# SHAMU

**Search and Help Aquatic Mammals UAS**

## Approvals

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<thead>
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<th>Affiliation</th>
<th>Approved</th>
<th>Date</th>
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</thead>
<tbody>
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<td>CETI and CU/AES</td>
<td>9/18/2017</td>
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<td>Dale Lawrence</td>
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## Project Customers

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</table>
1.0 Problem or Need

Marine sound pollution and ship strikes account for a significant number of annual sperm whale deaths. Sperm whales are now listed as vulnerable and more than 600 studies have predicted that their populations will collapse precipitously in the next three decades (Whitehead, 2002). Cetaceans, like sperm whales, use clicks for echolocation, a form of sonar, to “see” underwater. Some cetaceans also use clicks with highly-detailed click patterns in social behavior. Sperm whales can repeat clicks down to the exact millisecond and frequency, and re-organize them into new clicks. Some marine biologists believe that these clicks are encoded with communicative information, possibly sonographic images (Morozov, 1976). CETI (Cetacean Echolocation Translation Initiative - https://www.ceti.foundation) is an international team of engineers and conservationists that builds audio and video technologies to record and process cetacean click communication. With this data, CETI hopes to decipher sperm whale’s sophisticated click communication while bringing the depth, awareness, and global importance of these animals to millions of people across the globe. The research may also allow the development of needed technology to deter whales away from ships, where whales are often killed by the propulsion system, or prevent large number of whale beachings. Searching for sperm whale pods while limited to the bounds of a ship is extremely time consuming, fuel wasting, and cost prohibitive. Currently, marine researchers spend weeks equipped with binoculars and underwater acoustic listeners scouting for whales in the vicinity of the ship.

The multi-year UAS (Unmanned Aircraft System) project will allow CETI to efficiently find and engage sperm whale pods with CETI technologies. The mobile, aerial platform will scan the ocean surface with an instrument payload capable of identifying migrating sperm whales below. The UAS will aid marine researchers by providing GPS (Global Positioning System) location data of spotted whales. With GPS data received, the mothership will dispatch a smaller watercraft and divers to deploy a listening buoy at the whales’ location. The UAS provides an improved searching solution to binoculars and acoustics and makes more efficient use of time and resources while at sea.

The first stage of the multi-year UAS project is scheduled for the 2017-2018 academic year. The first stage focuses on engineering a modular UAS with radio-controlled and autonomous flight, launch and landing systems, and ground station. The UAS shall be designed to carry a 5 lb (TBR -To Be Reviewed) whale scouting instrument payload. The instrument payload will be developed by future teams in later project stages. Each UAS flight mission shall be capable of 6.5 hours operable flight time with the instrument payload. The UAS shall have a maximum distance of 10 km for ground station communications and total flight range of 400 km (TBR). The UAS search plane delivery system shall be launched and recovered from a representative, stationary 30 ft by 30 ft helipad, obstructed fore and aft. A modular design shall allow for a turnaround time from land to launch of 30 minutes for battery replacement and data transfer. The first stage shall validate the UAS platform for future CETI whale scouting instruments.

2.0 Previous Work

UAS landing and takeoff becomes difficult when the landing area is 30 ft by 30 ft. Multi-rotor copters with the ability to vertically lift off and land assist in finding a solution. However, it is harder for fixed wing craft. There are several ways getting an UAS out of the air. One way is designing a vertical takeoff and landing, or VTOL, vehicle. Various methods of VTOL are used. One of which is creating a hybrid vehicle, such as the Volantis (Blain, 2017), where there are rotors that produce thrust in the horizontal direction, as well as rotors that produce lift in the vertical direction. Another method that has been researched is having a tail-sitter aircraft. This kind of aircraft sits on its tail, and launches vertically, pitches over for horizontal flight, and then for landing it pitches upward to land vertically. Another method being researched is an aircraft that is a fixed wing aircraft during cruise, but for landing the wings rotate into a copter-like craft (Cetinson 2017). There are alternatives to VTOL. For landing, one way is using a net to allow the UAS to fall into (Lizarraga 2004). Another method, which is used for the ScanEagle, is having a hook on the UAS. When the UAS flies to its recovery destination, the hook catches onto horizontal or vertical wire, and the craft spins around it until it stops (Atherton 2015).
## 3.0 Specific Objectives

<table>
<thead>
<tr>
<th>Level</th>
<th>Aircraft Design</th>
<th>Guidance, Navigation, Control</th>
<th>Structures</th>
<th>Communications/Radio</th>
<th>Ground Control System</th>
<th>Electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lvl 1</td>
<td>Aircraft construction complete. Modularity: disassembly/assembly of TBD (To Be Determined) aircraft structures. Aircraft accommodates instrument payload (TBD size and weight).</td>
<td>Full manual control over servos and control surfaces via RC link while on the ground. Hardware-in-the-loop (HIL).</td>
<td>Weight of aircraft and suite must remain below 50 lbs. Wing structure passes a wing loading test of 8 g (TBR).</td>
<td>Downlink Telemetry (H&amp;S/AHRS /GPS), Range: local, external power. (Ground test)</td>
<td>Log incoming telemetry to files/database. Mission/waypoints programmable via files outside of flight operations.</td>
<td>Using only onboard power sources, equipment shall be powered for 1 hour while aircraft is stationary on the ground.</td>
</tr>
<tr>
<td>Lvl 2</td>
<td>Aircraft is airworthy and proven to fly. Performance- 5 minutes on mission time at TBD cruise speed with TBD weight and size payload with 8 kph maximum wind components.</td>
<td>Full manual control over servos and control surfaces via RC link while in the air.</td>
<td>Survive flight up to 4 g in RC flight conditions. Survive 2 ft/s descent recovery method.</td>
<td>Uplink mission elements (waypoints, commands), Range: local, external power. (Ground test)</td>
<td>Display telemetry to pilot on laptop and provide CLI (Command Line Interface) for sending commands/way points in flight.</td>
<td>Using only onboard power sources, equipment shall endure 1 hour in flight.</td>
</tr>
<tr>
<td>Lvl 3</td>
<td>Takeoff and landing within a 30ft by 30ft area with 24 kph steady wind speed. 30 minute on mission time at TBD cruise speed.</td>
<td>Piloted takeoff and landing with full autonomous in flight mission commands/waypoints including in-flight mission reprogramming.</td>
<td>Survive takeoff and aircraft recovery with TBD accelerations using systems designed for shipboard use.</td>
<td>Uplink/Downlink telemetry and commands, Line of sight range flight test on aircraft power.</td>
<td>GUI (Graphical User Interface) for displaying telemetry and sending commands/way points in flight.</td>
<td>Using only onboard power sources, equipment shall endure 2 hours (TBR) in flight.</td>
</tr>
<tr>
<td>Lvl 4</td>
<td>Aircraft can fly a simulated full design mission as specified, including launch and landing within constrained area. (6.5 hour endurance, 400 km range)</td>
<td>Autonomous operations expanded to launch and landing on 30x30 ft platform/area.</td>
<td>Maintains (TBD Uplink/Downlink rates for safe and sufficient operation. Downlink elements must include real time video stream and telemetry. Uplink elements must include (H&amp;S/Flight Path) and commands, 10km range on aircraft power.</td>
<td></td>
<td></td>
<td>Using only onboard power sources, equipment shall endure 6.5 hours (TBR) in flight.</td>
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4.0 Functional Requirements

The customer requires the UAV to search a 144 square mile area for whales. A nominal 60 deg sensor package FOV (field of view) was assumed to determine a required ground track endurance of 400 km to accomplish this at an altitude of 3000 ft with 1 km wide sensor sweeps. The required 6.5 hour mission endurance follows from a lower bound on aircraft speed of 60 kph (37 knots).

1. Operate in remotely piloted and fully autonomous modes throughout all phases of flight.
2. Takeoff and land from/to a stationary 30x30 ft platform obstructed fore and aft.
3. Modular with 30 minute land to launch by replacing battery and swapping data storage.
4. Electric power preferred.
5. 10 km communication range from ground control station.
6. Aircraft does not exceed 50 lbs gross takeoff weight.
7. Aircraft shall be operable and recoverable onto stationary platform in winds up to 20 knots (TBR).
8. Specifications to support full CONOPS (concepts of operations) by follow on project groups:
   8.1. 6.5 hours on mission endurance
   8.2. 7000 ft (TBR) AMSL (above mean sea level) service ceiling
   8.3. Aircraft supports downward-facing 5 lbs (TBR) simulated instrument payload with TBD dimensions
   8.4. 400 km (TBR) ground track endurance

![Functional Block Diagram](image-url)

Figure 1: Functional Block Diagram
5.0 Critical Project Elements

In order to achieve a mission of long range flight including launch and takeoff from a simulated ship, the team must meet the requirements of aerial vehicle design, a takeoff and landing system and procedure, communications with a ground station, an autonomous flight computer operation, and FAA approval (if required).
5.1 Aerial Vehicle Design

The vehicle shall be capable of travelling 10 km to and from the ship in 20 knot wind speeds (TBR). The first critical element, aerial vehicle design, was chosen as it is essential to the long range goal of the mission and the weight limit. The vehicle shall travel up to 400 km distance. Additionally, the design shall be modular and each module replaceable on the ship. These requirements will be tested via static load testing to 8g acceleration and computer simulated vibration testing. If the vehicle is to be acquired rather than designed, it may be a challenge to the budget.

5.2 Takeoff and Landing System

The aircraft shall be recoverable. The takeoff and landing system is a critical part of the mission as the vehicle will be landing on a 30x30 ft stationary landing pad obstructed fore and aft. This system is a challenge in terms of both software and controls in order to achieve the ultimate goal of autonomous takeoff and landing. Additionally, the physical takeoff and landing system will need to be evaluated and chosen by doing a trade study.

5.3 Communication and Ground Station

The ground station shall maintain live communications with the aircraft at a distance of up to 10 km. Additionally, the ground station must be able to update the flight path in real time while the plane is in the air. This communication shall follow a TBD communications protocol. Finally, the flight mission and health of the aircraft can be viewed or updated by a GUI (Graphical User Interface) based at the ground station. The ground station shall receive live video feed in manual flight mode.

5.4 Flight Computer

The flight computer will be responsible for the autonomous flight and takeoff/landing of the aircraft as well as telemetry gathering/storage and serve as the communications gateway with the ground station.

5.5 FAA Approval

The aircraft must be operated in accordance with Federal Aviation Regulations (FAR) Part 107 or waivers, as approved by the FAA. In order to test the system in the air, the remote Pilot In Command (rPIC) must have a Part 107 certification. Additionally, there may be other requirements with time sensitive paperwork. These will need to be reviewed in order to develop a schedule of requirements that shall be completed in time to test the system.

6.0 Team Skills and Interests

<table>
<thead>
<tr>
<th>Critical Project Elements</th>
<th>Team member(s) and associated skills/interests</th>
</tr>
</thead>
</table>
| Aerial Vehicle Design    | Grant Dunbar: RC/sUAS aircraft design, construction, flight. MATLAB, Python, C++, Solidworks.  
  Severyn Polakiewicz: RC aircraft design., SolidWorks, MATLAB, Python, C  
  Ben Mellinkoff: control surface design, modeling, MATLAB.  
  Ian Barrett: Solidworks, 3D modeling  
  Brandon Sundahl: Controls, modeling, manufacturing  
  George Duong: Electronic Components, MATLAB, C++, construction and computational modeling. |
| Takeoff and Landing System | Ian Barrett: Solidworks, Manufacturing  
  Severyn Polakiewicz: SolidWorks, Catia, Stress Methods Intern, ANSYS, Femap, NASTRAN NX, structures  
  Brandon Sundahl: Controls, modeling, manufacturing |
7.0 Resources

<table>
<thead>
<tr>
<th>Critical Project Elements</th>
<th>Resource/Source</th>
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</table>
| Aerial Vehicle Design     | ● Decisions on Design  
  ○ Trade studies: Allows team to compare solutions to one another and pick which one will lead the team to success.  
  ○ Dale Lawrence (faculty), internet, textbooks, etc.  
  ● Building/Testing the design  
  ○ Matlab/Solidworks modeling: Before testing, modeling the UAS will give the team an idea of the feasibility.  
  ○ ITLL : Lab areas, machine shop and materials.  
  ○ Hardware stores/Internet: Materials and parts.  
  ○ Air space (Boulder, TBR): Team can test the flight capabilities of the UAS.  
  ○ Faculty, textbooks, etc.  |
| Takeoff and Landing System | ● Designing the system  
  ○ Matlab/Solidworks modeling  
  ○ ITLL : Lab areas, machine shop and materials.  
  ○ Faculty, internet, textbooks, etc.  
  ● Testing the takeoff/landing system  
  ○ City of Boulder open space, permits (TBR): Allows team to test takeoff and landing capabilities of system in an open field.  
  ○ Air space (TBR): Team can fly UAS and test the takeoff/landing system.  
  ○ Faculty, internet, textbooks, etc.  |
| Communication and Ground Station | ● System integration  
  ○ ITLL: Lab areas, machine shop, and materials for communications testing, circuit tests.  
  ○ City of Boulder: A walking communication test can be done by going to different points around the city, other testing methods TBR.  
  ○ Hardware stores/Internet: Purchase parts.  
  ○ Faculty, textbooks, etc.  |
| Flight Computer (Autonomy) | ● System integration  
  ○ ITLL/Aerospace Instrument Shop: Lab areas, and materials.  
  ○ Specialized software (TBR)  
  ○ Faculty, internet, textbooks, etc.  |
| FAA Approval              | ● Part 107 sUAS pilot  
  ○ Grant Dunbar: Allows team to fly in regulated airspace~$5 aircraft registration fee.  |

Note: The SHAMU team may receive financial assistance from a crowdfunding video project (TBD).
8.0 References


