms

The three commonly used UAS platforms are rotary-wing, fixed-wing, and VTOL (vertical takeoff and landing). The rotary-wing UAS utilizes rotary blades to generate aircraft lift. Fixed-wing UASs have one rigid wing that is built to resemble an airplane and can fly using the lift generated by a mix of forward airspeed and the shape of the wings. VTOLs are considered a hybrid UAS, combining the technology of rotary and fixed wing. Each UAS type has strengths and weaknesses that may cater to one marine mammal species more than others (Raoult et al., 2020).

The most commonly used platform in marine mammal research is the rotary-wing UAS (Raoult et al., 2020). These UASs can have between four to eight (or more) motors and rotors. They are preferred for their few moving parts, which in turn reduces average cost and provides redundancy in the event of equipment failure. Also, these UASs do not need a large amount of space to take off or land. A negative to this UAS type is their low endurance, limited flight time, and wind speed limitations (Raoult et al., 2020).

The fixed-wing UAS is a less common platform for marine mammal research. Fixed-wing strengths lie in its ability to cover larger areas because of a higher endurance (Raoult et al., 2020). Due to its endurance capabilities, this UAS may be useful in covering large areas to survey large aggregations of species. Wind speed is less of a limitation and may assist in the flight. However, this UAS requires a larger area to take off and land than a rotary wing. Also, this platform is less likely to capture quality imagery.

The VTOL UAS aim to combine the benefits of rotary and fixed wing. It has the capability of longer range/ longer flight time (similar to fixed-wing) and the ability to take off from small landing areas (similar to rotary-wing) (Raoult et al., 2020). However, this platform has not been widely used in the marine mammal field to date. Since VTOL combines both aspects of two UAS types, they tend to be more complex and higher in price.

The Interface of Dolphin Hearing and UAS Detection

In this study, we focus on the interface between bottlenose dolphin perception to noise and UAS noise, so it is important to note the hearing capability of this mammal. Dolphins, like other mammals possess middle and inner ear canals, but they use other body parts to assist in hearing (Accomando et al., 2020; Bruno Cozzi et al., 2016; Ketten, 2000). The jawbone is utilized as a sound receptor that sends vibrations to the middle ear (Ketten, 2000; Southall et al., 2019). The used their melon (their large forehead) as an acoustic lens to aid in sound propagation and focusing (Au et al., 1980; B. Cozzi et al., 2016). The bottlenose can integrate information from their environment through audition (echolocation) and vision (Bruck & Pack, 2022; Pack & Herman, 1995). Dolphins use both senses to their benefit. They often rely on echolocation to hunt and navigate (Belwood & Fullard, 1984; Fulton, 2021).

Dolphins possess an extremely sensitive hearing apparatus (Hemilä et al., 2010) allowing them to hear and call in a broad range of frequencies between 75Hz to more than 150,000Hz, which is well beyond the hearing range of humans (20-20,000 Hz)(Au, 1993; McCormick et al., 1970; Ridgway & Carder, 1997). Bottlenose dolphins appear to be most sensitive to frequencies above 10kHz (Spence, 2015). More specifically, in Ridgway and Au (2010), they determined the auditory sensitivity of the bottlenose dolphin was in the 10-120 kHz range (Figure 2).

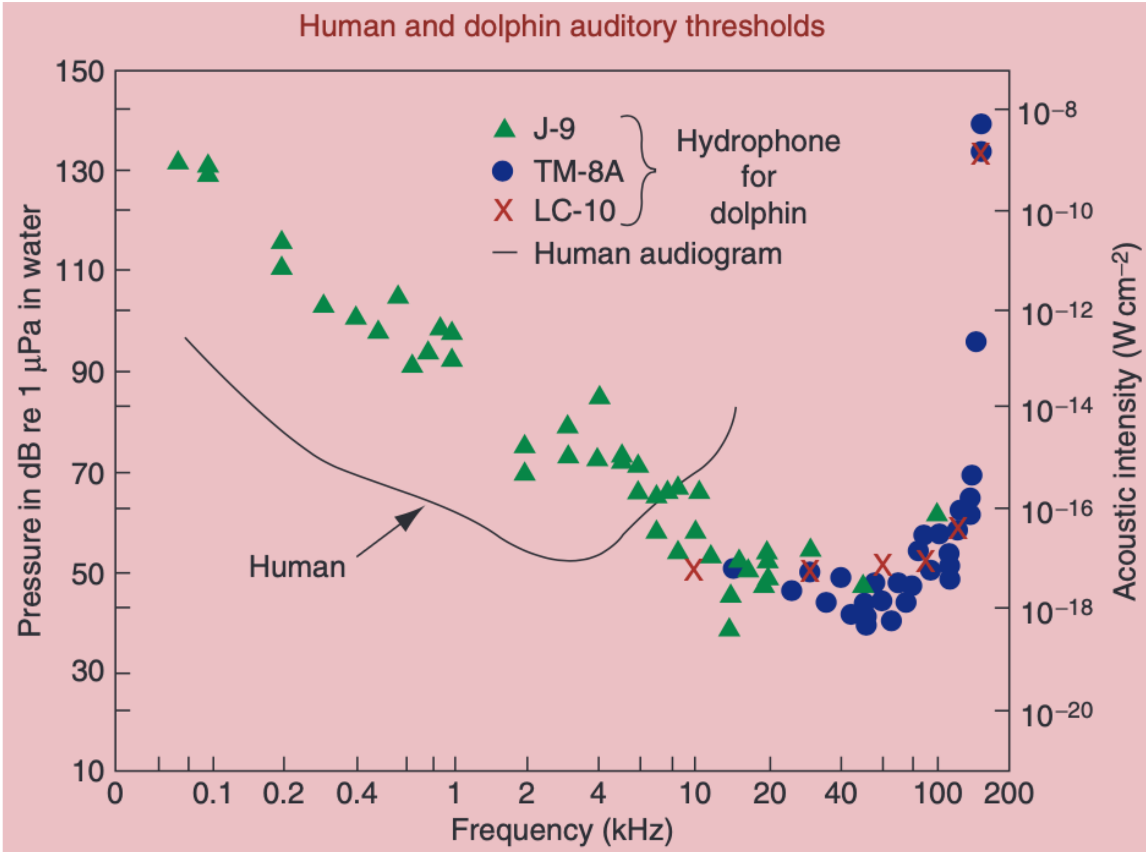


Figure 2. Comparison of auditory sensitivity of bottlenose dolphin (in water) and human (in air) (Ridgway & Au, 2010 adapted from Johnson, 1968, used with permission).

The primary noise sources from rotary UASs is from the blades (Duncan et al., 2021). The unique tonal noise associated with a UAS is created due to the small distance between blades. Surprisingly, the UAS motors do not contribute a significant amount to the device's noise profile, however the toroidal effect of the blades slicing the air does create noise (Massey & Gaeta, 2010). Payload on a UAS can create a larger noise profile as it increases the amount of effort the UAS must produce to maintain its position in the sky (Duncan et al., 2021). However, using larger blades on such devices can lead to decreased sound frequencies as larger blades can produce greater lift at the same rpm, which increases the period of the sound waves and the lowers the frequencies of the sounds emitted by the UAS (Noda et al., 2022). All things being equal (including lift), a large propeller will spin a few times per second less than a small one producing lower frequencies. Weather conditions can play a factor in sound production. Wind is a complicated factor for UAS noise measurements because wind can have a masking effect on UAS noise. However, wind can require the UAS to make compensatory movements to maintain its forward flight or hover (Duncan et al., 2021). According to Duncan et al. (2021), the average small UAS operates between 70 dB and 81 dB at source. This decibel range is comparable to a household vacuum cleaner or a washing machine. Given the same sized blades and the same number of propellers, the average tonal frequencies of small to medium multirotor UASs is 200 to 5000 Hz and the average tonal frequencies of medium to large multirotor is 200 to 10,000 Hz (Dumitrescu et al., 2020). Meaning UASs are comfortably within a bottlenose dolphin's hearing range, with the larger UASs frequency's entering on their high-acoustic sensitivity range.

It is important to note the noise properties of UASs because many marine mammals rely on sound and hearing as one of their principal senses meaning they are not only good at hearing, but that distracting/impeding them in this important modality can have consequences for their survivability (Christiansen et al., 2016; Southall, 2019; Stevens et al., 2023; Stevens et al., 2021; Tyack, 1998). Interfering with sound perception in a cetacean can effect foraging, orientation, and communication (Ketten, 2000). Due to the importance of sound to their life history, these animals can be susceptible to a variety of anthropogenic sounds (i.e. boats, shipping, seismic exploration, and military sonar) (Jensen et al., 2009; Southall et al., 2019; Stevens et al., 2021).

Smith et al. (2016) describes the effects of UASs on marine mammals and states the two potential disturbance sources as the visual cues of a UAS and the noise of the UAS. Three studies, Christiansen et al. (2016), Erbe et al. (2017), and Laute et al. (2023) investigated the ability of marine mammals to hear UAS produced noise underwater. Christiansen et al. (2016) used the DJI Inspire 1 and the SwellPro SplashDrone 1 to test for underwater noise. They found that dolphins near the surface may hear a UAS approaching, however the blade noise may be masked by ambient noise, meaning, the underwater noise caused by UASs flying at low altitudes may be minimal. Erbe et al. (2017) used the HighOne E1100v3, DJI S900, Phantom 3 Professional, and DJI Inspire 1 Pro to test an underwater noise profile. The researchers found that UAS noise levels exceeded ambient noise levels when measured in calm conditions near the water's surface and in shallow water. Also, marine megafauna would be able to detect and hear sounds in the frequency band of the used UASs. The team noted that the sound disturbance from UASs may be considerably less than for other forms of data collection. Laute et al. (2023) tested underwater sound levels of a DJI Mavic Pro Platinum, a Phantom 4 Pro v2.0, and an Inspire 1 Pro at horizonal and vertical positions. The group flew each UAS at varying vertical and horizontal levels above a hydrophone stationed 1 m below the water's surface. They found the most effective way to fly a UAS over a marine mammal to minimize noise impacts was to increase horizontal distance between the animals and the UAS. They determined that increasing altitude does little in minimizing disturbance in comparison to horizonal distance.

In two of the studies mentioned previously that investigate the ability of marine mammals to hear UAS produced noise, Christiansen et al. (2016) and Erbe et al. (2017), hypothesized that these animals may be able to detect UAS noise when close to the water surface and in relatively calm conditions. However, the UASs utilized in this study represented a majority of larger and earlier generation UAS platforms. Also, all studies were conducted over a sound capturing device, not actual marine mammals. These two studies are important precursors to this thesis as they developed a framework of the potential reactions of marine mammals to UAS noise. To test the hypotheses developed in the Christiansen et al. (2016) and Erbe et al. (2017) papers, this thesis involves actual flights over bottlenose dolphins.

In Smith et al. (2016), the authors acknowledge there is a current gap and need for understanding the behavioral responses of various marine taxa to UAS type at differing altitudes. Also, they recognize that the noise data previously described is informative and motivating to further refine our understanding of how UASs affect marine animals as this tool is poised to become a standard in marine mammal science. Likewise, understanding this technology, and its effects on animals can potentially aid in advancing policies, guidelines, and regulations for safe human/marine mammal interactions using UAS.

Behavioral data are essential in this regard as Duncan et al. (2021) points out, the noise profile can be more important than the actual decibels in determining how impactful/annoying a sound is rated. In 2017, NASA investigated this phenomenon by presenting matched amplitude sounds to subjects. Listeners repeatedly ranked UAS sounds as the most "annoying" sound type beating out perineal nuisances like garbage and delivery trucks (Christian & Cabell, 2017). This means that it is critical to assess behavioral responses in subjects rather than just draw conclusions based on sound amplitudes, as not all sound profiles are the same.

PHASM Development

Presently, biologists are limited in their ability to determine the physiological impacts that anthropogenic stressors pose on wild marine mammals, particularly with non-invasive methods. Often, approaches used to determine small cetacean stress and health data involve capture and release, which implicates removing the animal from the water to conduct a series of welfare assessments (Barratclough et al., 2019). Such approaches can increase the individuals' stress hormones, giving improper measurements and risking the subject's wellbeing. Therefore, there is a critical need to develop methodology to allow biologists to collect health hormone samples from cetaceans in a non-invasive, stealthy manner, without eliciting additional stress. With such a method, we would be able to increase our understanding of cetacean health more safely and efficiently in areas with high levels of human disturbance.

Stephen F. Austin State University and Oklahoma State University's Unmanned Systems Research Institute are collaborating on a custom hormone collecting fixed-wing UAS platform developed as part of a project called PHASM (Passive Health Assessment in Sea Mammals). This tool is being developed to survey and assist in examining physiological impacts of anthropogenic stressors on cetacean populations in disturbed coastal areas. For example, this UAS system will help establish the potential relationship between anthropogenic noise and physiological evidence for stress in cetaceans, and further aim to determine the effectiveness of marine sanctuaries in reducing cortisol in wild populations. The platform will allow safe, reliable, biological sampling in wild populations that are otherwise difficult to reach by boat, are easily disturbed by humans or are too sick to have health data collected any other way than by UAS. With this system, if successful, the platform could establish a strong scientific framework to study vulnerable and endangered small cetacean species in a relatively noninvasive manner in the wild. These outcomes are expected to inform long term welfare and health assessments on wild cetaceans.

Project Goals and Objectives

As part of the larger PHASM project, a bottlenose dolphin population under professional care at Dolphin Quest Bermuda (DQB) was utilized to determine how animals subjected to persistent sources of underwater anthropogenic stimuli would react to commercially used and experimental UAS platforms. As such, the goal of this research project is to determine how bottlenose dolphins respond to different UAS types at various heights over multiple sessions to help in the development of a new UAS passive health monitoring system for wild dolphins consisting of both commercial sentinel UASs shown to limit cetacean behavior, as well as a fixed wing custom platform capable of directly collecting blow samples from wild cetaceans as they surface. Sentinel UASs serve the purpose of identifying target cetaceans for hormone collection as well as aiding in photographing subjects. For purposes of this study, it is important to work with a managed-care population of animals living amongst higher levels of human activity (i.e., open ocean access) as this more directly simulated the populations that will be addressed by the PHASM project, and therefore their responses to UAS may be more reflective of wild populations of interest. For example, persistent anthropogenic noise exposure may decrease dolphin responses to UASs through generalized habituation, or may lead to more responses over repeated UAS exposures due to sensitization and stress effects (Stevens & Bruck, 2019).

We evaluated how our subjects responded to multiple UAS systems. The DJI Mini 2, DJI Mavic 2 Enterprise Advanced, DJI Inspire 2, SwellPro SplashDrone 4, DJI Mini 3 Pro, DJI Avata, and PHASM (STRIX StratoSurfer) were used to assess dolphin responses to UAS noise at various altitudes over multiple exposures (trials). For this study, our objective was to evaluate how dolphins under managed care respond in terms of UAS type, UAS height, and UAS flight number (sequence). With each UAS flight, dolphins were evaluated at each height for submersion rate and number of look. We hypothesized that the UASs with the larger noise and sound profiles would generate the larger behavioral responses (number of looks and submersion duration) at lower heights and that the DQB dolphins may become habituated to UASs overtime, i.e., with each UAS flight, the dolphins respond with less looks for example than the flight before.

METHODS AND MATERIALS

Study Area

DQB is located at the National Museum of Bermuda, in Sandys Parish on the northwestern point of Bermuda (32.3291° N, 64.8324° W). This facility is located in the Keep of the Dockyard, a historic fort, providing a secure home for the dolphin residents. DQB is comprised of a lagoon divided into six sections: North, South, East, West, medical pool (Figure 3), and an open ocean habitat (Figure 4). In 2016, the dolphin's habitat was expanded to include an outer habitat with open ocean access. The large sea pen extends beyond the museum walls and allows dolphins to swim into the ocean. The dolphins enter the ocean through a connecting tunnel from inside the lagoon, the same British ships would use in WWII.

DQB is a public facility, allowing guests to interact with the dolphins. The facility provides guests with the opportunity to meet and view the dolphins in a sheltered and natural ocean lagoon. DQB provides high standards of health and animal care and has accreditation and certification from the Alliance of Marine Mammals Parks and Aquariums (AMMPA), International Marine Animal Trainers' Association (IMATA), and American Humane. This population is subjected to a degree of anthropogenic noise, as they live adjacent to a cruise ship port.

Figure 3. DQB’s lagoon (North, South, East, West, and medical pools is labeled). UAS were launched north of the lagoon.

Figure 4. DQB's open ocean habitat. Dolphins enter the unnetted enclosure from the tunnel connected to the lagoon.

Study Subjects

Eleven dolphins (two males, nine females) under professional care at DQB participated in the study (Table 1). The dolphins ranged in ages from three to forty-nine and all, but one dolphin lived under professional care for the entirety of their lives.

Table 1. DQB dolphins' sexes and ages (updated June 2023).

Name	**Sex**	**Age**
F1	Female	49
F2	Female	33
F3	Female	30
F4	Female	20
M1	Male	13
F5	Female	13
F6	Female	9
F7	Female	9
F8	Female	4
M2	Male	3
F9	Female	3

Materials

DJI Inspire 2

The DJI Inspire 2 (Figure 5) has a ConeCore2.1 imaging process system built inside the aircraft and a video recording capability up to 6K in CinemaDNG/RAW. The UAS has a 360° rotating gimbal, a 6K camera, and utilizes the Zenimuse X7 camera with multiple lenses, a 50mm, 35mm, 24mm, and a 16mm. It can capture 30 megapixels still images. The aircraft can reach a speed of 58mph. It utilizes a dual battery system that allows a maximum flight time of 23 minutes per flight. The DJI Inspire 2 is Flight Autonomy capable, meaning it provides directions for obstacle avoidance and sensor redundancy (DJI, 2021b). The UAS has a feature called spotlight pro, which allows a pilot to lock onto a subject in flight.

The DJI Inspire 2 controller possesses a 'Smart Return to Home' feature, meaning it has a failsafe mechanism that allows the pilot to safely return to its home point in case of emergency. The controller has a designated platform that safely holds the phone or tablet in place. With the downloadable application, DJI Fly 4.0, all logging, planning, recording, and photography can take place with the pilot's mobile device. The DJI Inspire 2 was utilized in this behavioral study. This UAS was chosen for its wind resistance ability, allowing it to remain stable through high ocean wind currents. The high-resolution camera, the Zenimuse X7, allows for high quality dolphin photos at close and far range.

DJI Mavic 2 Enterprise Advanced

The DJI Mavic 2 Enterprise Advanced (Enterprise) (Figure 5) has infrared thermography and visual camera capabilities. The aircraft offers a maximum flight time of approximately 31 minutes and a maximum speed of 45mph (DJI, 2021c). The 48MP visual camera is equipped with a ½" CMOS sensor and a 32x digital zoom. The thermal camera features a 30Hz frame rate, a 640 x 512 px thermal resolution, a 16x thermal zoom, and has ±2°C temperature measurement accuracy (DJI, 2021c). The infrared thermography (IRT) camera comes equipped with a spot meter. This feature displays the average temperature of an object. Also, it is capable of area measurement, which displays the average, lowest, and highest temperatures; and visualizes the corresponding locations of each area (DJI, 2021c). The Mavic 2 is controlled through the DJI Smart Controller, which has a 5.5-inch 1080p display and has the DJI Pilot app preinstalled. Through the controller, pilots can easily switch between visual, thermal, or split view for various project needs. Similar to other DJI UASs, the controller features the 'Smart Return to Home' feature. The Enterprise was utilized in the behavioral study. This UAS was chosen because of its unique thermal imagery capabilities, along with its ±2°C temperature measurement accuracy.

DJI Mini 2

The DJI Mini (Figure 5) provides a lightweight and foldable option for a UAS, weighing less than 249g. This allows for compact and convenient travel. This aircraft has a max battery life of 32 minutes and can withstand 29-38mph winds (DJI, 2021a). It possesses a three-axis gimbal with a 4k camera/ 30fps video and the ability to zoom in on an object 4x while remaining stationary in the air. Similar to the other listed UASs above, the DJI Mini 2 possesses a 'Smart Return to Home' feature on the controller (DJI, 2021a). The controller has a designated platform that safely holds the phone in place. With the downloadable application, DJI Fly, all logging, planning, recording, and photography can take place with the pilot's mobile device. This UAS was chosen for the behavioral study due to its quiet and stealthy nature, also for its easily transportable nature.

Figure 5. Photograph of the first three of the UASs utilized in the study. (Left to Right: DJI Mini 2, DJI Mavic 2 Enterprise Advanced, DJI Inspire 2)

PHASM

The PHASM hormone collection platform is a FPV (first person view) fixed wing system. The base of the aircraft is the STRIX StratoSurfer (Figure 6). This UAS has a blow molded fuselage allowing for an abundance of room for accessories. The plane uses a six-inch tribade propellor and a three-inch pitch. With the 5200 mAh LiHV battery, the plane has a battery life of approximately 20 minutes. PHASM can reach an airspeed of 20mph and can withstand up to approximately 25mph winds.

The UAS is flown using FPV controls, meaning the pilot operated the UAS with goggles and a controller. The radio controller used is a RadioMaster TX16S MKII V4.0 2.4G 16CH Hall Gimbals Transmitter Remote Control ELRS 4in1 Version Support EDGETX and OPENTX. The googles used are the Fat Shark Dominator HD FPV Goggles. PHASM is equipped with a custom 3D printed syphon attached to the bottom of the UAS to vacuum in small cetacean exhalation (Figure 6). This is the exhalation/ dolphin snot collection system. The purpose of the syphon is to suction the dolphin breath into the system where it can be stored and transported for future hormone analysis. This device has an iris (an attachment that opens and closes to protect the inside of the syphon from foreign materials) that would open and close with a switch on the controller. When the UAS is stationed above the cetacean, the iris will be manually switched opened to only collect the exhalation. Likewise, the syphon was controlled by a switch on the controller. When this switch is turned on, the suction mechanism will suck the exhalation into the syphon. The hormone collecting system (the syphon) was not turned on during the flights for this study.

Figure 6. TRIX StratoSurfer, the base model for the hormone collecting platform of PHASM.

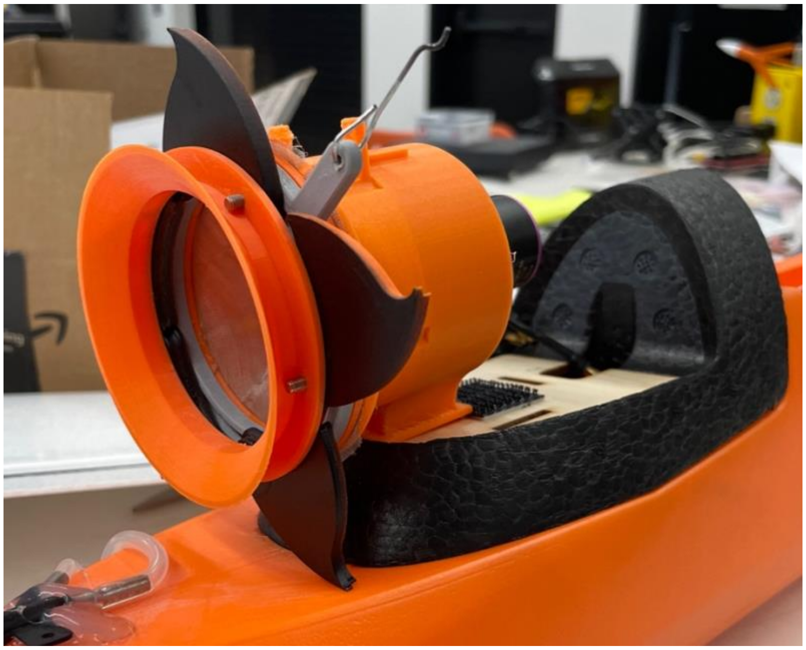


Figure 7. PHASM’s syphon. This device is used to syphon cetacean blow mucous onto a collection screen for analysis. The suction maintains the forward directed momentum of the system. The fan and the black colored iris (open) are controlled from the pilot's controller. The iris seals the filter from exposure before and after collection and prevents contamination.

SwellPro SplashDrone 4

The SplashDrone 4 (Figure 8) is a multi-functional waterproof UAS platform. This UAS provides a seawater proof, corrosion-free body and floating platform to allow for flight in multiple environmental conditions (SwellPro, 2023). It can withstand up to a 31-mph wind speed and a 2kg payload. The slide-in smart battery allows for internal management and safety from outside elements, such as seawater. This helps ensure a battery life of approximately 30 minutes per flight. The 4K 3-axis gimbal allows for quality video and pictures. Like the DJI UASs listed above, the SplashDrone 4 has the return to home feature.

The IP66 Waterproof Remote Control is equipped with waterproof motors and internal electronics, which is coated with corrosion-resistant coating (SwellPro, 2023). The controller contains a built-in GPS, a WiFi multi-point hotspot, and an eight-hour battery life. Instead of a built-in screen, the pilot uses their phone as a screen. The controller has a designated platform that safely holds the phone in place. With the downloadable application, SwellPro SDFly 2 App, all logging, planning, recording, and photography can take place. SwellPro's SplashDrone 4 was chosen for its waterproof capability. This UAS allowed or flights in all weather conditions.

DJI Avata

The DJI Avata (Figure 8) is a compact and lightweight FPV UAS, weighing approximately 410g. It comes equipped with a propellor guard, allowing for extra protection for the UAS in case of collision. With the aerodynamic design, the battery life can last up to 18 minutes. The UAS can travel at a speed of approximately 18mph in normal mode and 31mph in sport mode, while withstanding a maximum of 23mph winds. With a 1/1.7 inch CMOS sensor, the UAS supports 4k ultra-wide-angle recording (DJI, 2023a). The gimbal provides a single axis tilt (DJI, 2023b). For this study the DJI Remote Controller 2 was flown using the DJI Fly app connected to the pilot's mobile device. This UAS was chosen for the behavioral study to see the dolphin's reaction to an FPV style UAS.

DJI Mini 3 Pro

The DJI Mini 3 Pro (Figure 8) is a lightweight and portable UAS weighing under 249g, making it the smallest of the DJI Mini-series. The max flight time is dependent on the type of battery used. With the Intelligent Flight Battery, the aircraft can fly for approximately 34 minutes. With the Intelligent Flight Battery Plus, the aircraft can fly for approximately 47 minutes. The UAS can withstand windspeeds of 23mph. The three-axis mechanical gimbal allows for a wider rotation allowing for more versatility in low angled photography. With tri-directional obstacle avoidance, the Mini 3 Pro is equipped with forward, backwards, and downwards dual-vision sensors, providing a higher standard of safety when flying.

The DJI Mini 3 Pro comes with a controller with a built-in screen, the DJI RC. This new controller can switch between 4.0K/30fps, 2.7K/30fps, and 1080p/ 30fps. At 1080p/ 30fps the max transmission range is 9 miles, allowing for safe distance flying. This UAS was chosen for the behavioral study due to its quiet and stealthy nature, its easily transportable nature, and for the built in screen controller.

Figure 8. Photograph of three of the UASs utilized in the study. (Left to Right: DJI Avata, SwellPro SplashDrone 4, DJI Mini 3 Pro).

Table 2. Comparison of the seven UAS types used in the study.

UAS Name	*Weight (g)*	*Diagonal Size*	*Max Speed (mph)*	*Max Flight Time (min)*
DJI Inspire 2	4250	23.8" / 605mm	58	23
DJI Mavic 2 Enterprise Advanced	909	13.9" / 354 mm	45	31
DJI Mini 2	<249	8.4" / 213 mm	38	32
DJI Mini 3 Pro	<249	9.7 inches / 247 mm	23	47
DJI Avata	410	4.7" / 120 mm	31	18
SwellPro SplashDrone 4	735	17.7" / 450 mm	22.4	30
PHASM Collector Platform	3175	39" / 1000mm	20	20

Amplitudes and Dominant Frequencies of Study UASs

UAS noise recordings were taken using a Hausbell Parabolic Microphone to a Zoom H1n recorder at 96kHz sampling frequency. Each UAS was recorded while in stationary flight (as indicated in Figure 9) for 15 seconds. Each rotary UAS was recorded on the same day in the same weather conditions: wind speed at 3mph, wind gusts at 12mph, wind direction northwest and air temperature at 92°F (weather reported from UAV Forecast App) (Table 3). Acoustics were measured in PRAAT version 6.3.10 where predominate amplitudes and frequencies were determined using PRAAT's derived intensity feature. PHASM's propulsion was recorded on the ground in an anechoic chamber with three microphones in a 1.5m arc around the UAS. The UAS was programed to emit the exact motor and propellor frequency and sound intensity as when it flew over the dolphins (approximately 50% power). The data was analyzed by a custom python script and exported into a plot for descriptive analysis (Table 3).

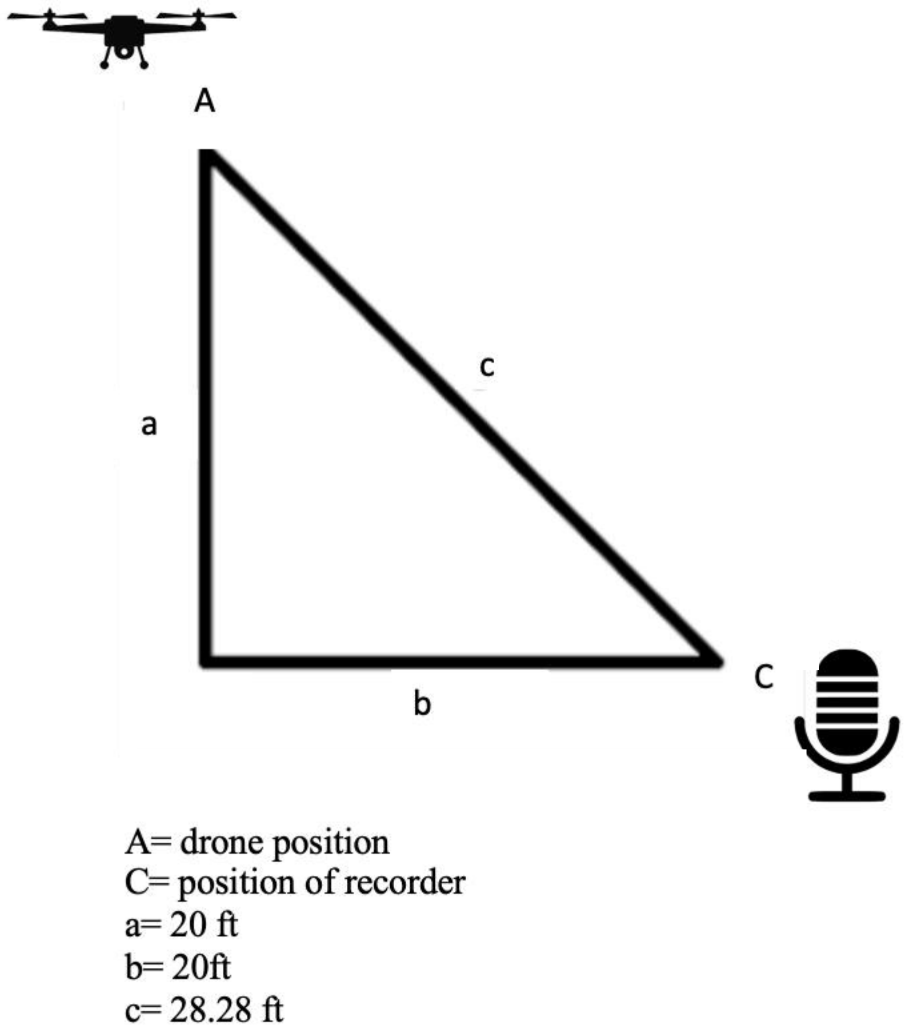


Figure 9. Rotary UAS position while recording the sound profile of each device. UASs were recorded in air at 20 feet (6.1 m) in altitude with a launch site 20 feet (6.1 m) in distance from the recorder. A parabolic microphone was aimed at the UAS to capture the sound profile of the device for later amplitude and frequency analysis in PRAAT (Boersma & Weenink, 2023)

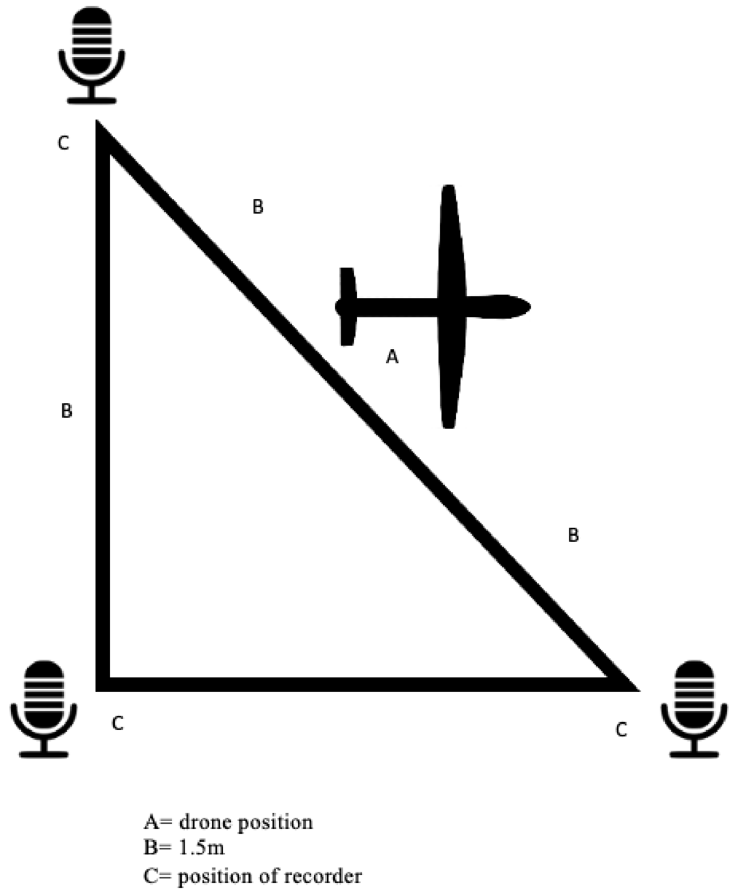


Figure 10. PHASM position while recording the sound profile. PHASM was recorded in an anechoic chamber with three microphones in a 1.5m arc around the UAS (not in flight). The UAS was programed to emit the exact motor and propellor frequency and sound intensity as when it flew over the dolphins (approximately 50% power). The data was collected with National Instruments Signal Express 2015 and processed with a custom python script.

Table 3.Results of UAS sound intensity and predominate output frequencies.

UAS Name	*Maximum Sound Intensity (dB)*	*Average Sound Intensity (dB)*	*Predominant Frequencies Measured (Hz)*
DJI Avata	89.92	88.08	9000
DJI Mavic 2 Enterprise Advanced	86.42	85.99	6000 9000 12000
DJI Inspire 2	90.22	89.5	6000 9000
DJI Mini 2	85.37	84.78	5000 8000- 12,000
DJI Mini 3	85.25	84.395	4000- 6000 7500- 9000 12000
SwellPro SplashDrone 4	93.00	92.79	5000-6000 8000-9000
PHASM	71.41	70.41	846

Methods for UAS Response

Pre-takeoff Procedures

All FAA Part 107 small aircraft rules were reviewed pre-flight, and the pilot(s) obtained Part 107 licenses. Each UAS is registered through the FAA and is legal to fly in designated airspaces flown for the study. Before flight, the app UAS Forecast was checked to ensure the area is safe and adequate for takeoff. Before takeoff, the UAS was placed in a location that is safe for takeoff and landing. All participants were updated on safety regulations. The camera's lens cap was removed, and all UAS batteries were checked for full charges. Charging stations were placed in an assessable location for battery changes. The airspace was scanned for potential hazards and the UAS always stayed in the pilot's line of sight.

Assessment of UAS Exposure on the Dolphin Population

This study was conducted over a one-week period in March 2022, a four-week period in May-June in 2022, a one-week period in March 2023 and a four-week period in May-June in 2023 at DQB. The DJI Mini 2, DJI Mavic 2 Enterprise Advanced, DJI Inspire 2, DJI Avata, DJI Mini 3 Pro, SwellPro SplashDrone 4, and PHASM were utilized for the behavioral assessment. For this study, we were interested in how dolphins respond to different UAS types as a function of height and habituation. As such a no drone control was not essential to determining which UAS caused the most disturbance, especially as a no drone control would not make sense to the habituation analysis.

The rotary UAS was launched from a launch pad approximately 200 ft north from the north dolphin pool (Figure 3). Each flight was approximately 10 minutes in duration. The UAS began at an initial hovering height of 300 ft above an individual dolphin in the north pool. Each target dolphin was in the north pool at the time of flight and was chosen at random from available dolphins in the pool. If the target dolphin did not show an aversive response consistently for 10 seconds at a determined height, the UAS decreased vertically in height at 10 feet increments (this means the behavioral responses taken at each height occurred during the 10 seconds the UAS was at that height). Aversive responses include speed swimming (rapid animal locomotion above 12-15 mph), extended submersion (conservatively defined as > 30 s across three consecutive heights (Giles et al., 2021), or prolonged paired swimming (a mechanism of stress mitigation in dolphins through social affiliation) (see Duranton & Gaunet, 2016; Sakai et al., 2010). If the target or surrounding dolphins did not show aversive responses the flight would end with the UAS 20 feet above the water. For each day a maximum of three flights could be conducted. Each day was divided into morning, afternoon, and evening flights. During each flight, all marine mammal specialists (dolphin trainers) and guests were off the docks and out of the water.

The fixed wing UAS (PHASM collection platform) was hand launched approximately 200ft from the north dolphin pool. The flights were performed on non-rainy days with wind speeds below 20mph. Since the PHASM hormone collector is a fixed wing UAS, it does not have the hovering capability of rotary UASs. Instead, the plane would glide over the dolphin pool. The UAS began at an initial gliding height of 300 feet and would decrease in 50 ft height increments until it was 100 feet above the dolphin pool (with the exception of one flight with an initial height of 400ft) (Figure 11A, Figure 11B). When the UAS was stationed over the water's edge of the west dolphin pool at its predetermined height, the 10 second countdown would begin as it continued to glide over the pool. With each height, a spotter evaluated dolphin responses to ensure the dolphins were not in an extended submerged response due to a certain UAS height. At the same time a Mavic 2 Zoom or a Mini 3 Pro would hover at 410 ft above the lagoon to record the responses without the devices themselves influencing the behavior of the animals (these UAS were selected for their zoom camera capabilities allowing for scorable videos and visible dolphins at these heights).

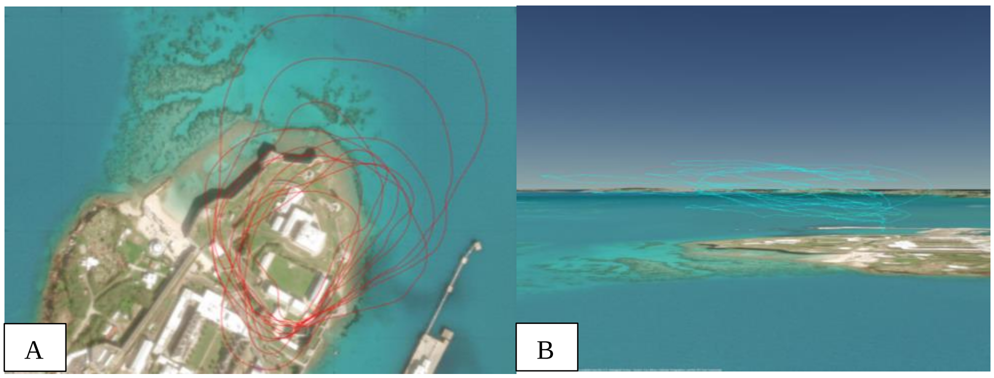


Figure 11. A) PHASM hormone collecting system overhead flight view for typical flight session. Red lines converge on the bottom of the figure over the dolphin habitat. Approach vector was consistently East to West over dolphin habitat as the system achieved target heights. B) PHASM hormone collecting system approach pattern from a 30-degree angle. System approach over the lagoon is captured on the right side of the blue lines as the view is from the Northeast.

The eleven individuals in the Dolphin Quest Bermuda population, were each tested for individual behavioral responses and compared. The specific behaviors scored per height and UAS type were number of looks and duration of submersion. After each individual flight is recorded, the video was analyzed and compared to other DQB dolphin behavioral responses. To analyze the look and submersion behaviors, we had two pairs of individuals score each video blindly with respect to UAS type or flight sequence. All scorers were trained as a group to understand the look and submersion behavior. Also, all were trained to understand the dolphin identifications via UAS. One pair would watch the videos and analyze the looks and a separate pair would analyze the video for submersion for the entirety of each video. For each variable, each pair would watch through the videos independently and compare analyses. If the animal was not visible in the camera view for the entirety of each height, the animal would not be scored for the analysis. They would not be scored for the specific height because if they were out of the camera's view, we co guarantee which behavior they were presenting. After comparison of each analysis, a percent agreement would be measured between each pair and averaged to obtain a total percent agreement for the entire analysis. The average percent agreement among both submerges and look scorers was 93.4%

Behavioral Analysis

I first focused on non-look and look behaviors (Figures 12A, Figure 12B) as a proxy of dolphin attention and detection of the UAS. Meanwhile, a look behavior is defined by behaviors where the UAS captures the animal's eyes. Dolphins can, however, see ventrally so a dolphin on its back can look up hence even if the eyes aren't visible here (Figure 12A), that would still be a look (Gunnars & Bruck, 2019). Each behavior is used to determine if the dolphin was attempting to visualize the UAS for analysis. Submersion behavior was defined as when the entire animal's body was contained beneath the waterline. While there is no hard and fast rule for this in terms of timing, extended periods of submersion may be indicators of an aversive response to aerial threats or UAS (Giles et al., 2021).

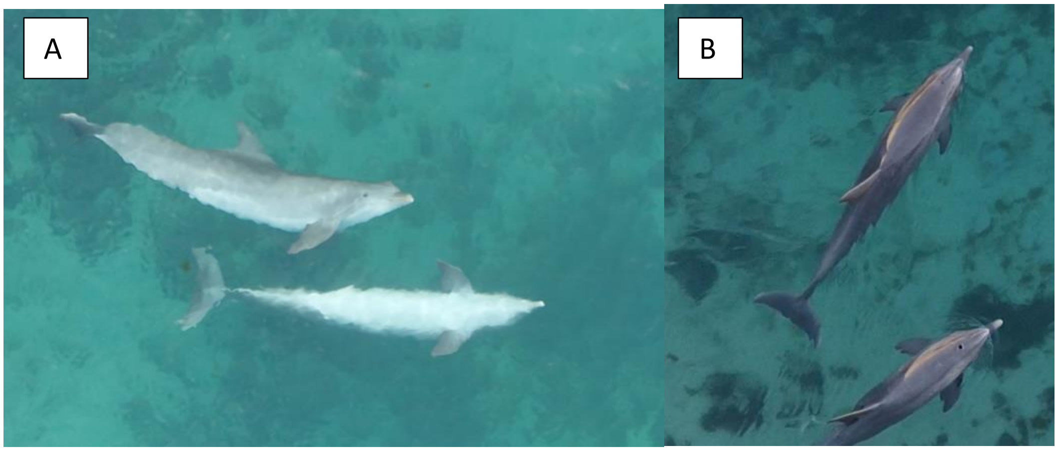


Figure 12. (A) Both dolphins exhibiting look behavior (the bottom dolphin doing so ventrally) and presenting a submerged behavior. (B) Both dolphins representing a non-look and unsubmerged behavior.

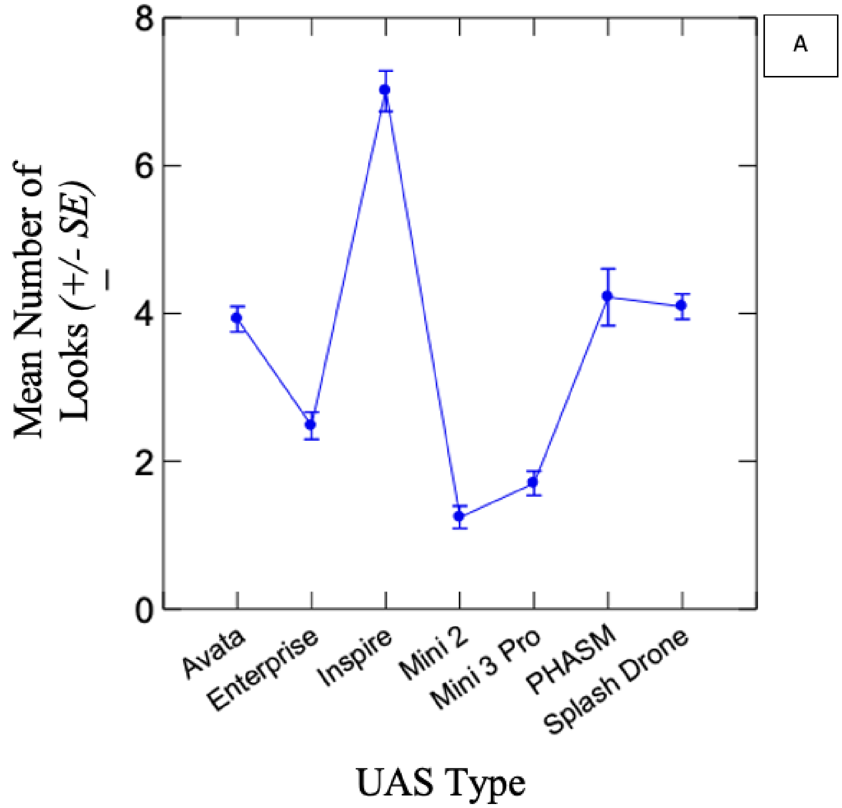
Statistical Analysis

To test differences in response by UAS type, height and flight number Generalized Linear Models (GLMs) in Systat v.11 (Wilkinson, 2004) were performed as this analysis is resistant to assumptions around unequal testing of subjects. For distribution fitness I used RStudio 2021.09.01 (R Development Core Team, 2021) and determined fit using the fitdistrplus package (Delignette-Muller & Dutang, 2015), plotted with Q-Q plots and Cullen and Frey graphs to visualize fitness. Subsequently, I used a gamma family and log function to test continuous submergence data and a poisson error distribution to test the discrete number of looks data. For each model, we used the test subject (target dolphin) as an effect variable to measure how each dolphin explained variation in the response. Other effects for each model included UAS type, height and first vs. last flight (for each UAS). Subsequently, we used GLM models to test whether there was a significant difference in look and submergence behavior by UAS, height, and flight sequence (first vs. last flight). Plots were made in Systat v.11.

RESULTS

Submersion and Number of Looks by UAS Type

To determine which UAS platform produced the highest number of looks and longest submersion duration, we analyzed each dependent variable against UAS type. Results showed that dolphins look at differing rates to certain UAS ($F (6, 1{,}469) = [82.658]$, $p < 0.001$) (Figure 13A). The Inspire 2 produced the greatest mean number of looks at 7.4 looks. The Avata, PHASM and SplashDrone 4 resulted in a middle mean number of looks at approximately 4 looks. The Mini 2, Mini 3 Pro, and Enterprise produced the least amount of looks at approximately 1.6 looks (Mini 2 and 3) and 2.3 looks (Enterprise). The mean submersion time per UAS type was considered significant with variation between UAS types ($F (6, 1469) = [6.364]$, $p < 0.001$) (Figure 13B). PHASM produced the highest submersion time with a mean of 105 seconds of submersion. The SplashDrone 4, Avata, Mini 2 and Mini 3 Pro produced a median amount of looks (between 90 and 78 seconds) and Enterprise produced a mean of 93 seconds. The Inspire 2 generated the lowest submersion time (inverse to the number of looks) with an approximate mean of 70 seconds of dolphin submersion time.


A
Mean Number of Looks (+/- SE)
8
6
4
2
0
Avata
Enterprise
Inspire
Mini 2
Mini 3 Pro
PHASM
Splash Drone
UAS Type

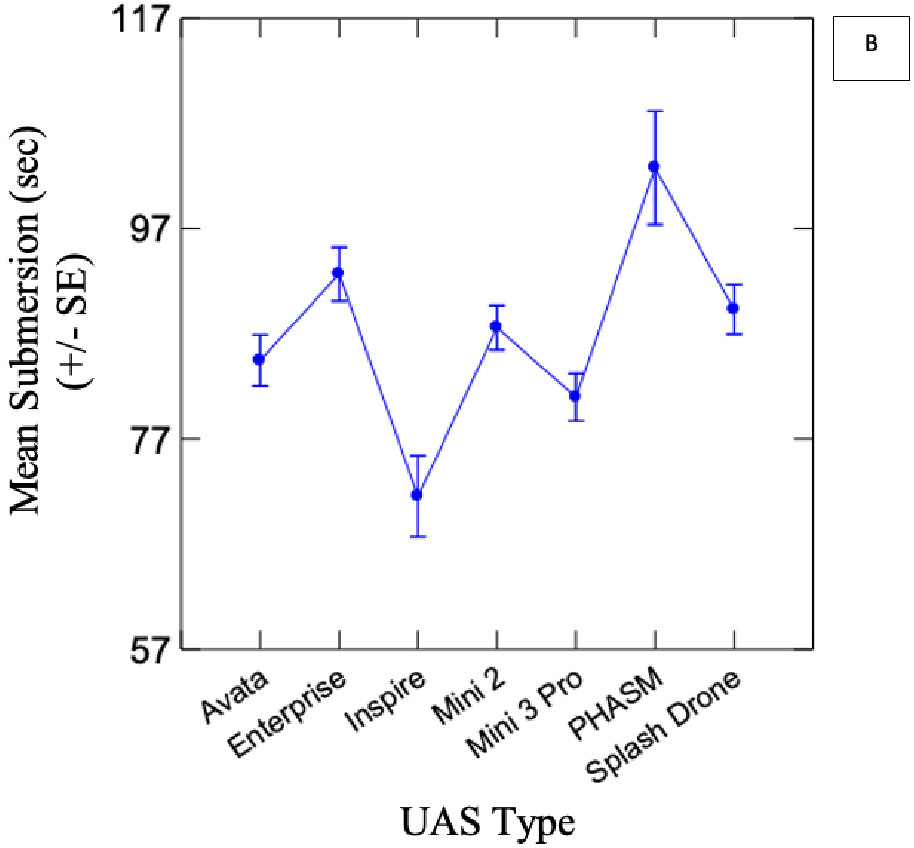
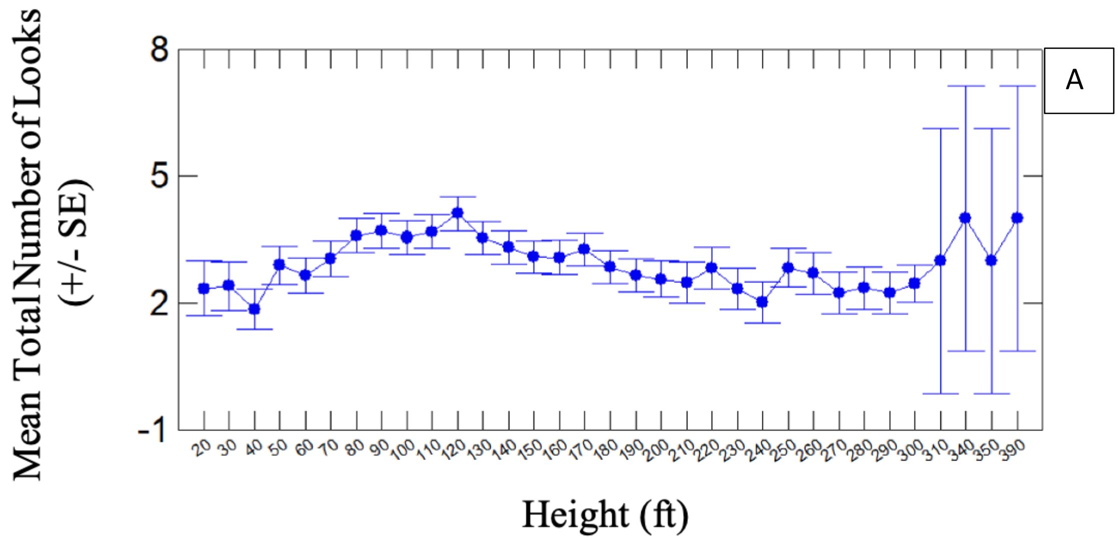
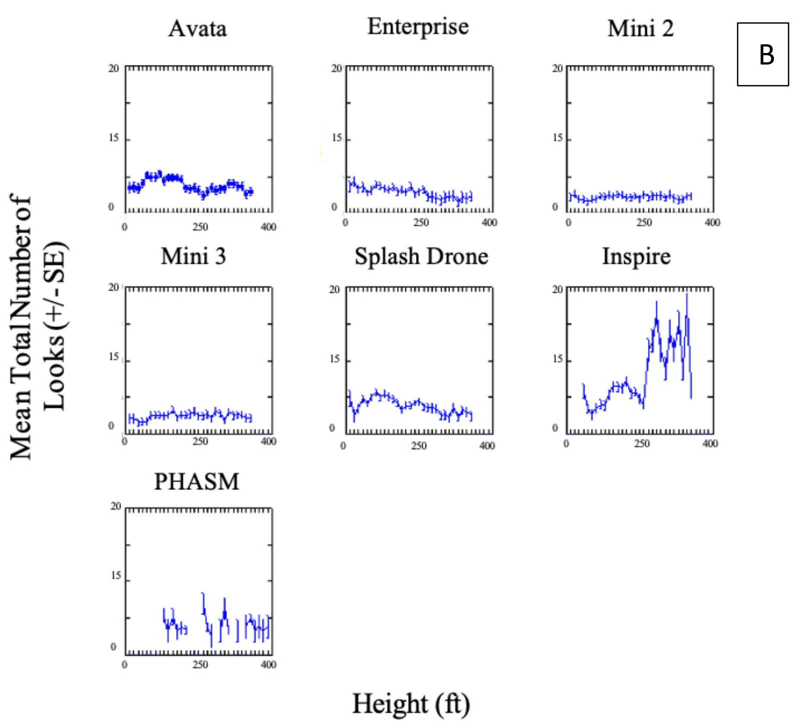


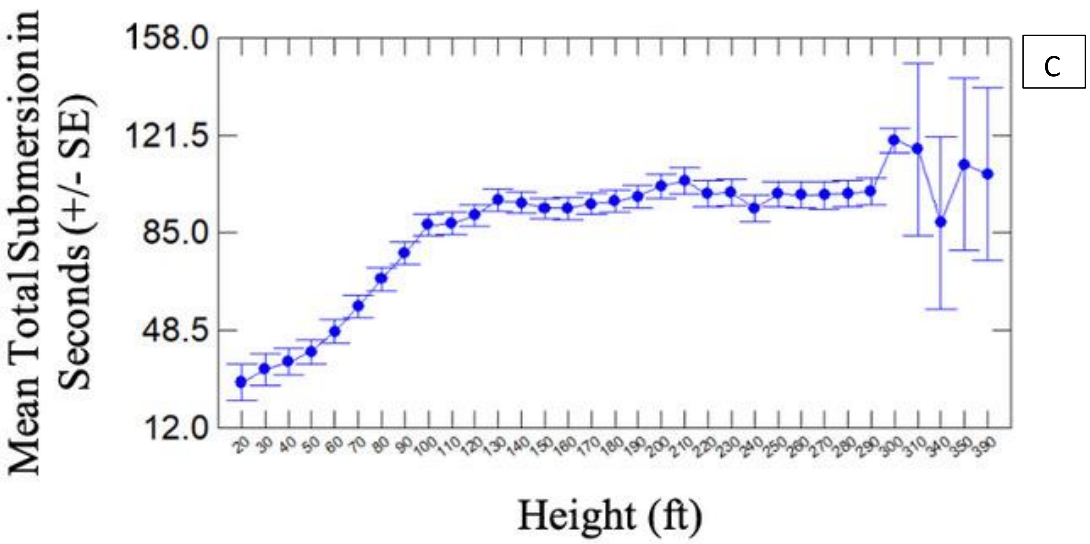
Figure 13. (A) The mean (+/- SE) number of dolphin looks per UAS type for all UASs. (B) The mean (+/- SE) duration of dolphin submersion time as a function of UAS type.

Submersion and Number of Looks as a Function of UAS Height

For this analysis, the mean total number of looks across all UAS heights was calculated. Results showed that the mean total number of looks was constant and were not significant for height (The error above 300ft represents the flights of the PHASM hormone collector as PHASM was the only UAS to fly above 300ft) (F (32, 1,443) = [1.446], p = 0.052) (Figure 14A), however there is variation in the Inspire 2's and PHASM's pattern (Figure 14B). The Inspire 2 produced high numbers of looks at higher heights, with a steep decline in looks at 260ft. PHASM produced varying amounts of looks with the greatest number of looks being generated at 250ft. Enterprise, Mini 2, and Mini 3 overall had a consistently low total number of looks across all heights. Avata and SplashDrone 4 had more variety in the number of looks, however the look numbers are still low. Mean total submersion response was significant with a decrease in submersion time in relation to decreasing height ($F(32, 11443) = [20.859]$, $p < 0.001$) (Figure 14C). This pattern was consistent across each UAS type (Figure 14D). For Avata, there was a decrease in submersion at 290ft (212 seconds to 75 seconds) and again at 50ft (75 seconds to 14 seconds). From approximately 300ft to 100ft the Enterprise submersion time is constant with a steady decrease in dolphin submersion at 90ft. For Mini 2, Mini 3 Pro, and SplashDrone 4 approximately 300ft to 150ft the submersion time is constant and decreased at 130ft. From approximately 300ft to 230ft, the Inspire 2 had consistent submersion and at 220ft there was a steady decrease. For PHASM there is a peak in submersion at 300ft and 130ft and a low at 300ft.


A
Mean Total Number of Looks (+/- SE)
8
5
2
-1
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 340 350 390
Height (ft)


B
Avata
Enterprise
Mini 2
Mini 3
Splash Drone
Inspire
PHASM
Mean Total Number of Looks (+/- SE)
Height (ft)


C
Mean Total Submersion in Seconds (+/- SE)
158.0
121.5
85.0
48.5
12.0
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
340
350
390
Height (ft)

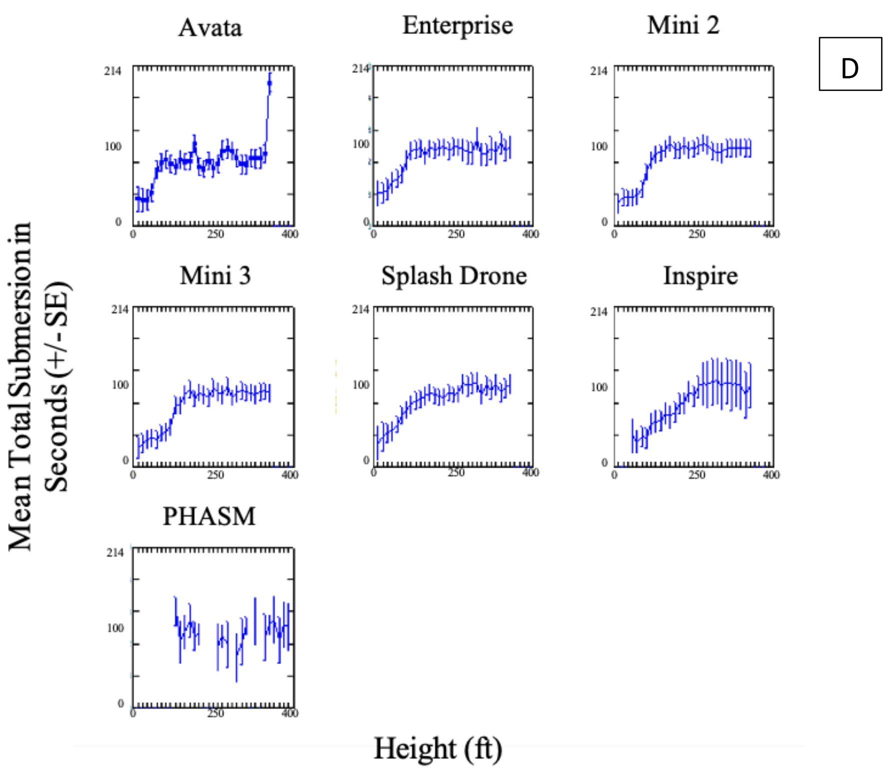
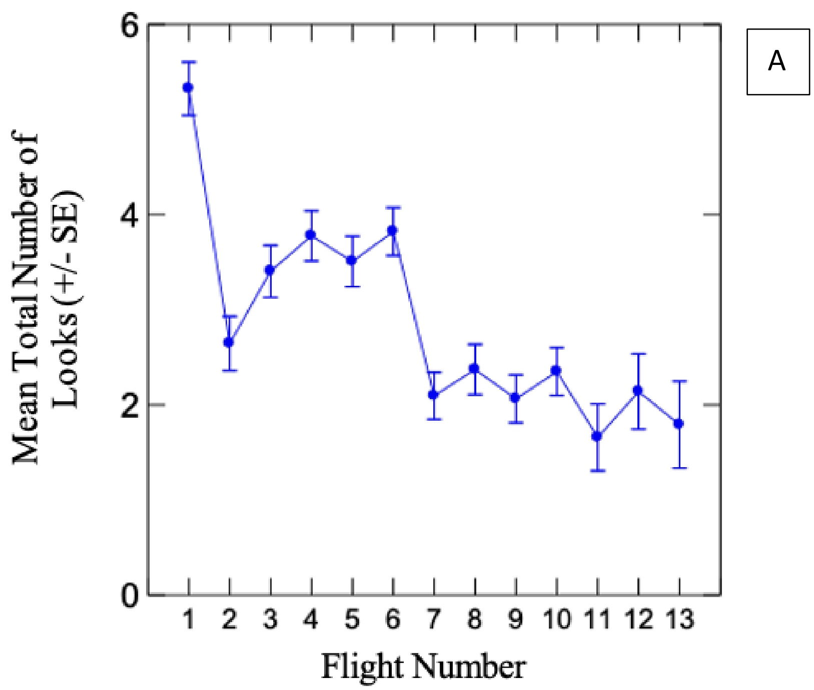

D
Avata
Enterprise
Mini 2
Mini 3
Splash Drone
Inspire
PHASM
214
100
0
250
400
Mean Total Submersion in Seconds (+/- SE)
Height (ft)

Figure 14. (A) The mean (+/- SE) total number of looks by dolphin per UAS height. (B) The mean (+/- SE) total number of looks per height for all dolphins by UAS type. (C) The mean (+/- SE) submersion time of dolphins per UAS height. (D) The mean (+/- SE) total submersion per height for all dolphins by UAS type. Missing data for PHASM indicates heights the system was not able to reach over the course of the study (including low passes over the walled lagoon area).

Submersion and Numbers of Looks for Flight Sequence

To determine the DQB dolphin's total number of looks per each flight on each UAS type, we evaluated the total looks over subsequent UAS flights. Look response differences between each flight were significant with a decreasing number of looks between the first and last flights for each UAS ($F(1, 300) = [19.72]$, $p < 0.001$) (Figure 15A). There was variation in how UAS affected the dolphin's look behavior (Figure 15B). Mini 2, Mini 3 Pro, PHASM, and Avata generated a rather consistent and low number of looks from the dolphins. For Enterprise, the dolphins appear to look less with each UAS flight, except for a peak for flight #6. The Inspire 2 produced the highest amount of looks for flight #1, however there is a decrease in looks at flight #2 and a steady increase afterwards. Splash Drone 4 produced a higher amount of looks between flight #4 and #5 with a varying number of looks afterward. As with number of looks, the analysis performed compared the mean submerge time difference between the first and last flight for each UAS. Results showed that dolphins submerge longer over successive exposures of UAS ($F(1, 300) = [7.995]$, $p < 0.005$) (Figure 15C), however there is variation to how this pattern manifests per UAS type (Figure 15D). For early Avata flights, dolphins appeared to submerge for less time in comparison to the later flights. Enterprise exhibited constant high submerge rates. The Inspire 2 showed one of the lowest submersion rates across earlier flights compared to all UAS platforms. Dolphins exposed to the Mini 2 and Mini 3 Pro produced consistently high submersion rates. PHASM generated the highest levels of dolphin submersion rates. Dolphins exposed to the SplashDrone 4 has a low level of submersion during the earlier flights; however, it quickly peaks to a stable high submersion rate for the later flights. Across all UAS the first four flights averaged 78 seconds of submergence per dolphin and the last nine flights averaged between 90 seconds to 96 seconds of submergence between dolphins



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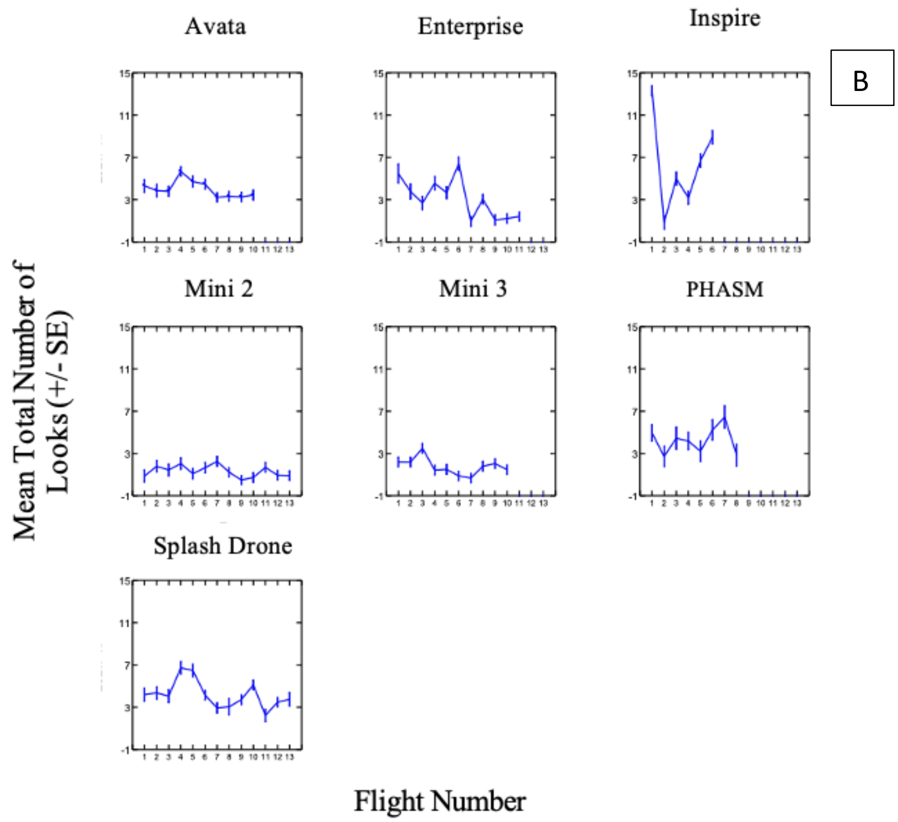
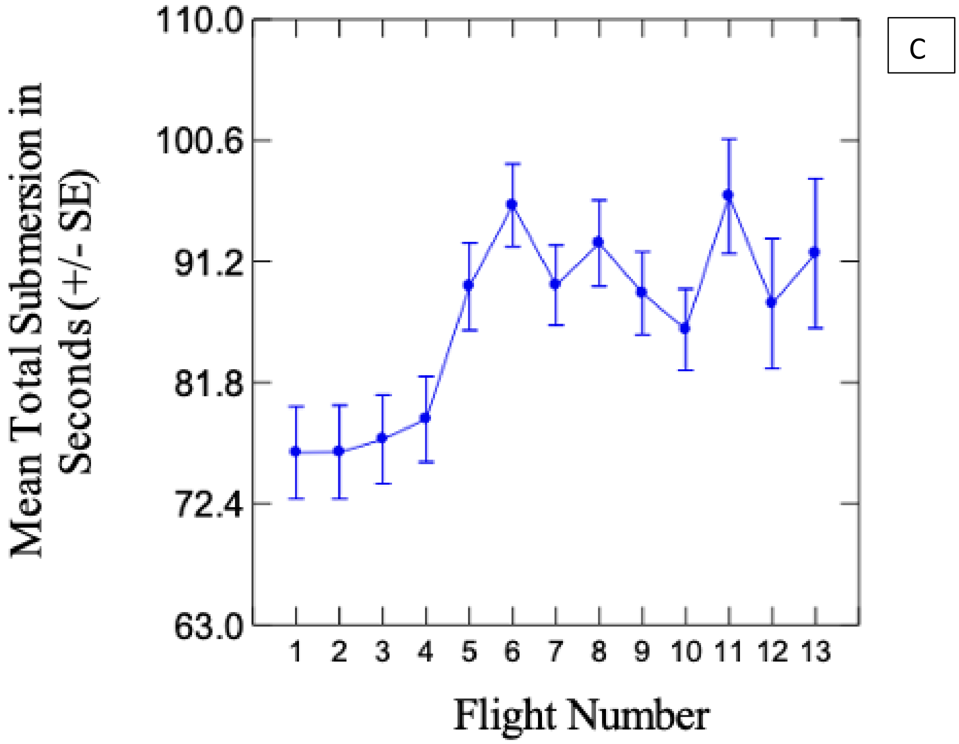

B
Avata
Enterprise
Inspire
Mini 2
Mini 3
PHASM
Splash Drone
Mean Total Number of Looks (+/- SE)
Flight Number



110.0
100.6
91.2
81.8
72.4
63.0
1 2 3 4 5 6 7 8 9 10 11 12 13
Mean Total Submersion in Seconds (+/- SE)
Flight Number
C

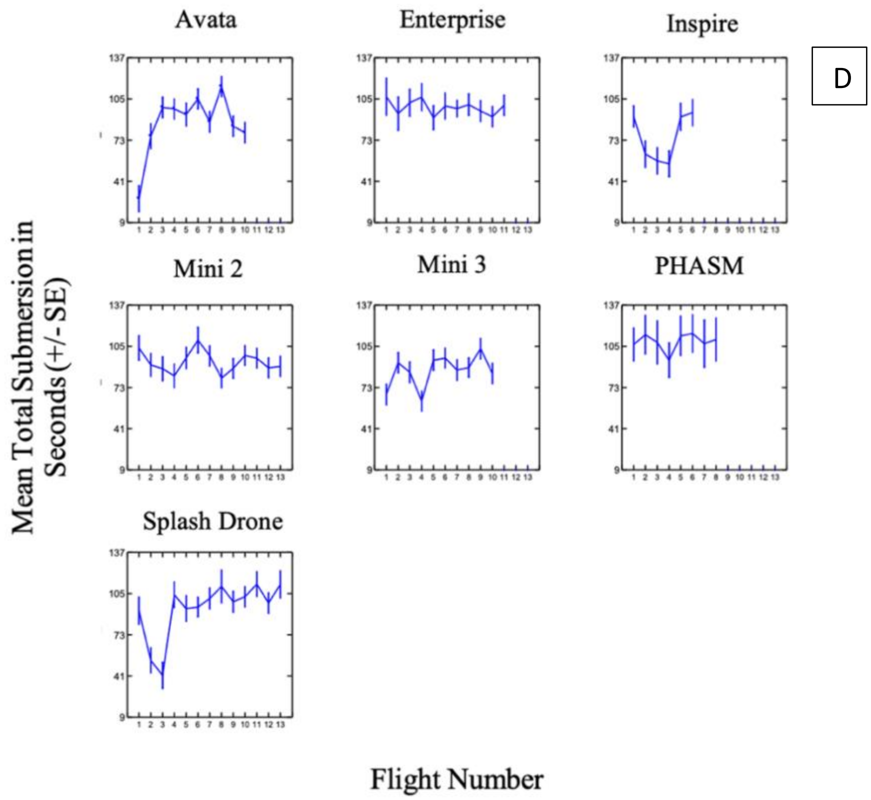


Figure 15. (A) The mean (+/- SE) total number of looks per flight number of all UASs. (B) mean (+/- SE) total number of looks by DQB dolphins per UAS flight across all UAS platforms. (C) The mean (+/- SE) total submersion time by dolphins per flight number for all UASs. (D) Descriptive analysis of mean (+/- SE) total submersions by DQB dolphins per UAS flight across each of the UAS platforms

Estimated Effect of Subject on Submersion and Look Behaviors

To determine the estimated individual DQB dolphin submersion and look response, an average analysis was made per dolphin in reference to the two variables. Subject was a significant factor for both duration of submergence (F (11, 1465) = [683.985], p < 0.000) and number of looks (F (11, 1465) = [131.199], p < 0.000), indicating that dolphins respond differently as individuals (Table 4). The higher the negative number, the lower the response. The higher the positive number, the higher the response (rounded to nearest tenth). In reference to submersion, there was variation in terms of dolphin age. On average, the older the dolphin (over the age of 10 years old), the lower the submersion response and the younger the dolphin (younger than 10 years old) the higher submersion response. In reference to the look behavior, the effects showed more consistency across all age groups.

Table 4. DQB dolphins' Estimation of Effect on Submerge and Look Behavior per Individual Animal. High negative number indicates low response and high positive number indicates high response (rounded to nearest tenth). Constant represents the variation caused by factors other than subject.

Name	**Sex**	**Age**	**Estimate of Effects Submerge (%)**	**Estimate of Effects Looks (%)**
Constant	-	-	86.0	3.0
F1	Female	49	-8.5	-0.5
F2	Female	33	1.8	2.0
F3	Female	30	-0.9	-0.5
F4	Female	20	1.0	-1.0
M1	Male	13	-8.2	0.3
F5	Female	13	-0.8	-0.7
F6	Female	9	3.8	-0.5
F7	Female	9	-0.8	0.7
F8	Female	4	3.0	0.5
M2	Male	3	5.3	0.7
F9	Female	3	9.3	-0.2

DISCUSSION

The goal of this research project was to determine how bottlenose dolphins respond to different UAS types at various heights over multiple sessions to help in the development of a new UAS passive health monitoring system for wild dolphins as well as assess the value of common UASs in cetacean research both in general and specifically for the PHASM project as sentinel systems. As we evaluated how dolphins under managed care respond in terms of UAS type, UAS height, and UAS flight number (sequence), we determined that the dolphins at DQB responded to multiple UAS systems in different ways and differently as individual dolphins. These insights helped shape decisions with the PHASM project and will be valuable to cetacean researchers interested in minimizing how their choice of UAS affects cetacean behavior.

For UAS type, results showed that the number of looks for the Inspire 2 served as an extreme outlier eliciting the most amount of looks. The Inspire 2 was the largest rotary-wing UAS platform utilized. These responses could potentially be explained by the obvious in that large noisy UAS cause a lot of interest, measured in look responses above water. Although acoustically it is not technically the loudest UAS (that distinction belongs to SplashDrone 4, Table 2), this UAS was presented to the dolphins a year before the SplashDrone 4. Since the dolphins were presented the Inspire 2 first, this may have prepared them for the SplashDrone 4's loud noise profile- although there is some evidence that dolphins readily lose habituation to noises after a short period of sound cessation (Stevens et al., 2023). To support our hypothesis, one of the UASs with the largest noise and visual profile (Inspire 2) generated the most amount of looks. However, the Inspire 2 produced the lowest amount of submergence by the dolphins. This could be attributed to the dolphin's spy hopping or swimming above the surface to view the UAS instead of remaining submerged, meaning the dolphins are potentially trading a submersion response for an above water look response. Additionally, the low submersion response could indicate the dolphin's interest in the UAS. The dolphin could be coming to the surface to visualize the UAS due to a high level of curiosity. Against previous knowledge on fixed wing aircrafts (Smith et al., 2016), PHASM produced the second highest number of looks and the highest submersion rate. These data show a major flaw in PHASM as its purpose is to collect dolphin exhalations from a surfaced animal. These data show that PHASM produces the most submersion out of all tested UAS types, which is inverse to the platforms intended purpose. The high submersion duration could be an aversion response to this UAS and an attempt to hide underwater. This data provides us with a better understanding of improvements that need to be made for this platform. This includes adapting the PHASM UAS to provide a higher level of acoustic and visual stealth.

In Laute et al. (2023), they tested the DJI Inspire 1 Pro, Phantom 4 Pro v2.0 and Mavic Pro Platinum in a vertical decreasing height pattern of 10 meters per 20 seconds over a hydrophone stationed in the water. The hypothesized that UASs with large sound profiles would generate higher response levels when flown above marine mammals. According to this literature on UAS type, they recommend using a UAS with a low noise profile if the goal is to reduce potential animal responses and impacts. This hypothesis from Laute et al. (2023) was validated by the look data gathered in our study. The smaller UAS (the Mini 2 and Mini 3) produced the least amount of looks and a medium submersion rate due to their small size and quiet noise profile. Duncan et al. (2021) and Erbe et al. (2017) described how larger UASs with larger payloads produce more noise. To stay aloft, heavier UAS's blades must spin faster which produces a higher noise profile.

For dolphin number of looks per UAS height, the results indicate that UAS height does not change dolphin number of looks. In reference to submersion duration UAS height, the data showed an overall pattern of decrease in submersion as the UAS decreases in height (except for PHASM due to its inability to decrease in a similar way that rotary UASs do). This pattern may be due to the dolphins encountering difficulty visualizing the UAS at lower heights and having to break the surface to visualize the UAS, causing the low submersion duration at low heights. Inversely, the dolphins may be submerging at higher heights because they can visualize the UAS underwater with ease at higher altitudes. Also, the submersion durations at the higher heights could be considered a normal submersion pattern for the DQB dolphins, but when the UAS reaches an approximate 100ft in altitude, the dolphins break their normal submersion pattern and surface more often to visualize the UAS. However, this is mostly speculative and would need further testing to prove (such as measuring dolphin submersion rates without UAS/anthropogenic stimuli). Also, these results are attributed to the smaller number of dolphins seen on camera as the UAS decreases in height. With this decrease in height, the dolphins that are not in the target pool (north pool) cannot be seen in the camera's point of view as the UAS descends on the target pool/ dolphin.

The number of looks per UAS height results (with the exception of Inspire 2 and PHASM), although insignificant, were validated by previous literature (Laute et al., 2023) which suggests that increasing and decreasing in vertical altitude may not minimize animal response to UAS. However, horizontal distance away from the marine mammal may minimize response. Meaning, that vertical height may produce similar behavioral responses no matter the altitude. However, this does not prove true with the submersion duration per UAS height because there was a divide in behavior between high and low altitude. Our findings would support Christiansen et al. (2016)'s study. This study used the DJI Inspire 1 and the SwellPro SplashDrone 1 to test for underwater noise over a recording device stationed one meter below the surface, they hypothesized that dolphins above the water's surface can hear a UAS approaching when five to ten meters above the surface, however the UAS noise can penetrate approximately one meter into the water and is less noisy than above the water. Due to the dolphin's ability to hear the UAS better on the surface of the water may create a high interest in the aircraft, bringing the dolphins to the surface to look at a higher rate than submerging under the surface.

The dolphin behavioral responses via flight number results indicate that as dolphins become more exposed to UASs, the less they will look up at the UAS. On the last flight of each UAS platform, the dolphins looked (on average) 4 times less than they did on the first. The Inspire produced the highest amount of looks for flight #1, with a decrease of looks at flight #2 and a steady increase afterwards. SplashDrone 4 produced a higher amount of looks between flight #4 and #5 with a varying number of looks afterward. Inversely, the results show as the dolphins became more exposed to the UASs, they would submerge for longer periods of time. The average dolphin submersion increased approximately 10 seconds from the first to the last flight. The high submersion rates for flight number could be that the dolphins get more annoyed/ disturbed with the UASs overtime and chose to submerge in attempt to hide. Inversely, the mean submersion rate of 90 -96 seconds (Figure 15C) may be the normal DQB dolphin submersion rate, meaning they could be habituating in terms of submersion around flight #5. This could show that dolphins may be trading submersion for a look response with increased UAS exposure. Habituation could explain the opposite patterns we see between look and submersion per flight number, as previously. The decreasing number of looks and an increase in submersion could be described as the dolphins responding less to the UASs. However, this is mostly speculative and would need further testing to prove (such as measuring dolphin submersion rates without UAS/anthropogenic stimuli).

A study suggested that marine mammals can habituated to some anthropogenic noise (Castro et al., 2021). Castro et al. (2021) reported that common dolphins show a short-term habituation to UASs. Also, in Houser et al. (2013), the authors found that bottlenose dolphins can habituate to sounds ≤ 160 dB more readily than sounds ≥ 175 dB. Likewise, dolphins living in areas of high anthropogenic disturbance may habituate more readily than dolphins living in areas of low anthropogenic noise (Richardson & Würsig, 1997). The DQB dolphins reside in an ocean fed lagoon in a touristic area. Outside the walls of the National Museum of Bermuda, on the other side of the outer ocean habitat, large cruise ships dock, jet ski and fishing vessels frequently motor by, and other forms of recreation exist. Due to this anthropogenic hotspot outside their enclosure, these animals may be more accustomed to higher level of human based noise than other animals under human care.

Regarding the estimated individual DQB dolphin submersion and look response (Table 3), we found that number of looks was mostly consistent across all age groups. However, the younger dolphins (age 9 and under) had on average higher submersion responses than the older dolphins (age 10 and up). This could be explained by the younger dolphins being more sensitive to the UASs acoustically than the older dolphins. As stated previously, dolphins possess an extremely sensitive hearing apparatus (Hemilä et al., 2010) allowing them to hear and call in a broad range of frequencies between 75Hz to more than 150,000Hz. With the sound tests we ran on each UAS platform, we found that each UAS is within their hearing ability. The frequencies of the UASs utilized are between 6,000- 12,000Hz (Table 2), which is well inside the range of an average dolphin's hearing. In a study conducted on an old and infant Risso's dolphins, scientist found the infant could hear much higher frequencies than the old dolphin (Nachtigall et al., 2005). Like Risso's dolphins, juvenile bottlenose dolphins may possess a larger hearing range than adults, allowing them to respond at a higher level, however this is speculative and would need further tests.

UAS Recommendations and Summary

As of present, the Inspire series is the standard of marine mammal research across multiple labs and agencies (Atkinson et al., 2021; Christiansen et al., 2020; Christiansen et al., 2016; Martins et al., 2019; Vivier et al., 2023). This UAS is often used for its ability to withstand ocean air currents and it has a very high-resolution camera; however, results show that this UAS generated the most amount of looks. This could prove troubling for marine mammal scientists flying the Inspire 2 with a goal of generating low levels of behavioral impact on bottlenose dolphins. Still, this UAS would be recommended to fly in high wind levels, however, would not be recommended if the goal is to be non-invasive. Likewise, PHASM produced the highest submersion rate and the second highest number of looks across the test platforms. The results provide us with valuable information on the need to improve the hormone collecting platform because with PHASM producing the highest submersion rates out of all tested UAS types, this is inverse to the platforms intended purpose. For PHASM to perform in its intended purpose the system needs a higher level of acoustic stealth. Inversely, the Mini 2 and Mini 3 Pro proved to be two of the best UASs to generate a low level of look responses and a moderate level of submersion responses. These UASs would be recommended for cetacean research if the goal is to generate a low response level. I consider the Enterprise, SplashDrone 4 and Avata the medium response UAS for both looks and submersion. In non- behavioral research, the Enterprise could be used for IRT, the SplashDrone 4 can be advantageous if the research requires a UAS to get wet, and the Avata could be a benefit if FPV maneuverability is required, but none of these systems should be considered a low noise alternative.

Overall, these results can benefit scientists planning to study the same or varying bottlenose dolphin population for an extended period with a UAS. Likewise, for biologist using the PHASM platform, the results are beneficial in knowing when the target population would surface to collect breath samples and how to accommodate a higher level of stealth. An ideal population for this version of PHASM study would be a population with minimal UAS exposure, because the first flights shift towards lower submersion rates. However, if the target population is habituated to UASs, one can expect slightly longer submersion rates than the less habituated dolphins. However, the more habituated dolphins may show lower submersion rates at lower heights (as seen in results), which can still benefit PHASM. With the detailed height data, we understand that a UAS habituated population will submerge less when the UAS flies at lower altitudes.

With the information gathered from this thesis, we can help inform biologist on how and where to effectively fly a UAS over a bottlenose dolphin that will generate the least amount of reaction from the animal. Also, we have gathered valuable information on how to alter and improve PHASM. In addition, this thesis can inform marine biologists looking to become involved in UAS work on which UAS can fit their research needs.

Future Studies and Conservation Applications

The next step for this project is twofold. First, we need to gather data on baseline submergence times using fixed cameras from elevated positions for control submergence data. Upon receiving this data, the first step for the future of this project is to utilize the same methods used on animals under human care and apply them to wild dolphin populations upon NOAA grant approval. These methods will be conducted on wild bottlenose dolphin populations in Galveston Bay, Texas and in the National Marine Sanctuary in Hawaii. The animals in Galveston Bay live in highly disturbed waters and face high levels of anthropogenic noise. Inversely, the animals in the National Marine Sanctuaries live in NOAA (National Oceanic Atmospheric Administration) protected areas, meaning overall better conditions for bottlenose dolphins. The future of this project is to determine wild bottlenose dolphin responses to the noises of various UAS platforms at various heights. The combined results from facility and wild dolphins will help inform biologists wishing to utilize commercial UASs in research on which UAS would be most effective to their research.

The second step is to validate a custom hormone collecting using fixed-wing UAS (PHASM) on wild cetacean populations in disturbed coastal area and a National Marine Sanctuary (as a control group). We hypothesize the UAS system will help us establish the relationship between anthropogenic noise and physiological evidence for stress in cetaceans, and further we aim to determine the effectiveness of marine sanctuaries on reducing cortisol in wild populations. The platform will allow safe, reliable, biological sampling in wild populations that are otherwise difficult to reach by boat, are easily disturbed by humans or are too sick to have health data collected any other way than by UAS. With this system, if successful, this platform could establish a strong scientific framework to study vulnerable and endangered species in a noninvasive manner in the wild.

These outcomes are expected to inform long term welfare and health assessments on wild cetaceans. This project will aim to collect data from bottlenose dolphins (*Tursiops truncatus*) in Galveston Bay and Hawaiian Islands Humpback Whale National Marine Sanctuary. Data from non-sanctuary dolphins would be used to compare noise and stress hormones to sanctuary dolphins. The results from this project will indicate if sanctuaries are providing the physiological relief from anthropogenic effects that we all hope they are. Understanding the health and wellbeing of populations is important to consider when studying wildlife in areas affected by human activity. Proper health and welfare assessments allow for a knowledge base on a population’s biology, structure, and environmental or anthropological stressors (Barratclough et al., 2019). From a conservation standpoint, welfare assessments are important to assess the positive and negative impacts on an individual and its population. Assessments can be used to inform ethical conservation practices and decision making (Beausoleil et al., 2018). Animals can have negative, positive, or neutral feelings towards daily experiences that humans can infer through knowledge of animal biology (specifically stress hormones like cortisol) and behavior (Stevens et al., 2021).

Cetacean populations are in constant danger due to humans and there is a need to conserve and manage populations inhabiting coastal and open water ecosystems in a way that does not cause additional stress to the animal. The first step to solving these conservation issues is understanding the health of dolphin populations. Through the new UAS system proposed, biologists can gain new understanding of the health status of wild cetacean populations and compare the results of animals outside and within sanctuaries. Furthermore, Through the PHASM UAS system health data can now be obtained non-invasively from animals in ways never possible before, that lead to less stress and better data as well as outcomes. This project will be the first hypothesis driven work to highlight a system we are confident will become a new standard for health assessment in cetaceans. Through this project we expect PHASM to become a user-friendly platform standardizing method which will be replicated and used across multiple national marine sanctuaries by a variety of biologists.

CONCLUSION

The goal of this thesis was to determine how bottlenose dolphins under human care would respond to a variety of UASs in terms of type, height, and sequence and this study met the goal. Through this study, we were able to determine that the larger the UAS type the more looks it would produce and that PHASM produces a high submersion rate. We learned that height was not an overall factor of look response, and submersion duration decreases as height decreases. Also, we found that number of looks decrease with flight number, but submergence increases with flight number. Lastly, we discovered younger dolphins submerge at higher rates with a UAS present than older dolphins. Overall, these data indicate that there is a possible patten of habituation to UASs that could be a topic of further study in wild animals to gauge if these learned responses apply to fully naturalistic groups.

With the help of managed care animals, we were able to gain a better understanding of ideal UASs to use in the new passive health monitoring system in wild population. The future and continued use of UAS could allow for a safer and non-invasive way to study and collect data from wild cetaceans. Additionally, this thesis provides PHASM developers valuable input on ways to improve this platform to collect hormone samples efficiently, effectively, and discreetly from wild bottlenose dolphins

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