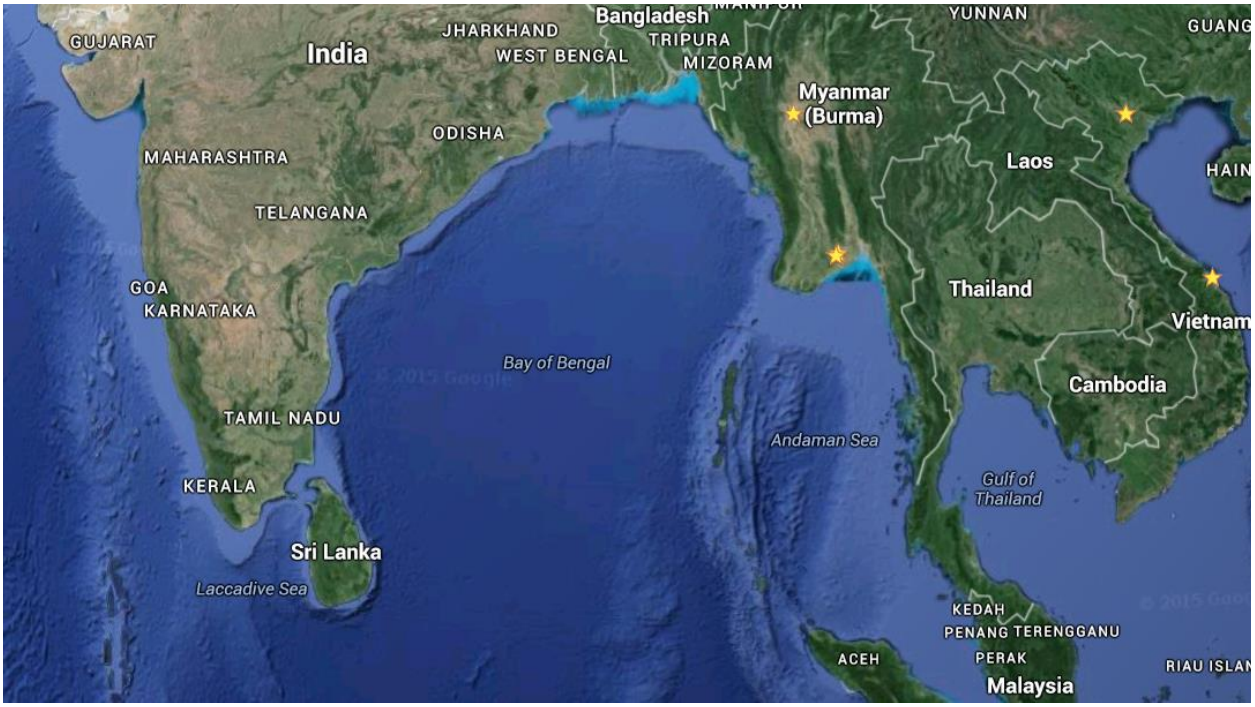
Autonomous System for Deep Sea Search and Recovery

Systems Engineering Plan



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1. Executive Summary

When a plane is lost over open ocean, airlines scramble to determine what went wrong. For many of the recent incidents, such as the Malaysian Airlines 370 flight that disappeared in the Andaman Sea, the searches took upwards of 18 months. That's two years of fear, loss of trust, and loss of valuable time distributed across multiple parties of interest-- from government agencies to families who lost their loved ones. Our project focuses on developing solutions to help look for these unsolved mysteries in remote and undeveloped locations like that of the Andaman Sea.

The ocean poses its own set of problems. Lack of high fidelity communication, variability in weather conditions, and sheer size are only a few of the challenges with any search mission in open water. To put this in perspective-- with GPS satellite technology we can have a visual map of the United States with a 15cm resolution vs with the sea floor we only have a 1km resolution via satellite technology. Therefore higher resolution of the sea floor is dependent on the use of unmanned underwater vehicles (UUVs) -- a system that requires vast resources as the support vessels can cost $50,000 USD/day.

A variety of factors contributed to the difficulty of the MH 370 search. That particular flight was lost over a part of the ocean very few elite navies knew anything about-- a part that has historically been avoided because of fierce currents and the monsoon seasons. Poor airport infrastructure, booming economies, and lack of regulation all helped lead to an incident with a bounded search area the size of Australia three miles beneath the surface of the ocean-- enough to fit almost 2 billion of the same Boeing 777-200 planes they were looking for. This problem lies on a scale that no one can really fathom.

Our solution comes at the problem from the novel perspective of combining available technologies with recent technological advances. Given the high cost measures, and the relative lack of information on this part of the world, we analyzed the alternatives and came up with a viable integrated unmanned vehicle system that could be airdropped off of a standard cargo plane. This document details our decisions and a full list of system design requirements and conceptual design of our solution.

2. Motivation and Background

Over the past decade there have been several instances of aircraft being lost over remote parts of the ocean. Airplane companies scramble to determine the cause of failure, the anguished families of the customers onboard demand answers, and the current technology takes years to produce results because of the complexity of trying to find something in a large environment that we know very little about. Current search methods to search the area using current methods can cost $50,000/day, take days to deploy, and require large crews to maintain. Costs aside, the system is also subject to weather conditions in these vast, remote areas. The challenge lies in building a reliable system that can quickly identify potential wreckage sites at a lower cost and risk. Our system will have the ability to be rapidly deployed and search large areas of the ocean, including the surface and seafloor. A payload containing a central hub and underwater search vehicles will be air dropped into the search zone. The robots leave the hub and autonomously search a predefined area, then surface and report data via satellite.

Maintaining the public's trust is incredibly important for a large commercial airliner. The company lost over $184 million USD in 2014 from losing two planes in one year (one to the ocean, one to a missile) -- which equates to about 12% loss of revenue. Due to the media and the ongoing search for the missing MH 370 plane, consumer confidence is still low.

To put this all into context, in the past 60 years there have been less than 100 fatal plane crashes. Not many have failed over the ocean, but each plane that has fallen in has taken upwards of 2 years to find. Where Malaysia Airlines flight 370 went down is the Indian Ocean-- an area twice the size of Russia (Wardell, 2014) -- or roughly 3.6 times the size of the US. (nationmaster.com, 2015). Ports and countries that have the infrastructure to support an investigation lie far away-- with Perth being the closest major city-- and it takes 8 hours by plane and 10 days by freighter to reach the area (Jacobs, 2014).

With MH 370, the plane went down unexpectedly in an area that has traditionally had limited air and freighter traffic and is only now undergoing serious development and expansion. Additionally, unlike the standard air traffic patterns seen in developed countries, where essentially invisible on-ramps and freeways exist and are generally adhered to, these developing countries see lax and few safety regulations, an older variety of planes, variable storm seasons, and fast ocean currents (and therefore high winds). Pilots are manually tracked by ground station radar and constant communication with local airports. Their planes do not have the same safety features built in. Worse still is the rule that if a pilot realizes they need to go to a higher altitude in order to avoid a storm, they are usually denied the opportunity by air traffic control- which the pilot can actually override by declaring an emergency-- and potentially losing all contact they have with the ground station. It is because of these factors that our system is primarily focusing on this particular area of the ocean.

3. Scope & Boundary

3.1. Scope:

The system is to respond rapidly to search for aircraft that have crashed in the sea. The goal is to find the aircraft within six months. It is necessary to know what happened to an airplane. This information is necessary for the insurance agencies, liability, forensic and failure analysis. This system will be different by finding the wreckage faster, cheaper, safer. To be considered a success certain criteria will have to be met: speed of deployment, reliability, cost, and data quality. The specific numbers are discussed later in the paper.

3.2. Bounds:

The main limitations are: huge area to search, technology, power, speed, corrosion, propulsion, sensing, logistics (i.e. stakeholder cooperation), international borders, transportation, and regulations.

The adjustable parameters of the system include, deployment method, support requirements, costs, and power use. The resulting variables are cost, speed, and area.

3.3. Stakeholder Analysis

Figure 1: Stakeholder Onion Model

The stakeholders for this complex system are diverse. Figure 1 provides a graphical representation of an onion diagram of stakeholders, as outlined in the article "A Better Fit-Characterization of Stakeholders" (Alexander, 2004). On the innermost layer directly interacting with "The Kit", in this case, the physical search system of interest, are the trained operations and field service engineers directly operating the system and maintaining the system during use in the field. Also included in this level are the task programmers, who are responsible for programming the system for a specific task specified by the customer.

The containing system level includes the airline requesting our system to find a lost airplane, and its insurance agencies having a significant investment in a successful search and recovery of a lost airplane. This level also includes the families of the missing, as well as the project managers interacting with the customer and relaying customer needs to the developers.

In the outermost level in the wider environment are the developers of our company designing the search system, and regulatory bodies such as the Federal Aviation Administration (FAA), Environmental Protection Agency (EPA), and Occupational Safety and Hazard Administration (OSHA), who will be the types of agencies most concerned with the deployment of our system into the ocean and the human safety of a crew that recovers the system. Governments of nations surrounding the search area (such as Myanmar and Thailand) will want to ensure that our system complies with their regulations if it should enter national waters. Also benefitting from our success are publicly-funded oceanographic institutes whose public favor and funding will likely increase with our successful data collection and analysis in the deep sea. Negative stakeholders include those who are also developing deep sea search vehicles, such as Bluefin Robotics and Hydroid, who may be negatively impacted if airlines choose to use our system instead of theirs.

4. Conceptual Design Using the System Engineering Process Model

4.1. Needs Analysis

4.1.1. Current state of Underwater Vehicle Research and Development

All major underwater vehicles are made in the state of Massachusetts in the United States by three companies: Oceanserver, Hydroid, or Bluefin. They are all are somewhat similar in design-- optimized for forward motion, ranging from man portable sub 100 lb models to 20 footers that require a crane to lift and place into the water. They have a basic inertial package and GPS module for tracking location at the surface, and generally have a few common sensors such as doppler velocity measurements and side scan sonars. Since they require a support vessel, the vehicles move close to five knots in order to efficiently scan a given area at the least amount of overall cost (since you're paying for the use of a boat and the underwater vehicle(s)). This increased speed however, means higher-precision and more expensive instrumentation is required. What makes mapping the seafloor challenging is that the sensors need to be as close to the bottom as possible, but they also need to remain as orthogonal as possible in order to get the best returns-- which is incredibly challenging in variable terrain. In order to meet the large demand, some of these vehicles have not been fully updated in over twenty years and have therefore not been able to take advantage of many technological advances.

From an overall technological standpoint, there are now things that exist in combinations that were not possible in the last decade. Processors, inertial packages, GPS systems-- many of the computing aspects necessary for a repeatable and reliable system are now readily available with the advent of smartphone technology and consumer demand. Additionally, satellite imagery is widely available and in increasing resolution in different spectra. For over 20 years, many countries like the US have used Geographical Information Systems (GIS), which have been collecting high resolution images over land with 15-30 cm resolution. This same technology is being used by Scripps Oceanographic Institute to measure the variation in the surface of the ocean-- they realized that the changes in depth can be mapped to features on the seafloor. Companies like Autonomous Marine Systems are developing products that are capable of long-endurance to essentially be disposable marine network modules that can cheaply acquire information, which oil companies are especially interested in for monitoring their oil pipelines. The advent of computers and sensor technologies becoming cheaper, faster, and smaller combined with affordable satellite technologies allows for innovation potential in this space.

4.1.2. Exploitable Technology

A complex system for such a challenging task will take advantage of pre-existing mature technologies. Some of these exploitable technologies are listed below.

- Sensing / Scanning
  - Similar to other search vehicles, Sonar could be a primary scanning tool for long-range scans in a low-light environment.
  - Sonar sensors come in several configurations, some of which have long range in open water, others can even detect objects below layers of mud and silt. Figure 2, displayed below, shows a side scan of a ship, layers of silt below the visible sea bed, and a larger scale height map of a plane wreck, all obtained with sonar.

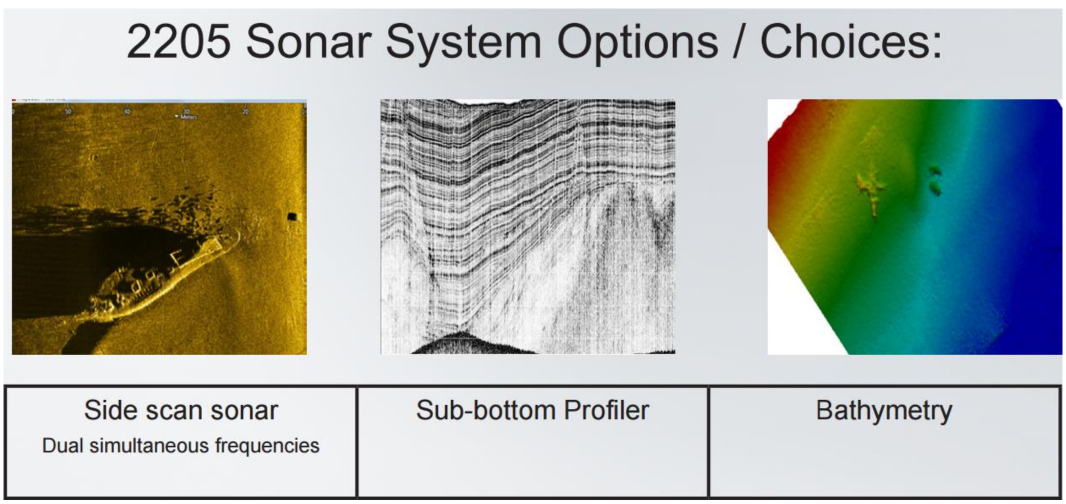


Figure 2: Side Sonar options (Edgetech.com, 2015)

- In-Water Propulsion
  - Brushless motors are common, powerful, long-lived, and only moderately more complex than DC motors.
  - Off-the-shelf solutions for deep-sea propulsion are available (Thruster, 2015)
- Remote Power
  - Solar panels can deliver 120 watts per square meter in sunlight

    - Lithium Polymer batteries (LiPo) offer the highest energy density of any battery chemistry, and can be made pressure-tolerant.
- Communication
    - Iridium provides global 2-way satellite communication at at least 10kBps, and has been used for data gathering in deep sea expeditions before. Data would not be available underwater.

4.2. Feasibility Study

There are many potential ways that the problem of finding lost aircraft in the Indian Ocean can be approached. Solutions include satellite imaging, a network of buoy sensors, Unmanned Underwater Vehicles (UUVs) and a surface hub, a redesigned Black Box, and equipping sensors to commercial vessels. Each of these approaches has their benefits and their challenges. In the following section we will delve more into these details.

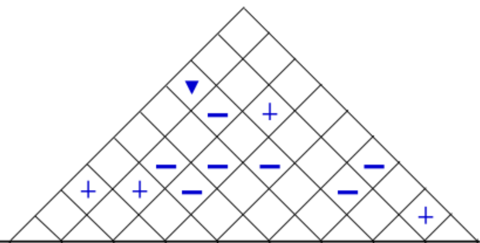
4.2.1. Approach Evaluation

Each approach was evaluated based on the needs defined earlier (Sec. 4.1.1).Our first need is the need for a rapid response. When a plane crashes into the ocean, its parts can be distributed all over the ocean floor depending on the ocean current and weight of the pieces of the vehicle. Therefore our system must be rapidly deployable. When the pieces of a plane settle, they settle onto the ocean floor, so our system will also need to be able to search the ocean floor. If the system dives underwater, then additional constraints come into play such as: maximum depth, sustained pressure, descent rate, and ascent rate. Our geographic focus is off the west coast of Thailand and Myanmar, and the average ocean floor depth of that area is around 3.8 km. This means that whatever system is decided upon needs to be able to discern aircraft parts from the ocean floor at that depth. Our system also needs to be affordable. If it is unaffordable there is no reason to build it.

The designs we will look at in more detail later, are as follows:

- Satellite Imaging
- Grid of Permanent Buoys
- Robotic Underwater Vehicles
- Updated black box
- Sensor equipped commercial ships

4.3. House of Quality (HOQ)



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Fast propulsion system	High quality sensors	High quality materials	Robust communication platform	Standard, interchangeable parts	Non-hazardous materials	Long-lasting battery	Anti-fouling exterior	Corrosion Resistance System
				Column #	1	2	3	4	5	6	7	8	9
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	▲	▲	x	x	▲	▼	▼
1	9	12.5	9.0	Quickly Deployable	Θ								
2	9	12.5	9.0	Quick Detection	O	Θ							
3	9	12.5	9.0	Accurate detection	▲	Θ							
4	9	12.5	9.0	Durable in deep sea/air drop		O	Θ					Θ	Θ
5	9	8.3	6.0	Speedy transmission of relevant data				Θ					
6	9	8.3	6.0	Repairable					Θ				
7	3	4.2	3.0	Repurposeable					O	O			
8	9	12.5	9.0	Able to search for extended periods of time	O	▲	O				Θ	O	O
9	3	8.3	6.0	Low Cost	▲	▲	▲	▲	O	▲	▲	▲	▲
10	3	8.3	6.0	High Endurance			O				O	O	O
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	8	7	8	5	4	10	7	7
				Max Relationship Value in Column	9	9	9	9	9	3	9	9	9
				Weight / Importance	208.3	283.3	183.3	83.3	112.5	20.8	145.8	183.3	183.3

Figure 3: House of Quality, helps us to determine the most important features to focus on

High quality sensors and propulsion systems are of utmost importance, as they are the primary technological features that impact the key performance of the system. The faster and more efficiently these technologies perform, the better our system will be. This House of Quality illustrates the relative need to focus on these aspects of the system more than the other components. Following these two features of the system are high quality components resistant to breaking and corrosion, upon impact with the water and during extended use. A system that is physically broken will not be able to properly function and complete its mission.

4.4. Critical Requirements

There are 5 critical requirements of this system. These are the most important requirements of our system. If any of these requirements are not met, then this system will not accomplish its task. They are as follows:

4.4.1. Critical Requirement 1:

The system shall be able to operate at 4km depth and 401 atms of pressure. This requirement is derived from the geographic focus of the Indian Ocean, specifically the Andaman Sea, or up to 200km off the east coasts of Thailand and Myanmar, where the average depth is 3.98km.

4.4.2. Critical Requirement 2:

The system shall be able to find the aircraft wreckage within 6 months of searching if given an area of search with a 90% certainty of the aircraft water impact site. This requirement is derived from the current state of underwater vehicles, and the need to find aircraft wreckages quicker to offer closure to the families and to discover any potentially fatal issues that may be arising in the aircraft model.

4.4.3. Critical Requirement 3:

System shall survive autonomously for a minimum of 6 months. Due to the need to find aircraft within 6 months the system will need to stay submerged and searching as long as possible. Therefore should operate as autonomously and continuously for the 6 months as possible.

4.4.4. Critical Requirement 4:

The system shall communicate findings. If the system finds an area of interest it must communicate these findings for further analysis. If it does not we may never know if it finds the aircraft the system will be searching for. This comes about due to the need to find the aircraft within 6 months' time.

4.4.5. Critical Requirement 5:

The system shall be able to operate in an ocean environment. This requirement is derived from the geographic focus of the Indian Ocean, specifically the Andaman Sea, or up to 200km off the east coasts of Thailand and Myanmar. This requirement also brings about the issues of operating in a saltwater environment such as salinity and barnacles.

To make sure that these critical requirements are met, not only will each system and subsystem be tested but every component will be tested to the critical requirement standards as well. By integrating testing down to the component level there will be a stronger likelihood that the system as a whole will pass these requirements. If it doesn't then every test of every component will be documented and will make finding the failure point slightly easier. Also if all the individual parts are known to be up to these standards then the linkages could be a point of focus. For more detail please refer to section 6.1.

4.5. Considered Designs

4.5.1. Satellite Imaging

The first one, satellite imaging, has many benefits but also some significant drawbacks. It is a very mature technology that is continually advancing and improving. However there is the issue with government regulations. If a United States company placed an advanced imaging satellite into geosynchronous orbit there may be a lot of restrictions placed on it and it could make doing the work necessary in the area of focus difficult. Especially, since the satellites have been able to map the ocean floor but due to their 1km resolution they are unsuited to try and find things that are smaller than mountain ranges (Coletta, 2015; Sandwell & Smith, 1996; Scripps, 2014). Therefore the other countries could ask; what is the true intention of the satellite as the technology and resolution needed to find aircraft parts at the bottom of the ocean does not yet exist. Also satellites need other items such as high resolution, high power, sonar-equipped ships and Unmanned Underwater Vehicles (UUVs) to confirm what they see. Most satellites have a lifespan upwards of 10 years. Additionally maintaining satellites implies the need for trained astronauts and a trained satellite maintenance personnel. It's definitely progressed in the last 20 years, but there are still challenges left to address before this becomes a reliable system.

4.5.2. Grid of Permanent Buoys

Another option is the use of multiple permanent buoys, with instrumentation attached, that are fixed to the ocean floor. These could be set up around the geographically focused area to constantly monitor a part of the water column from the ocean's surface to 3 meters beneath the surface. A constant survey would allow for an almost immediate notification of the location of a large disturbance. Which could be a downed aircraft, or a ship collision, both which would require immediate response. There are some challenges with this idea though. One being the necessity for a large amount of buoys. The average buoy has multiple sensors to measure temperature, wave height, currents, etc. There are multiple companies that will work with their customers to develop a custom buoy but most of their brochures discuss one buoy not a series. Another aspect to think of is there are already companies who are building these buoys, although none are being used to find aircraft. Most buoys are commonly used in shallower water (eg. near and around ports/harbors). The amount of cord necessary to keep them in one place (relatively speaking) would be difficult in open ocean where the ocean floor is 3.8km deep. Potentially a dense enough grid in remote parts of the ocean could lead to unnecessary obstacles for large surface or undersea vehicles. Another potential challenge could be international naval regulations and naval agreements concerning permanent monitoring structures in open ocean.

4.5.3. Robotic Underwater Vehicles

Many unmanned underwater vehicles (UUVs) and remotely operating vehicles (ROVs) are utilized for various tasks such as surveying large underwater structures or the sea floor. However the systems in current use need to be deployed and recovered by a fairly large ship because of the size required for a mission in deep-water to be economical. Using multiple smaller vehicles could allow for the similar search area without needing as large of a support vessel. Most of the technology has remained fairly constant for the last 10 years, but is still developing and advancing. A lot of components on these vehicles can be considered off the shelf (OTS) components which can save money. Also with these systems being Earth bound the maintainers, operators, and company can have regular access to systems and therefore can easily maintain and update them. However, underwater vehicle mission planning technology has not advanced as far as the technology has, and generally in order to obtain high resolution detail, the vehicles trace out a very tight grid of “corn rows” along the seafloor which requires a lot of time, effort and money to get the necessary data. Another issue is the need for ships to deliver these systems to and from their designated work zones. The ships needed are specialized with cranes, and any technical equipment needed to store and maintain the UUV.

4.5.4. The Improved Airplane Black Box

For a different option there is the possibility of enhancing and overhauling the current Black Box system that is used to collect information about the vehicle continuously throughout its use. There are a lot of Federal Aviation Administration (FAA) regulations on what the black boxes can and cannot be. However the FAA is only regulates aircraft that flies in US airspace. The technology does exist in the current form, but to enhance it or make any radical changes and with all the restrictions upon it, a lot of technology may need to be developed.

4.5.5. Sensor Equipped Commercial Ships

A final option to consider is sensor equipped ships. This means equipping commercial ship traffic with ocean monitoring sensors. These would allow for someone monitoring these sensors to constantly view the ocean floors, currents, etc. However using the commercial ships restricts the monitoring to the commercial shipping lanes. As can be seen in figure 4 the ship channels do not cover the geographic focus we are concerned with. Another potential drawback is the Navies of the world saying no. Submarine traffic is highly classified and sensors on the commercial ships may reveal submarine locations. Due to the potential electrical draw or just companies wanting money rent may be changed to have access to the data on the sensor system attached to the ships.

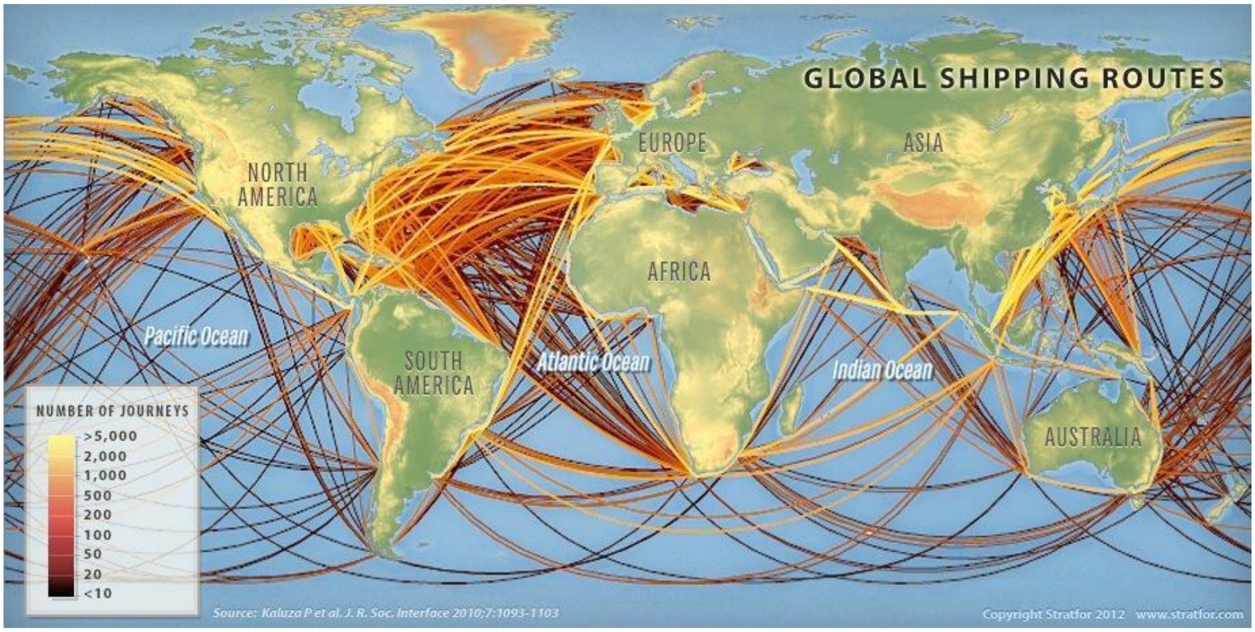


Figure 4: Trace of global shipping routes around the world with density measurements. Notice that the area of interest has comparatively no traffic to the Atlantic or Pacific Oceans.

4.6. Course of Action

Due to the challenges and benefits explored in the section above. We have decided to pursue a hybrid solution that utilizes unmanned underwater vehicles, or UUVs. Due to the time and cost issues with using ships to deliver the UUVs an alternative method of using planes to airdrop the UUV will be explored. UUVs allow for relatively fast solution development as most of the industry has standardized around interchangeable modular components and are fairly reliable. By combining it with the airdrop method, our solution is able to be quickly deployed and does not need an expensive support vehicle for the length of the mission over 3 month periods. We will improve the design from the current standards and elevate the UUV to be able to find a missing plane within 6 months of incident date given a 90% confidence of where the plane impacted the water. A graphical representation of the decision process is shown in the decision matrix below.

Table 1: Alternate technology decision matrix

Need	**Importance**	**Buoys**	**Satellite**	**UUVs**	**Ship Sensors**	**Black Box**
Fast Deployment	3	5	3	3	2	5
Effective Search for UO	3	3	1	4	5	3
Thorough Search	1	3	5	5	3	5
Reduce cost	2	2	3	5	2	2
Wide deployment range	1	1	5	5	2	5
	Totals:	**32**	**28**	**41**	**30**	**38**

4.7. Planned Operational Capabilities

Our system has quite a number of planned operational capabilities to help each stage of its mission. The capabilities span the three domains of land, sea, and air.

4.7.1. Cargo plane drop

Currently, the fastest way to get anywhere in the world is by some form of air travel. For our system we determined that it made the most sense to be able to deploy a system by air since the system does not need a local support vehicle during the search process. The C130 cargo plane, developed by Lockheed Martin, has been flying around the world since 1954 (Thompson, 2014). It is ideal for our application because of its usage around the world, payload capacity, and range. Additionally as a low velocity, low altitude plane its flight constraints allow for the potential to build in proper cushioning into the system itself instead of relying on corrugated cardboard, wooden pallets, and other structural waste materials. Eventually, integration with directed parachutes that through a series of actuators and its own calculations will allow for accurate guiding of the parachutes while in flight to the correct destination. New autonomous guided parachute systems could mean that drops from 20,000 ft are now possible.

4.7.2. Marine-related Capabilities

A different set of capabilities are required for the surface and underwater components. Onboard computer processing is required in order to send reports of detected features as well as assist in accurate underwater navigation. Satellite communication that would beam data back to the main server would allow vehicles to be monitored in near real-time and allow for emergency manual overrides of the vehicles. GPS navigation is a necessary component that will help in autonomous navigation on the surface and help to mitigate positioning errors for the deployed underwater vehicles.

4.7.3. Parachute with controlled flight path

Controlled flight paths (onboard the payload) now allow for precise airdrops out of the backs of cargo planes (Boyle, 2011)-- joint precision airdrop system- requirement is for 2000 lb package to land within 110 yards of its target with a 30ft parachute canopy--JPADS 2k has an Autonomous Guidance Unit (AGU) that weighs 150 lbs, and can be released at 5000-25000 ft. (cargo airdrop overview parachute industry association meeting) Though there is also a family of systems that exist for payloads from 10-60,00 lbs (Bagdonovich, 2011).

4.7.4. Unmanned Cargo Planes

Unmanned Cargo Planes could prove to be useful for our system. Like all other unmanned vehicles, there is a reduction in human error. Additionally, unmanned planes are lighter because they no longer need to carry the additional weight necessary for life support. However, the biggest unsolved challenge is obstacle avoidance-- especially important at lower altitudes (Grose, 2014). Overall, they could allow for increased range, ease of use, and reduced costs.

4.8. Operations

4.8.1. Mission Definition

Each time a customer orders a search a new mission starts. Figure 5 shows a high-level sequence diagram depicting a search mission. Figure 6 shows a more detailed sequence diagram with a focus on looking at the overall system during the search phase. How the components interact is described on the arrows. The system will be deployed by plane and airdropped at the location. Underwater subsystems will be deployed from the main hub to search a specified area. Data will be transferred through a satellites back to base. After the mission is complete the system is shipped back to the company.

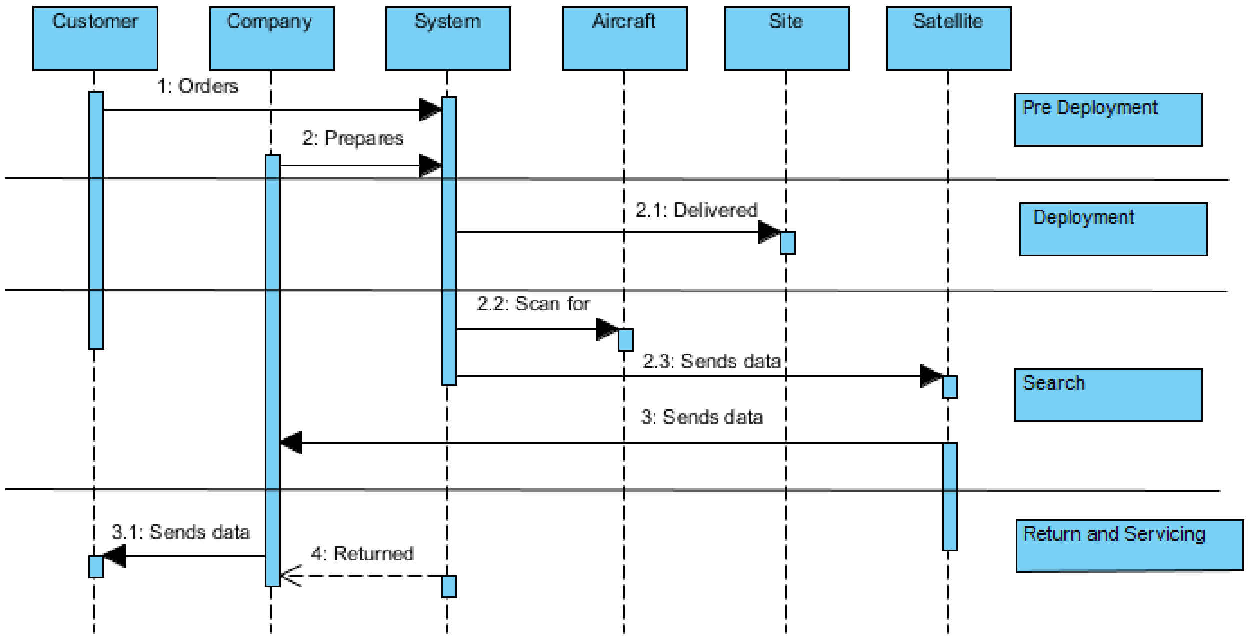


Figure 5: - A high-level sequence diagram that shows the basic premise of the mission

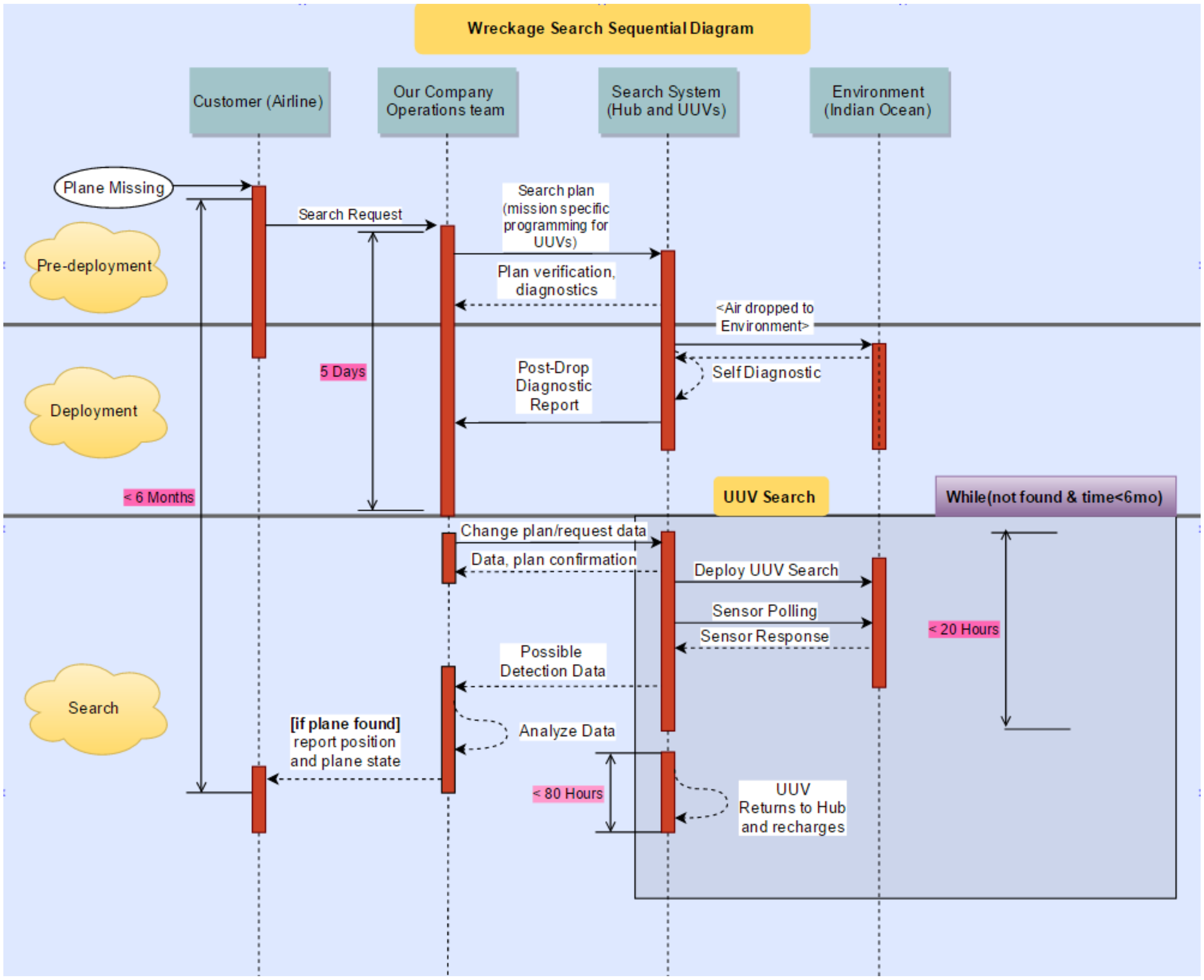


Figure 6: Detailed Sequential Diagram of Overall Search Mission

4.8.2. Operational Requirements (OR)

Operational requirements are the quantitative requirements that need to be met in able to operate in the designated mission environment. They are as follows:

4.8.2.1. OR 1. The system shall withstand a 7G impact with 90% operational capability.

This means that when airdropped the system may encounter a 7G force when impacting the water. In all likelihood this would only happen if the parachute fails, therefore it is something to be aware of but should not happen with frequency.

4.8.2.2. OR 2. The system shall scan the ocean floor for unnatural objects.

Unnatural objects are defined as being items not normally found in the area of search. To include straight lines and metal or composite materials. The system will achieve discovering this through its scanning capabilities.

4.8.2.3. OR 3. The system shall have a lifespan of at least 5 years with maintenance.

Due to anticipated technology changes and growth, 5 years has been determined as a reasonable lifespan for our system. At 5 years it will undergo an overhaul where all the technology will be either updated or replaced due to wear and advancements in the field.

4.8.2.4. OR 4. The system shall operate at 3 to 35 degrees Celsius

Due to our geographical constriction and operating depth these temperatures have been determined to be the necessary operating temperatures.

4.8.2.5. OR 5. The system shall use internal sensors to send status updates every 30 minutes.

To make sure that the system is still there and functioning it will be required to send a status update every 30 minutes. This will allow for data such as location and speed to be collected throughout the project and also to be able to do a health check and with time discover trends that indicate proximity to failure.

4.8.2.6. OR 6. The system shall navigate the ocean environment.

It will be operating in the Andaman Sea (Part of the Indian Ocean), and it’s main mission is to search the ocean floor. Therefore the system must be able to dive, surface, and otherwise propel and navigate the designated search patterns

4.8.2.7. OR 7. The system shall be able to recharge its power source in a 25% duty cycle.

To be able to fulfill a 6 month mission requirement the system will need to be rechargeable. A 25% duty cycle is standard within the field, and will allow for not only maximum battery charge but also maximum time searching.

4.8.3. Key Performance Parameters

To make sure that the critical requirements (Section 4.4) are met, a measurable aspect must be able to be achieved for each requirement. Key Performance Parameters or KPPs, are those measurable aspects. Critical requirements are considered the most essential for a successful mission. Therefore the KPPs represent those capabilities or characteristics so significant that failure to meet the threshold value of performance can be cause for the concept or system selected to be reevaluated, or the program to be reassessed or terminated. Each KPP has a threshold and an objective value. The measurable values and their related critical requirement are as follows (Johns Hopkins, 2013):

- Fully submerged as pressure equivalent to 5km statically for 48 hours (4.4.1)
- Fully submerged with constant and rapid changing pressures (between 5km and 0km) for 48 hours (4.4.1)
- Max operating depth of 4km (4.4.1)
- Sensors should be able to detect aircraft wreckage in multiple situations, from clear view on rocky soil, to covered in silt on soft soil (4.4.2)
- Batteries and all technology will need to last at a minimum 7 months to allow for a 1 month safety buffer since missions are anticipated to be 6 months in length (4.4.3)
- Method of recharging the battery (4.4.3)
- Self-diagnosis (4.4.3)

- Able to stay in contact with mission control center, sending findings of interest immediately, send general findings every 24 hours (4.4.4)
- Be able to navigate ocean and localize within a 10ft accuracy (4.4.5)

4.8.4. Technical Performance Measures (TPMs)

For our system we will have quantifiable measures that will constantly be checked to make sure that our system will perform at its best possible level. It will first have a maximum operating depth of 4 km, and will operate in the Indian Ocean (specifically the Andaman Sea). The stakeholders interested in this measure are the customer, as they designate the geographic location, and our company. We are interested because if it cannot operate at the correct depth or environment as geographically determined, then there is no reason to develop it. The environment is derived from CR 5. The depth is derived from CR 1, which was decided upon after researching the average depth of the Indian Ocean, which is 3.89 km (Wikipedia, *"Indian Ocean,"* 2015). There are some areas of the Indian Ocean that are much deeper such as Diamantina Trench, which reaches a depth of 8.047 km, however this trench is off the west coast of Australia thereby putting this area out of the scope of this system design. For emergency situations the system will be able to withstand a maximum depth of 5 km, but will not operate at that depth. This is the ultimate threshold of the system and with a maximum operating depth of 4 km and an additional 1 km increase for a system tolerant of the pressure at 5 km, which allows a factor of safety of 1.25.

This system is being developed mostly to shorten the time period within which lost aircraft are found, hence CR 2. Therefore this system will find the wreckages within a 6 month period if given a 90% confidence of where the plane impacted the water. This measure is extremely important to the Customers, Government Regulating Bodies, Families of passengers, our company and of course the negative stakeholders. For the customers and government regulating bodies knowing why the plane crashed and if this may indicate a fleet wide issue is of utmost importance because if it is a fleet wide issue they need to act as fast as possible to prevent another potential crash. To aid in the 6 month deadline, this system will be able to survive autonomously for 6 months (CR 3), be deployed from the factory within 4 days, and withstand a potential 7G impact with 90% functionality when airdropped on location. As it was discerned that delivery by aircraft is not only cheaper than by boat but also faster.

There are many facets to this system and one major aspect is to ensure the reliability of system intercommunication so that it can be determined that the system is functioning normally. As is communicated by CR 4. This is very important to our company, the operators and the customers. Therefore there will be communication systems set up between the surface and deep sea systems. This communication path will have four types of communication:

- "Heartbeat" ping - sent once every 30 minutes, from deep sea subsystem to surface hub system
- Data Delivery - scheduled data delivery at the end of each pass, through the designated area, from the deep sea subsystem to the surface hub system
- Mission Updates - a packet of instructions from the surface hub to the deep sea subsystem if an area analyzed by the mission control center needs further investigation
- Emergency - in an emergency the deep sea subsystem will send all its data to the surface hub.

These types and paths of communication allow for constant acknowledgement that the system is working and gathering data. The data also can be further analyzed at the company and if need be corrective instructions can be sent back to the surface hub system that would pass it on to the deep sea subsystems if an area needed to be examined more closely.

As long as the system is properly maintained it will last up to 5 years. At 5 years a complete system overhaul will be needed to make sure that the system is brought up to date and continues to work as needed to. The company is the most concerned with this measure is it is related to OR 3.

4.8.5. Performance and Physical Parameters

The System deals with the following parameters:

- Range of potential drop altitudes (<10,000 ft)
- Variable search area grid-- size of daily search (on the order of 5-30 sq miles for a system of vehicles)
- Operating pressure of 6600 PSI (4500m max depth)
- Number of days system can tolerate in marine environment (on the order of 28 days)
- Operating temperature of 3 to 35 deg C

4.8.6. Operational Life Cycle

The operational life cycle does depend on how the system will be used and how often. We are setting the requirements that the system will be operationally active for 5 years and then will need an overhaul of the whole system to be able to incorporate any technological advances that will have occurred over the previous 5 years. Each single mission will last for a minimum of 6 months, so the system has to be reliable and operable for that time period. The operators and maintainers will be the systems company’s people as due to the necessity for rapid deployment there will not be time to properly train people unfamiliar with the system. The operators will be onsite, at a mobile mission control center that can be set up and utilized either on land or on a ship. This mobile mission control center will also serve as a mobile maintenance area. Within this center will not only be means to monitor and communicate with the system and company headquarters but also will have diagnostic tools, spare parts for commonly replaced items, and and specialty equipment necessary. The operators will monitor the whole system in addition to the main mission control center back at the company's headquarters. If needed the operators will perform maintenance of the systems on site. They will also be in charge of the system recovery operation, once the mission is completed.

As with any human built system there will be parts that will have a shorter life cycle than the overall system. With that in mind, the overall system will be designed to be modular. This would allow for quick repairs by replacing the section that went bad, and then diagnosing further why that particular section failed. For the parts that maintenance is expected to occur on, such as electrical parts wearing out, and parts deemed at risk for failure within the 6 month mission time periods, as designated by lifetime testing done back at headquarters, these parts will be with mobile mission control set up. Also the systems time in the field should come into consideration when designated parts that need to be place within the mobile mission control center. This is mostly due to nature of electro-mechanical systems as they age. For example a car usually does not need non-routine maintenance until it is has reached a certain mileage or use. The same would go for this system. As it is used items will wear, therefore more parts will need to be on hand for a system that is three years old and has performed six month missions, than a system that is two years old and has performed one eight month mission. As alluded to in this example our system will be monitored by years in service, by time in use, and by cycles. A cycle for the subsystem is defined as one round trip from the surface of the ocean to the search depth back to the surface. A cycle is deemed an appropriate measure for the deep sea subsystems due to the nature of the different hazards at the different depths of the environment in which the subsystem will be working in. For the surface hub system, time in use will be used due to it staying on the surface versus diving like the subsystems. For the more abstract aspect of the system, such as software, updates will be made as they are available. They will be constructed so that when softwares have been tested and vetted the system will be able to have over air updates, which would be then held by the surface hub system and delineated to the deep sea subsystems once they resurface and meet with the surface hub system. The company will rent time on the satellite that is best situated for near constant communication in the area the system and subsystems will be operating in.

At the end of the system and subsystem's life span there a few methods of disposal. One method is removing all potentially hazardous materials and then sinking the remaining structure to be used as an artificial reef. A second method of disposal is to gift schools, specifically high schools and universities/colleges, non proprietary parts of the system for education and research. A system will be deemed at the end of its life span when the physical aspects can no longer perform to specifications, or if the there is a redesign of the system as a whole due to new technologies becoming available.

4.8.7. Utilization Requirements

Based on flight trends over the Indian Ocean shown below, (Cheshire, 2015) we expect most flight routes to fall within 35S to 20N, where 35S is the worst case for average solar power.

Figure 7: Flight trends over the Indian Ocean, (Cheshire, 2015)

In the winters there, we can expect a solar intensity of around 200W/m^2. For most of the time across the possible latitudes, power will be between 300 and 410 W/m^2.

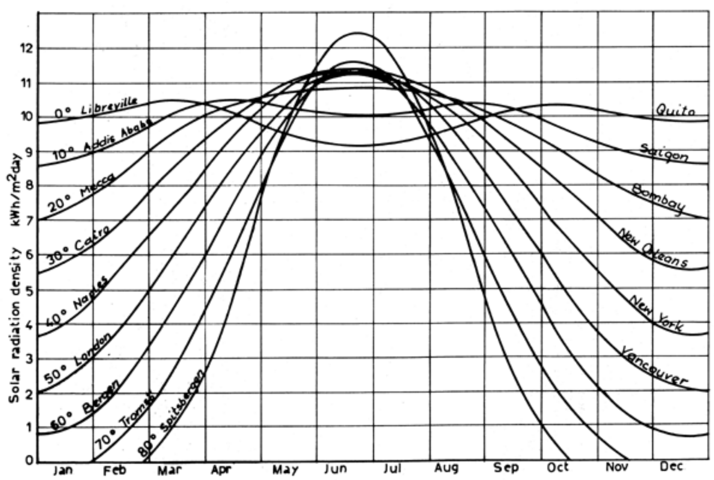


Figure 8: Solar Intensity Diagram

At those rates, and accounting for day and night cycles, a reasonable target for UUV duty cycle, the time a search UUV spends searching vs. charging at the hub, is 25%.

4.8.8. Effectiveness & Environmental Factors

In order to determine its effectiveness, any solution we provide must be comparable to one that already exists. The solutions are highly dependent on the search area-- for example, when the Air France 447 flight went down in the Atlantic, they first tried to search a 750 square mile area (about the size of New York and Los Angeles combined)-- and that took a whole year with three Remus 6000s, vehicles designed for ½ mile views of the sea floor at depth that traveled for 22 hours at 6 mph. (Wise et al, 2011) That is roughly a linear distance of 132 miles, which multiplied by the ½ mile width, was equivalent to 66 square miles in 22 hours. With three vehicles running simultaneously, that comes out to roughly 200 square miles per day, which means it would have taken about 4 days to complete a full pass of the 750 square mile area if the vehicles could run continuously without recharging and resurfacing and diving. The air france example highlights how difficult it can be to identify the right target area and how even with vehicles that were capable of finding the plane within a week (which they did, at a later date, once the search area was recalculated), it is impossible to find something as large as a plane if you're looking int the wrong place to begin with.

With an increasingly aware consumer group that cares about the environmental impact induced by a plane's crash landing in the ocean, the groups who would be most interested in our system would also be interested in the overall lifecycle and environmental impact we have in our own processes.

As the vehicle system is launched from the airdrop vehicle, there will most likely be waste materials such as cardboard, wood, nylon webbing, or parachute material that will fall with the system into the ocean. Ideally you would want these to sink as quickly as possible such that the sea life did not end up consuming or getting tangled in it.

For the system at end of life, if it was in the ocean when determined it would no longer be able to reach the surface or has hit a critical failure, it would sink and become an artificial reef. This requires the materials to be well encapsulated or fairly non-toxic, which is a nontrivial task for components like energy-dense batteries, heavy metal laden PCB electronics boards, or anti-fouling lead-based paint. Alternatively the vehicles could be donated to research centers or schools (if the vehicles are recoverable).

4.9. Concept of Operations

4.9.1. Operational Scenarios

There are four primary modes of operation: Programming and Testing, Emergency Response, Maintenance, and Failure.

4.9.1.1. Emergency Response (Main) Scenario

This operational procedure is for a situation in which an airplane is suddenly and unexpectedly lost in the deep sea, specifically the Andaman Sea, off the coast of Myanmar and Thailand. Under such a scenario, our company would be contacted by the airline once it determined a search and rescue was in order. Our programmers would modify the code for the system to meet the parameters of the mission, while the client with our administrative staff make arrangements for the aircraft. A mobile mission control center will be set up as close as possible to the search area that can be sent to retrieve the system when its search is completed. Once the mission plan is finished and verified, the product would be loaded onto the aircraft and flown to the area of interest.

The whole system will be airdropped by a C130 type aircraft into the agreed upon search area. Parachutes will deploy on the system to minimize the force of impact with the water. Upon landing, the system will conduct a status test and send the results to the mobile mission control center. If deemed sufficiently operable the four deep sea subsystems will detach from the surface hub and begin their search. These deep sea subsystems will disperse in a predetermined radius from the hub and will be able to search for 24 hours at a time. They will keep in contact with the surface hub via a “heartbeat” ping every 30 minutes. Every 1 hour the deep sea subsystems will send their data to the surface hub, which will then conduct a preliminary analysis of the data. If any data triggers an alert, it will be sent via satellite to the mission control center for further analysis. If the finding warrants further investigation, instructions will be sent from the mission control center to the surface hub via satellite, which will relay the instructions to the deep-sea subsystems. At the end of the 24 hours the deep sea subsystems will return to the surface hub for a full charge, full data exporting and receive any mission updates. The surface hub will then alert the mission control center and propel itself closer to land to expedite recovery by boat.

4.9.1.2. Failure Mode

If a deep-sea subsystem does not have enough power to return to the surface hub or has been critically damaged, it will send a distress signal to the hub. Based on the information provided, the hub will determine the next course of action. If the other deep sea subsystems are in danger of having the same damage occur to them, they will be immediately recalled to the surface hub. If the deep sea subsystem has a minor problem that could be easily fixed, it will enter power saver mode and only broadcast its location to the hub at regular intervals for eventual recovery. If the damage to the deep sea subsystem is critical, it will enter end-of-life mode, in which it will transmit what information it can to the surface hub, disable itself, and sink, allowing itself to turn into an artificial reef. If the nearest deep-sea subsystems to the disabled deep sea subsystem have enough remaining power and will not encounter the same danger as the disabled one, the surface hub will direct them to search any area not covered by the disabled subsystem.

In the event of a surface hub failure, it will immediately alert the mission control center of its location and damage state if it is able, so that it can more quickly be retrieved and fixed. If it loses communication with mission control, it will broadcast a distress signal and its location as long as it is able. Because of the large amount of useful data on it and high cost, it will stay afloat rather than sink so it can more easily be retrieved.

4.9.1.3. Logistics and Maintenance Concept

There will be a trained user on standby at the mission control center at all times to retrieve data as it arrives and make decisions as needed. Once the surface hub is retrieved a technician will extract all data erase it from the vehicle, charge the hub, and perform basic inspection of the deep sea subsystems to ensure they are charged and ready to be redeployed. If any damage exists that prevents the system from being redeployed, it will be fixed by the technician as much as possible, or be returned to the company for rebuilding or replacements.

4.9.1.4. Programming and Testing (Engineering) Mode

As components of the system are designed, their functionality and effectiveness will be analyzed through simulations. Components such as sensors and mechanisms will be individually tested at the detail design and development phase before being assembled into a prototype. The prototype systems as a whole will then be transferred to the testing department, where they will undergo environmental, cyclic pressure tests and acceleration tests as described in Section 6.1. The testing department will create an evaluation report for the prototypes and submit it to the engineering design department for redesign. Once a prototype passes these tests, second generation systems will be manufactured for demo and testing. Full acceleration demos and wreckage finding tests will be conducted by the testing department as described in Section 6.1. Modifications to the design will be made as necessary. Once a system has been sufficiently tested and proven to work, it will be manufactured for production. The engineering team will continuously re-evaluate the system to iterate upon future models of the system.

4.9.2. Limitations

The biggest limitations to our system are technological. They are also some of the most important features for the functionality and performance of the system. Battery life limits how long the subsystems can function without returning to the hub. The longer they can function, the more area they can search and the faster they can find the wreckage.

Corrosion limits how long the system can perform without maintenance. Currently, no technology can avoid corrosion altogether (Seidman, 2013), although some can delay or mitigate its effect on key components, such as sacrificial anodes (Nave, 2001). Ultimately it is a problem that our system is not focused on solving as it is far beyond the scope of our system.

Our system is also limited by its ability to sense and transmit information about its environment in the water. The primary method of sensing would be side-scan sonar, which has limitations in depth measurement and range (NOAA, 2015) Image processing algorithms are continuously in development, but there is a lot of room for improvement in quick, efficient and accurate detection, especially in low light environments such as the deep sea where images may appear to be distorted. The ability of the subsystems to correctly identify wreckage and relay it through water to the hub is limited by current through-water communication systems. Currently they are not very powerful, and underwater vehicles often rely on tethered communication, (Ross, 2013).

Table 2: These are some of the future technologies anticipated to become viable solutions that get integrated into our system.

Technology Area	**Technology Forecasts**		
	Short-Term (0-12 mo)	**Mid-term (12-24 mo)**	**Long-term (24- mo)**
Physical Innovations			
New materials		applying antifouling nano-technology/nano coating instead of lead paint	
Battery technology	every 6 months, higher charge density batteries in the same form factor are released		Possible we may find better battery chemistries/better ways of storing energy
Image Processing	Better processors are on the market every 3 months or so	More efficient algorithms might become widely available	Machine learning tools would allow for faster processing and less human overhead
New Lateral Line Sensors	still in infancy/pure research stage	probably only robust enough for lab testing within a controlled swimming pool environment	May be developed into a commercial product if proved successful
External Environment			
Satellite Communications	Rock7 Communications offers small form factor IRIDIUM TX/RX. Turtle/Large fish tags are tied to the ARGOS satellite network and are very small form factor.		Iridium satellite networks are about to become more distributed and the industry is trending towards cheaper satellite communication
Long-range autonomous cargo planes			Cargo companies are already in negotiations to automate cargo planes and this could definitely be a program within the next 5 years
Self-Directed parachutes		The Army's Natick Lab Research Center and Lincoln Labs have been working on this-- most	

		likely a prototype for a desirable weight class could become available	
Autonomous surface vehicles	Long endurance craft (such as liquid robotics') already exist and they could potentially be outfitted with a similar payload to ours to help monitor the missions from the surface in addition to our existing system		There are a few startups, such as ASV, that are trying to create a distributed network of directed propulsion surface vehicles for oil rig monitoring, which could just collect data on the ocean in general so we have a better idea of the baseline
Weather pattern tracking and prediction systems	Updated based on data collected by weather balloons		Microsoft is developing predictive weather forecast systems that use machine learning with satellite and almanac data and physical models-- this could be a tool that we integrate into our system when it becomes commercially available
Techniques/Skills			
Better algorithms for multi-robot control	Still in early research phase	Simulation of behaviors is possible with limited amount of "real" marine physics	More simulation would be needed, depends on state of the vehicles.

5. Preliminary and Detailed Design for the System

5.1. Use Case Scenarios

Over the course of the mission lifecycle, there are 4 main actors: the vehicles, the transportation company, the communication satellites, and the maintenance/operations engineers. Their main interactions can be seen in figure 9.

1. The Vehicles are deployed into the marine environment, which includes being loaded into the cargo bay of the transportation vehicle and delivered by plane to the designated site, all of which are tasks performed by the Transportation Company Crew.
2. The Vehicles search the area of interest, which includes recording data internally.
3. The Vehicles report data back to the mission control station, which includes sending smaller updates through communication satellites, and storing data in the remote database, which is monitored by the Operations Engineer(s).
4. The Vehicles prepare for the next mission, which includes a full system check which is performed by the Maintenance/Operations Engineer(s).

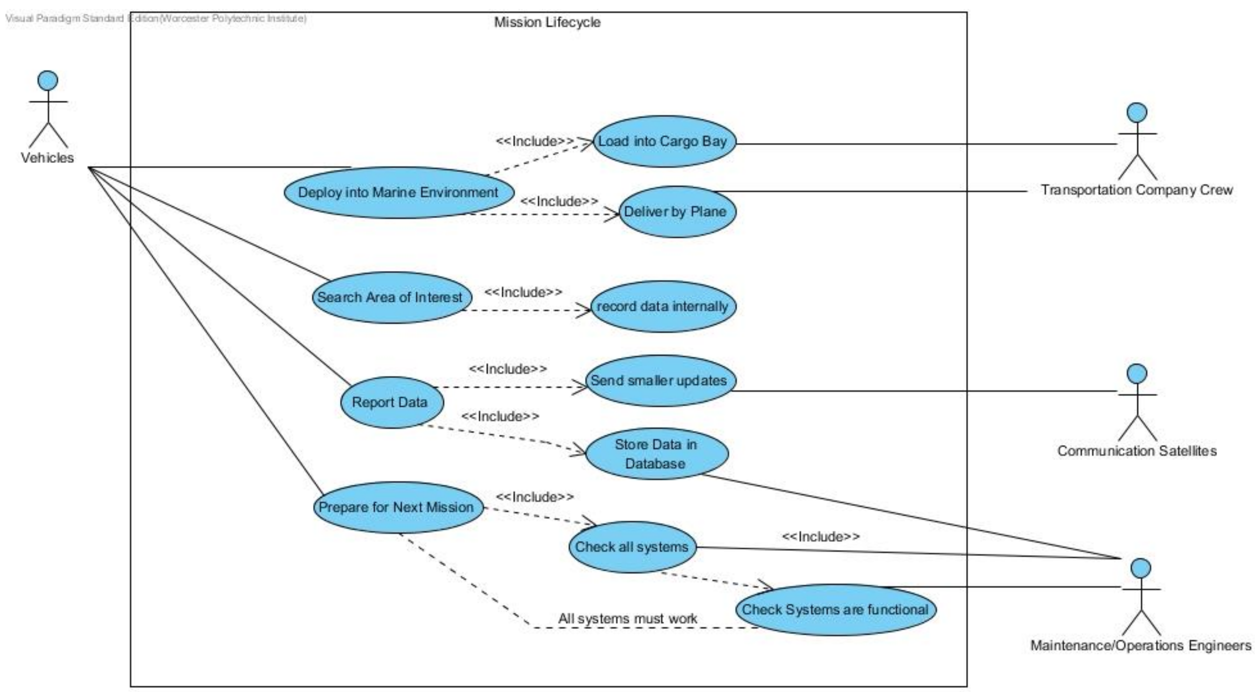


Figure 9: Overall System Use Case Diagram shows the various interactions between the main actors during the mission lifecycle: the vehicles, the transportation company crew, communication satellites, and maintenance/operations engineers.

5.2. Functional Analysis and Allocation

The following is a functional analysis of the system. The Functional Flow Block Diagram in section 5.2.1 shows the functions that the system will perform during each phase. The functional allocation diagram in figure 15 shows how these functions are distributed among the subsystems.

5.2.1. Functional Flow Block Diagram

The functional flow block diagram shown in figures 10 through 14 display the functions that the system will perform during each phase.

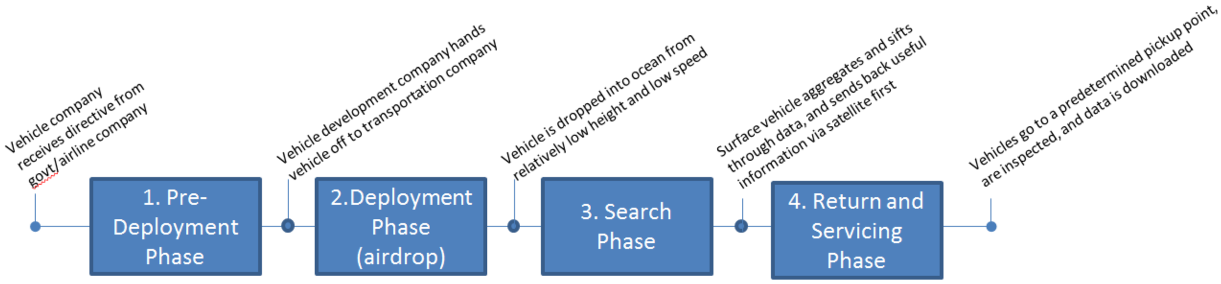


Figure 10: The overall phases of the system.

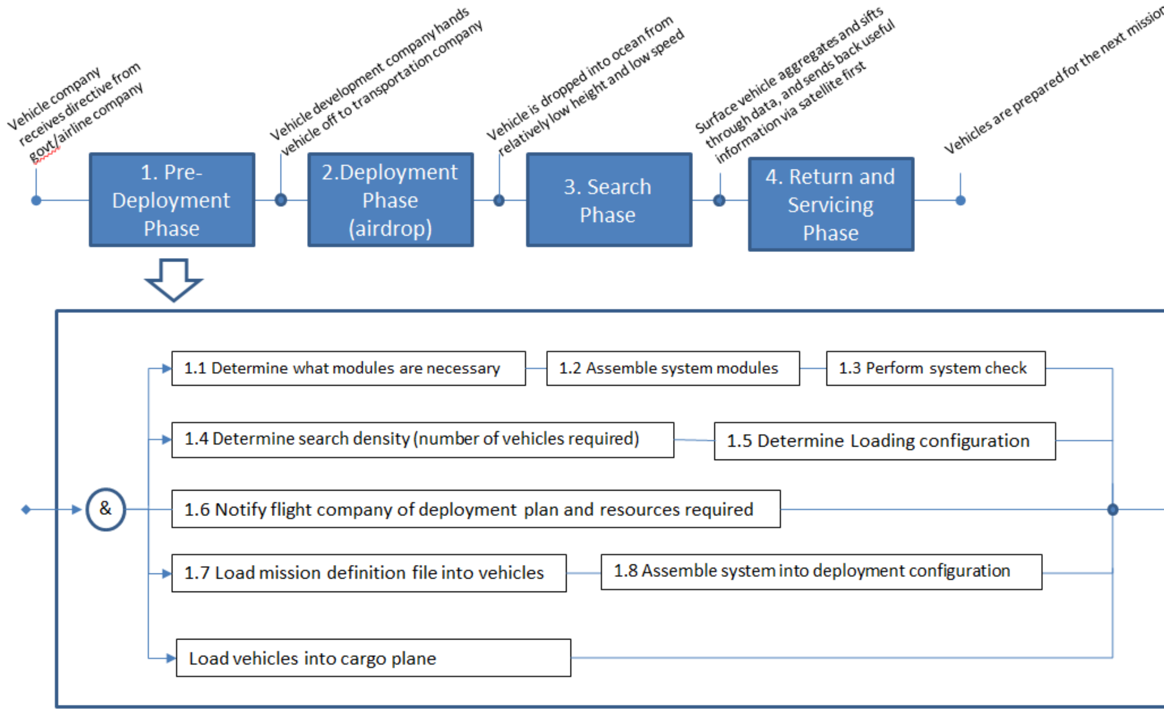


Figure 11: the view of the functional flow within the pre-deployment phase

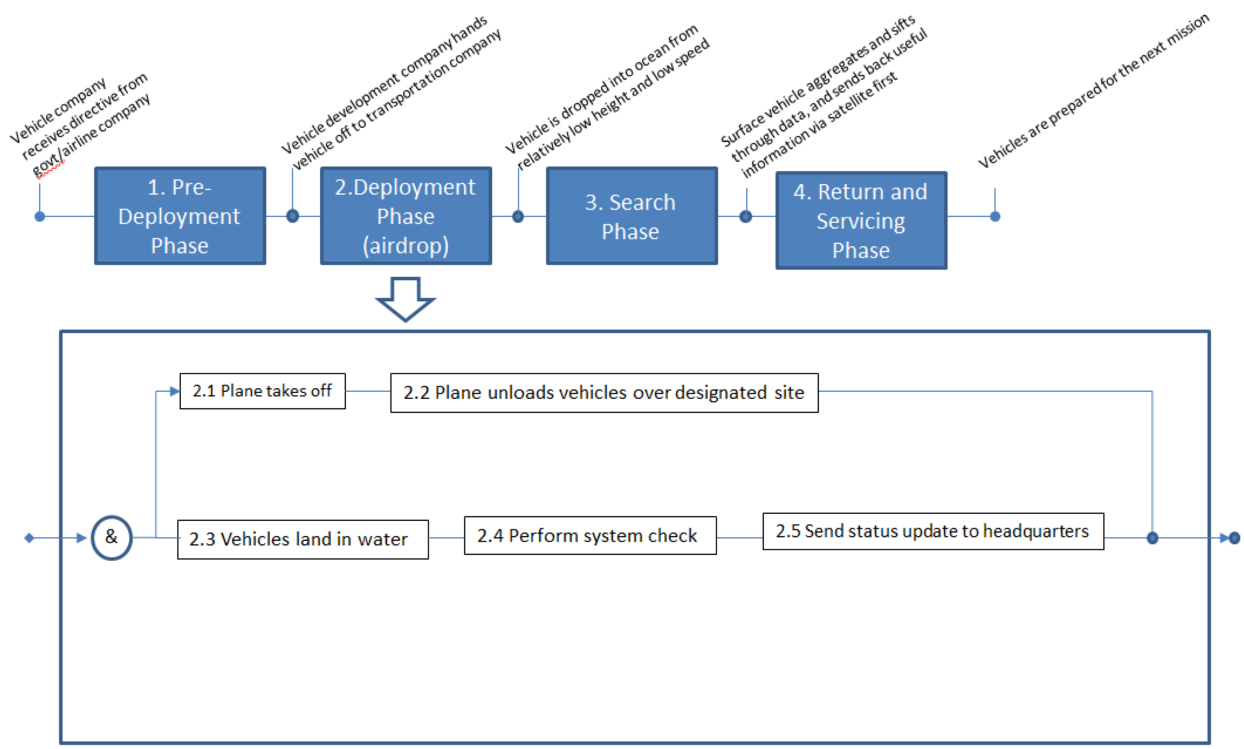


Figure 12: the functional flow within the deployment phase.

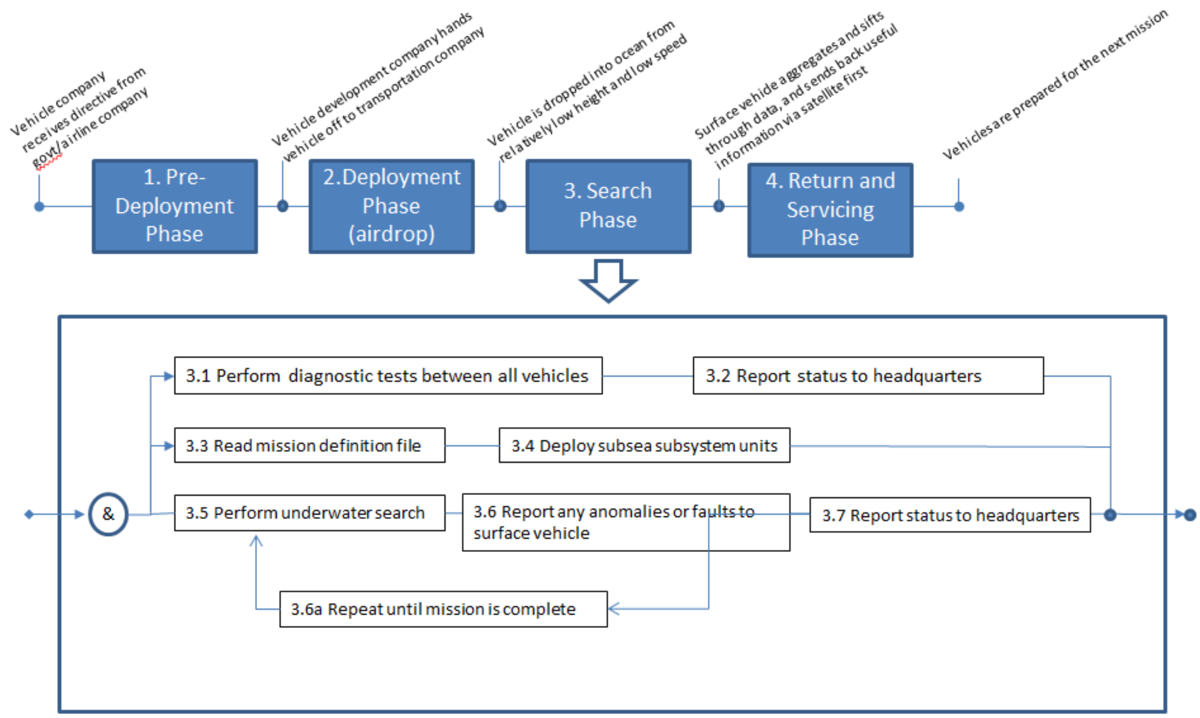


Figure 13: Functional flow within the search phase.

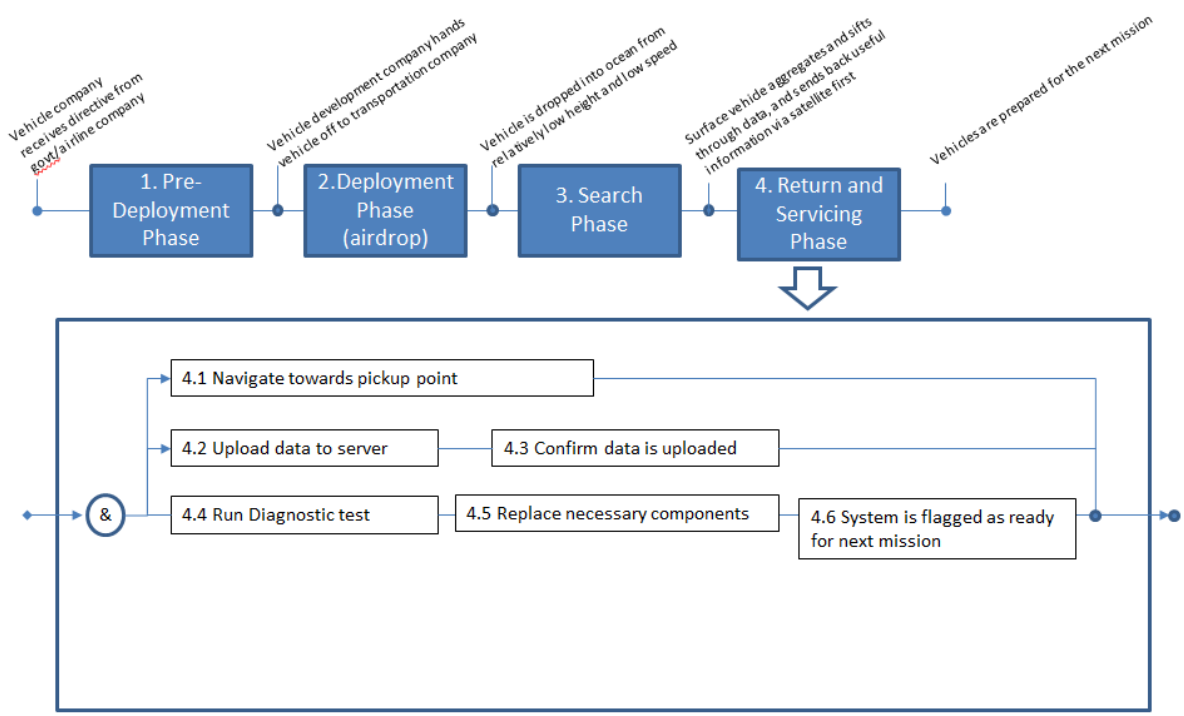


Figure 14: Functional flow within return and servicing phase.

5.2.2. Functional Allocation

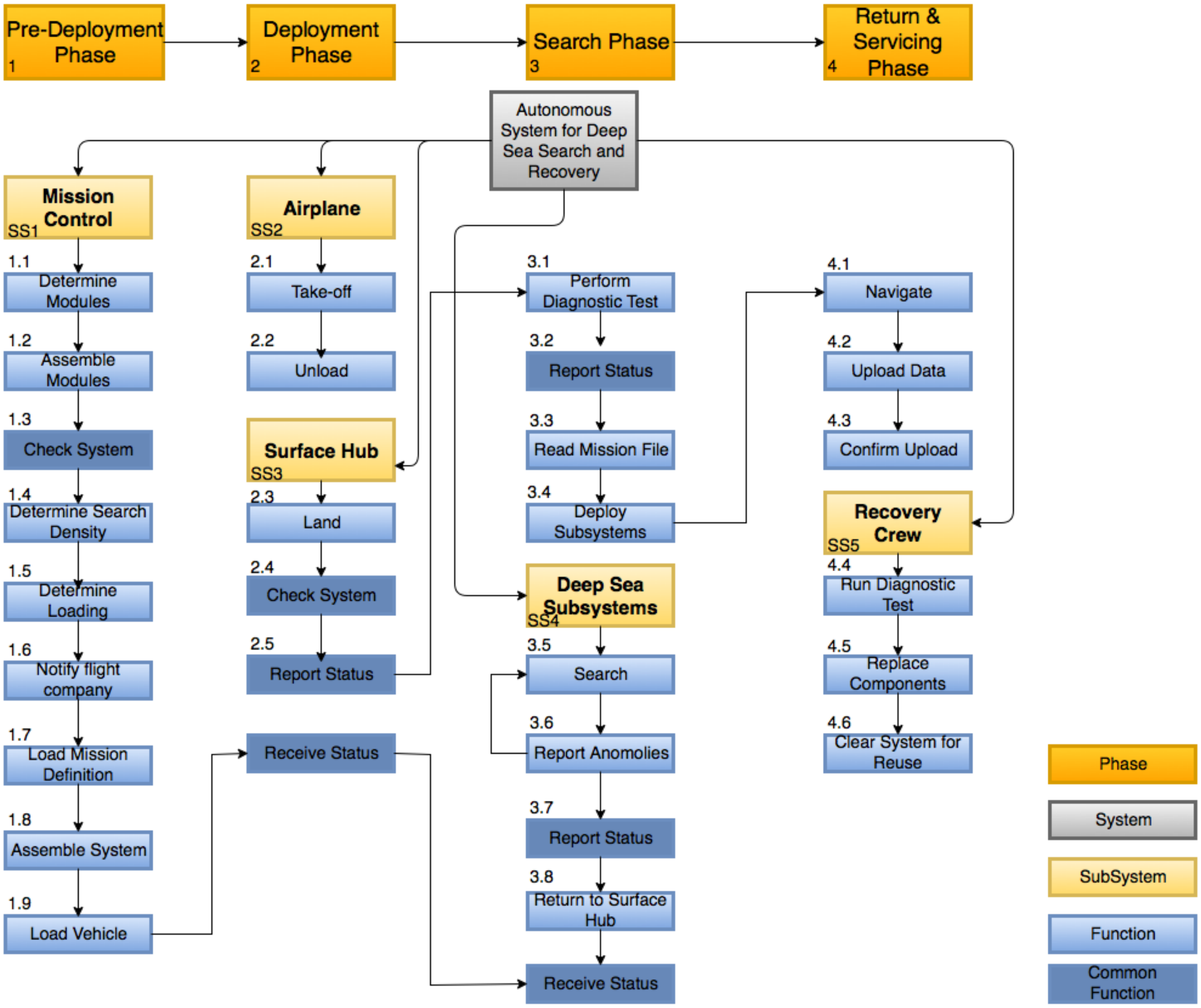


Figure 15: Functional Allocation diagram for the system, divided by phase and indicating which subsystems perform which functions

The following diagrams are detailed allocation diagrams for the Search Phase of the system, for both the Surface Hub and the Deep Sea Subsystems. These diagrams show the inputs and outputs to each of the functions in this phase, in addition to the sub-components that will be performing each function.

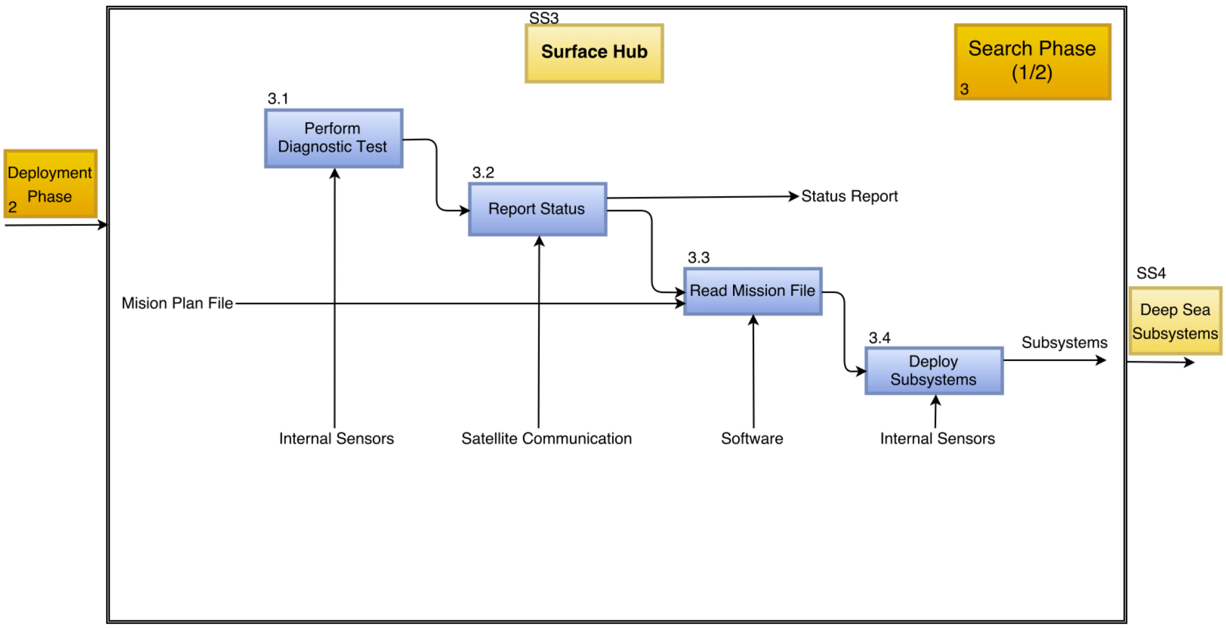


Figure 16: Detailed functional allocation diagram for the Surface Hub during the Search Phase, with interactions of inputs/outputs and components necessary for functions

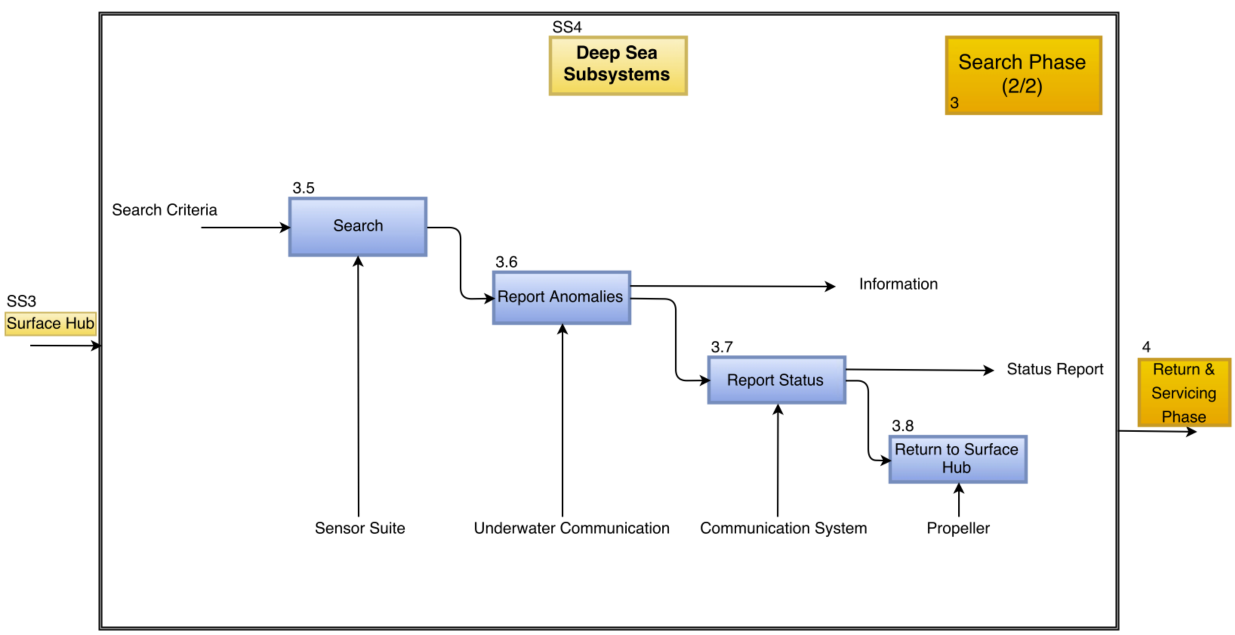


Figure 17: Detailed functional allocation diagram for the Deep Sea Subsystems during the Search Phase, with interactions of inputs/outputs and components necessary for functions

5.2.3. N-Squared Diagram

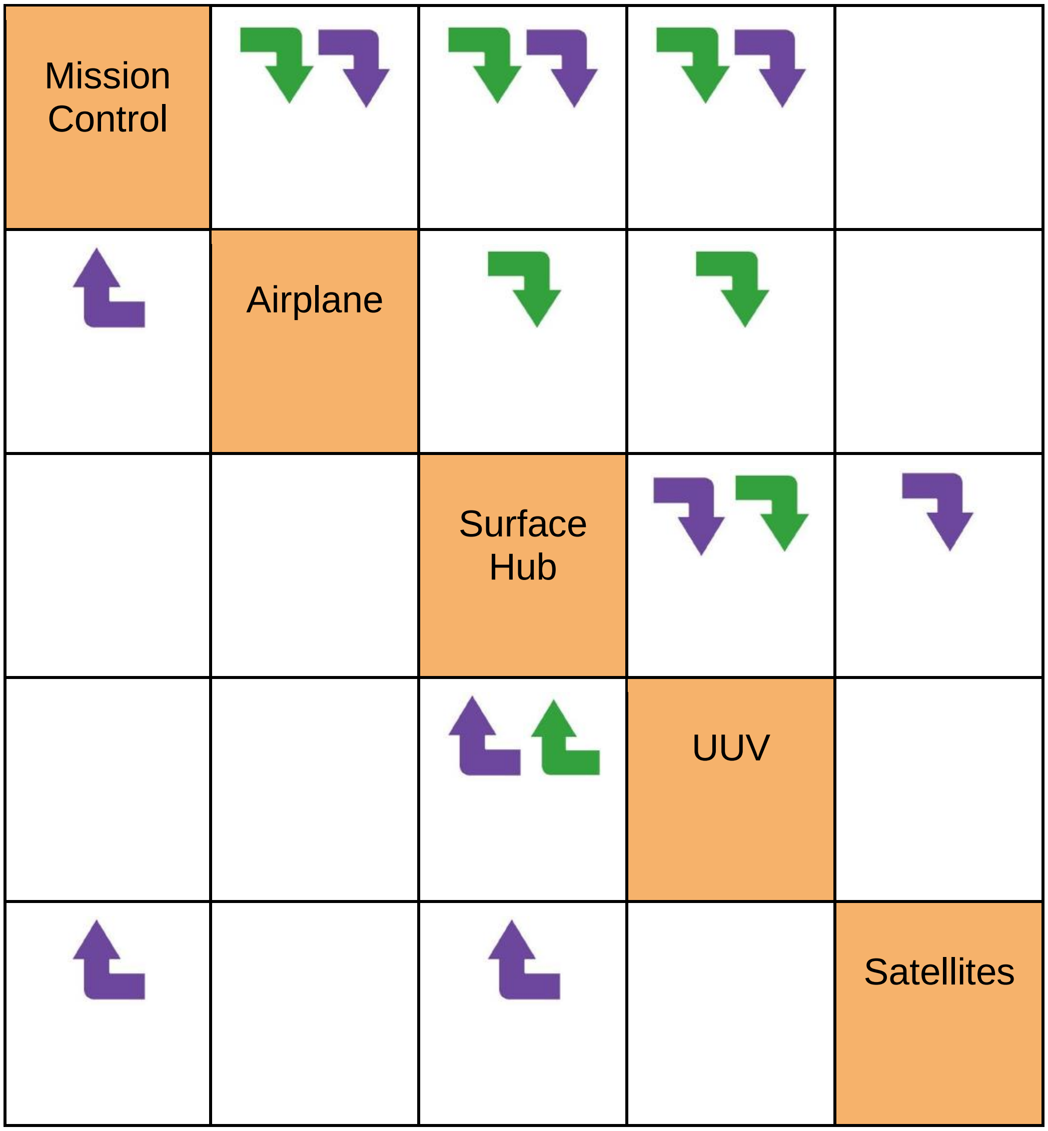


Figure 18: N2 diagram for the system. The purple arrows indicate a data or software interaction. And the Green arrows indicate mechanical or physical interaction.

This N-squared diagram shows the physical and data flow interfaces between systems in the search phase. Dark purple arrows indicate control or reporting data interfaces, and light green arrows indicate mechanical interfaces. In this case, all data interfaces are bidirectional; generally, control commands are sent from the ground base to the hub through satellites, and then to each UUV through the hub. Scan data is reported from each UUV to the hub, and relayed back to the ground base. The only mechanical interface is the docking and charging interface between the UUVs and surface hub.

5.3. System Detailed Design

The following structural diagrams show the component breakdown of the key hardware systems that comprise the system. The larger diagram in Appendix 2 shows all the components together with the overall hierarchy of the system.

The Low Velocity Airdrop Hardware diagram in Figure 19 shows the components that make up this system, (Parachute, shock absorbers, etc.) The Surface Hub diagram in Figure 20 show the subsystems that comprise the Surface Hub (Power System, Chassis, and Communication System) and their subsequent components. Some of these subsystems are dependent upon the components that comprise the, and are indicated as such with the filled in diamonds. For example, the propulsion system could not exist without a propeller, motor, and electronics. The same applies to Deep Sea Subsystems shown in Figure 21.

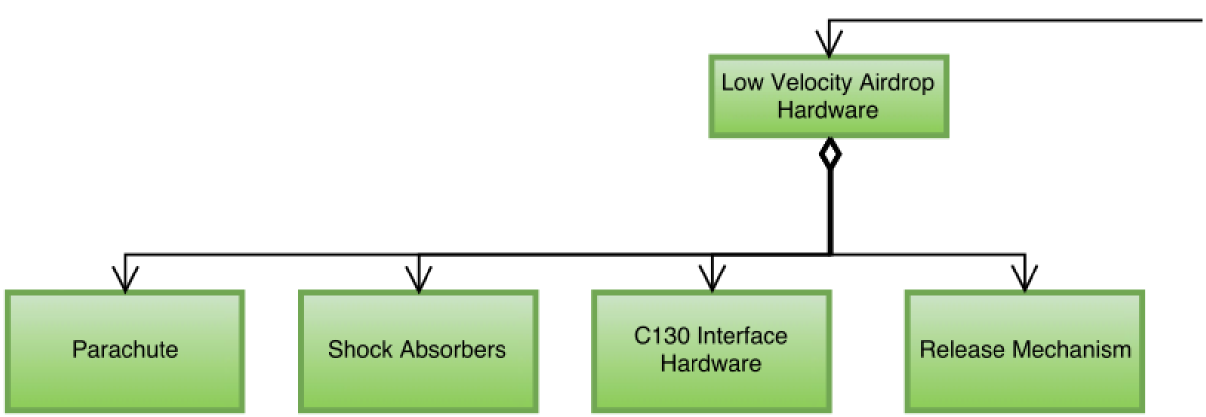


Figure 19: Low Velocity Airdrop Hardware Structural Diagram

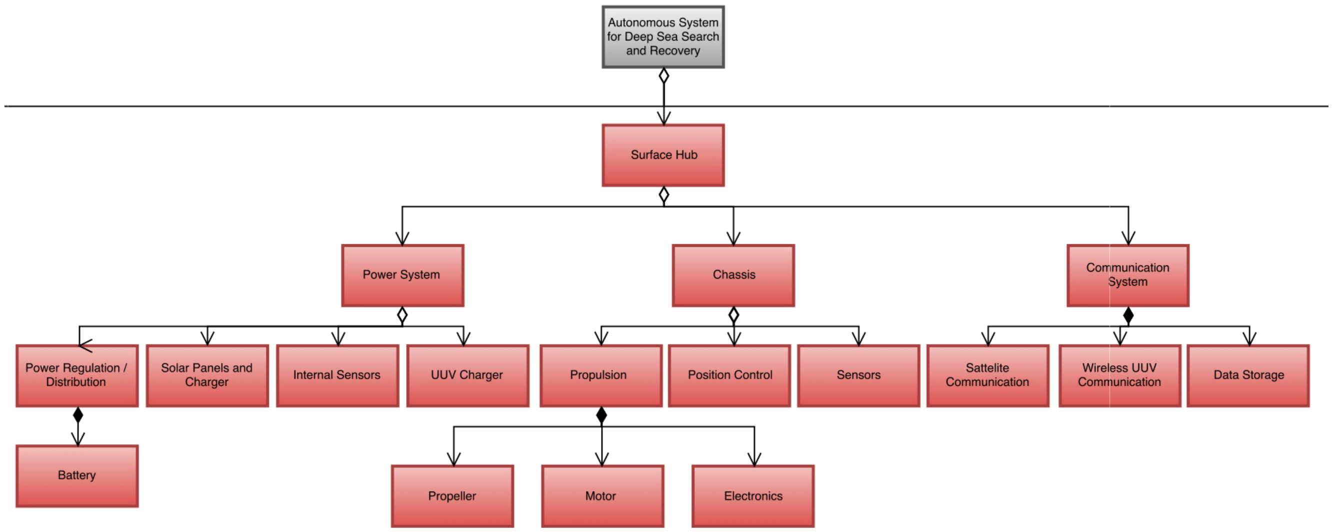


Figure 20: Surface Hub Structural Diagram

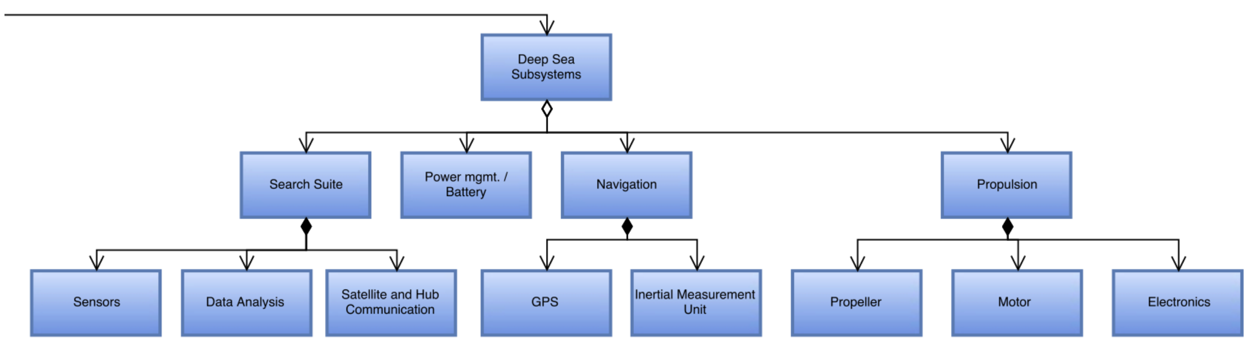


Figure 21:Deep Sea Subsystem Structural Diagram

5.4. System Feasibility Analysis

5.4.1. Risk Matrix

Because of the remote operating nature of the system, any issue that would require human intervention is severe. – The search would be delayed until the system could be repaired or a new one could be deployed, and speed is one of our key measures of effectiveness.

From the analysis below, we see that the hub is a critical point of failure: If it is unable to recharge the UUVs, the system will never search a significant area. (The hub is the floating solar recharger that the search UUVs periodically dock and charge at) The biggest hub-related risks are that the charging system fails, either through internal hardware, or charger contact corrosion.

5.4.2. Risk Mitigation Plan

Based on the risk analysis, the following plan aims to minimize the risks, especially the ones impacting mission-critical functionality. Items are listed from highest to lowest priority. The corresponding risk numbers are in bold before each item.

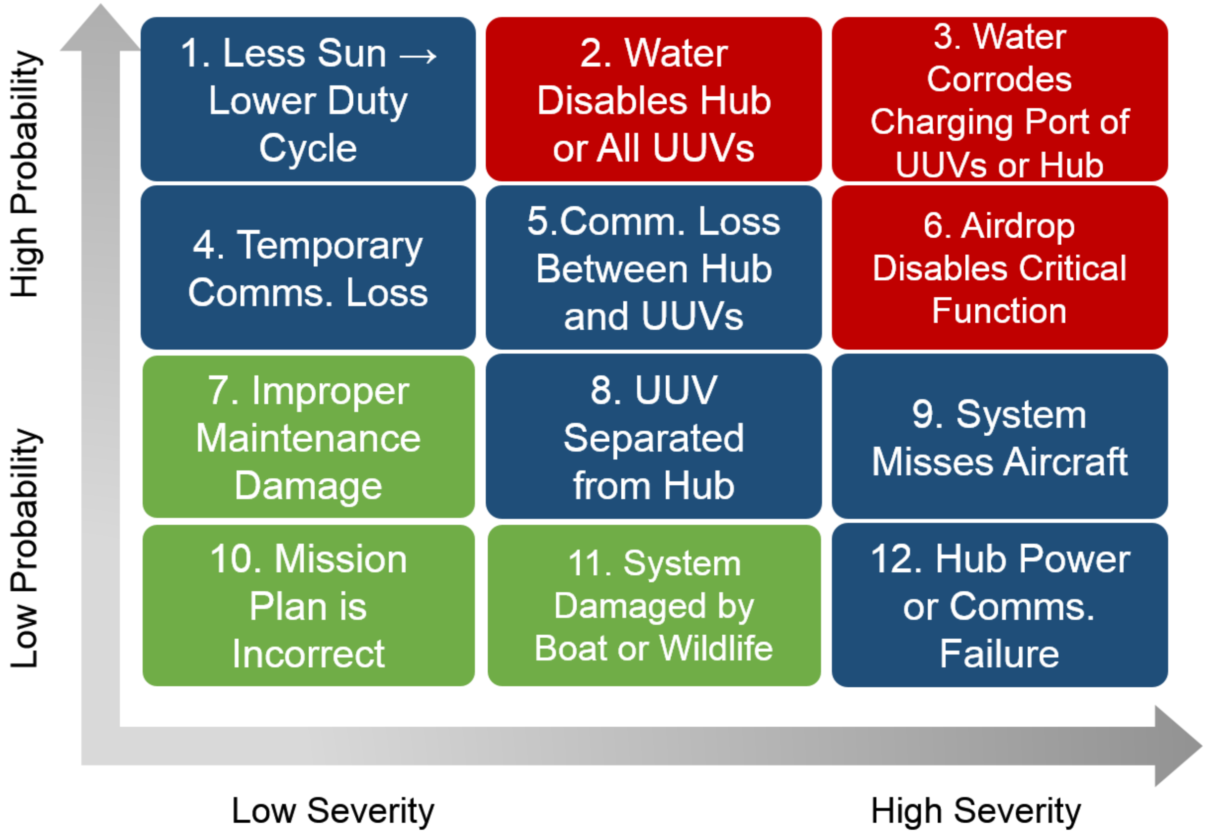


Figure 22: Risk Matrix

Highest Risk Items:

The high risk items are especially challenging engineering problems, but we have to dedicate the resources to mitigate these risks, since they could cause the whole system to fail.

- **Items 2,3,6:** For both the air drop tolerance and corrosion resistance, we should consult with experts in both fields, and set up a system of oversight in the development and testing processes of the hub and corrosion-resistant contacts. Testing will include live field tests and exposure to worse-than expected marine conditions.
- **Item 3:** Having alternate charging ports, or redundant power electronics on board is another option.

- **Item 6:** In addition to the impact tolerant design, we can also have a thorough airdrop checklist that covers likely packing problems that could cause the airdrop to fail.

Medium Risk Items:

- **Item 12:** Permanently losing communications to the hub could be another critical problem. We can mitigate some of this risk by allowing each UUV (also equipped with Iridium radios) to relay the same commands to the hub. It is possible, but unlikely that the whole Iridium satellite system would stop functioning as well. If a backup communication system could be installed without significantly impacting performance, it would be worth doing.
- **Item 8:** If 1 UUV unintentionally navigates far away from the hub, it could be stranded. The search capacity would be impacted, but not completely removed. The hub could navigate to the lost UUV and recover it (a failure recovery).
- **Item 1:** A likely situation is that unfavorable weather reduces the solar panel power output, and the UUVs take longer to recharge. There is nothing we can do about the weather, so we should relieve the power requirements on the solar system. This would decrease the duty cycle of UUV search vs. charging.
- **Item 4:** Weather can disrupt Iridium satellite communications. The system should be designed with enough autonomy to operate with intermittent communications losses. Simulated dropped communications will be easy to test.
- **Item 5:** Communication loss between a search UUV and surface hub could render the UUV inoperable, without new commands. Using a corrosion-proof communication method, wireless radio for example, is key. Additional measures could include a backup communication method, and developing a procedure to adapt to interrupted connectivity.

- **Item 9:** A false negative, or missing the aircraft in a search is an inherent risk in such a difficult search task. Since search is the whole system's purpose, this is a high severity risk. Mitigating it will involve using multiple modern scanning technologies in the design, consulting with experts on the subject, and possibly live tests on known wreckage.

Low Risk Items:

- **Item 10:** One feature of our system is fast deployment – If in our rapid deployment, the "mission plan" or parameters programmed onto the hub and UUVs was incorrect, we need a system to adjust mission parameters remotely. Fortunately, that should be easy to do, and a feature we would want anyways to deal with changing conditions. We need to test that any parameter can be remotely adjusted, and that it is possible to recover from software errors using some reset system.
- **Item 11:** Damage from boats is unlikely, but could disable the hub. Planning ahead and researching shipping routes in our search area should minimize this risk. Large wildlife damage to a UUV is hard to predict or prevent, though we can take preventative measures against barnacles and other life that may grow on the hulls. This is a common problem, so we would use a commercially available solution.
- **Item 7:** Disabling a system from improper maintenance is also a possibility due to the amount of maintenance required for such a complex system in a harsh environment. Batteries, contacts, electronics, or actuators could all be damaged. Mitigating this risk involves designing simple procedures and interfaces, but mostly training technicians properly before a live deployment.

5.4.3. Airdrop

At the moment, our area of interest over the course of the next 20 years is that of the ocean near India and Myanmar known as the Andaman Sea as it is not well-patrolled or monitored. In order for the system to be deployed, the best way would probably to use a C130 cargo plane, which is used all over the world by various militaries, to drop the system over a given area.

As per the US Military specifications, most airdrops fall into one of two categories: low velocity (500-1000 ft) or high velocity (10,000 ft). For our purposes our system will fall into the low velocity category. The C130 plane is the vehicle of choice because it has been in production for many years by Lockheed Martin and is used by over 16 countries (with many others maintaining the hand-me-down models as well) and there are approximately 2000 variations in use globally as the vast majority of militaries in the Western hemisphere, Southeast Asia, Western Europe, and Arabia depend on them (Thompson, 2014). These planes fly at max altitude of 28,000 ft, speed of 417 mph, max payload of 42,000 lb, range 2350-5200 mi. The speed is roughly 150 knots for a payload that requires the rear door/ramp to be deployed and the plane generally flies at an altitude of 225-300 ft. (“Baseops,” 2012; Petty, 2009).

A low-velocity airdrop requires labor intensive rigging setup operations that require wood pallet material, paper honeycomb, nylon webbing, and other such materials. To put this in perspective, a comparable example payload for the C130 is a Zodiac F470U Combat Rubber Raiding Craft (CRRC) that is dropped singly or in pairs. When inflated, each boat is 75 inches wide, 22 inches high, 185 inches long, and weighs 322 pounds. Minimum total rigged weight is 2100 pounds, which includes the 75 by 144 inch combat expendable platform with one G-12E cargo parachute, and the 35/55 horsepower outboard engines add an additional 136/215 pounds. In order to achieve the minimum total rigged weight, there must be an additional load that weighs anywhere from 650-1,170 pounds. When fully rigged, it measures in at 60 inches high, 75 inches wide, and 189 inches long (“Airdrop of Supplies and Equipment,” 2007). These numbers give us an idea of the size requirements for our own system. The C130 is able to achieve long distance missions while carrying fairly heavy loads. A good first-order estimate of the system would be to have it be based off of the similar size and weight of the Zodiac CRRC payload, which would leave us at a minimum weight of 2100 lb and a maximum size of 189 in x 75 in x 60 in.

Good infrastructure is something that all of us who live in the first world are familiar with. For example, the North Atlantic region has had generally good communication, good training, good safety regulations, and access to the best technology almost immediately for over 40 years. It’s a very busy route (both in air and sea), however there is a defined set of predesignated routes given before each new day of westbound and eastbound waves of traffic, known as the North Atlantic Tracks, that change based on wind conditions, are like freeways with entrances and exits-- and once you get on a NAT, you can’t get off. You could avoid them, but that means flying longer distances and using more fuel, or flying at higher altitudes (eg. the Concorde). These tracks keep aircraft separate and safe, which is vital in an area with limited information-- eg, there are no surface radar stations (like there are ground radar stations) in the ocean. (Derner, 2013) Given the high density of planes flying through this area every day, as shown in figure 23, (Harmonycentral.com, 2015) it is a testament to how reliable and safe the air traffic control system is between North America and Europe.

Figure 23: A graph of the flights around the world in one day. Notice how many flights take place in Europe and North America (they are much brighter) (Harmonycentral.com, 2015)

However that doesn’t exist in developing countries, such as some of the ones we see in South and Southeast Asia. In comparison, Southeast Asia has recently boomed in air traffic with a wide variety of planes and altitudes, outdated infrastructure, frequently bad weather because of its location on the equator and the cold air from Antarctica clashing with the humid moist air in that region. In the past five years the region has seen a 66% increase in air traffic to flying more than 1 billion passengers annually. These flights are mostly run by budget airlines run by individuals with fewer hours of training and experience in comparison to their 1st world counterparts (Wardell, 2014; Jacobs, 2014). More alarmingly, much of the technology in this region is outdated. For example, Indonesia’s air traffic control uses procedural separation where they use pilots’ radio reports to calculate positions of planes relative to other traffic. This technique is not only slower than the current radar separation technology used in the rest of the developed world but also relies on constant contact with control towers (Wardell, 2014). Additionally, many airstrips have no measuring equipment for on-ground wind-shear detection to help pilots land and take off (Wardell), which also makes takeoff and landing difficult in extreme weather conditions. For future consideration there are other rapidly developing nations like Brazil, Russia, India, and China. These nations are investing in infrastructure development-- so surrounding oceanic areas by these countries should be considered for future iterations.

5.5. Trade-off Analysis

5.5.1. Battery Chemistry Decision

In terms of how quickly the system can search a given area, one of the key decisions is the choice of battery chemistry. Of the many varieties available, some last longer, provide more power, hold more charge, are more tolerant to full discharges, and other parameters. The five common chemistries for unmanned robotics are considered below. The most critical requirements for out batteries are that they can operate for 6 months without maintenance, and are suitable for the high-pressure environment. High power density also allows for smaller battery arrays that provide power for longer missions, allowing the UUVs more time to search vs. diving and surfacing.

Table 3: Battery Trade-off Analysis

Need	Importance	Lithium Ion	Lithium Polymer	Marine (Lead Acid)	Nickel-Metal Hydride	Nickel Cadmium
Deep Cycle	1	4	5	5	3	2
High Current	1	4	4	5	3	5
Low Self Discharge	1	4	4	5	1	2
6 Month Life	3	5	5	3	2	1
Pressure Tolerant	3	5	5	2	2	5
Power Dense	2	4	5	1	3	2
	Total:	**40**	**43**	**26**	**21**	**29**

From this analysis, it is clear that either lithium polymer or lithium ion batteries would be preferable. Lithium polymer (or LiPo) offers higher power density over lithium ion, so it is the first choice.

5.5.2. Propulsion Type Decision

One other important technology choice is the motor design for the propulsion systems. Here, there are only two applicable types of motors: brushed motors, which are simple and use brushes to pass current to a spinning rotor. Brushless motors are more complex to operate, but do not use brushes, and deliver more power. A decision matrix below compares the choices.

Table 4: Propulsion Trade-off Analysis

Need	Importance	Brushed DC	Brushless
Energy Efficient	3	2	5
G-Tolerant	2	3	3
6 Mo. Operation	3	2	5
Simple Operation	1	5	2
	Total:	**23**	**38**

Brushless motors are the clear choice here. Although brushed motors are much simpler to operate, brushless motors are more efficient and critically, require much less maintenance. As stated before in the KPPs, the system must be able to operate for six months at a time without maintenance. Brushless motors are more appropriate here because they require much less maintenance, while the brushed type require the brushes to be replaced periodically.

5.6. System Architecture

Our system architecture decided to look at the overall system and then break that down into the more appropriate or needed systems to illustrate. These include: The high level operational concept diagram, the deployed communications diagram, and the traceability matrix between all the parts of the system. These diagrams display all the relationships between the parts of the complete system, how they operate and how they interact with one another. Plus the system technology forecast diagram gives an idea of what will be needed to continue operations for the full five year life cycle of our system.

5.6.1. High Level Operational Concept Diagram

This graphic presents a high-level illustration of how the system will function. Upon instruction by the customer, the company readies a system and sends it out with 4 days, the system is then loaded onto an aircraft which will drop it into a designated location in the ocean. The surface hub then disperses the subsystems to search for the crashed aircraft wreckage. As the subsystems are searching they will relate their findings back to the surface hub and then from there to the command centers via satellite. This would be an operator’s and customer’s view of how the overall system would be deployed and work in deployment once ordered.

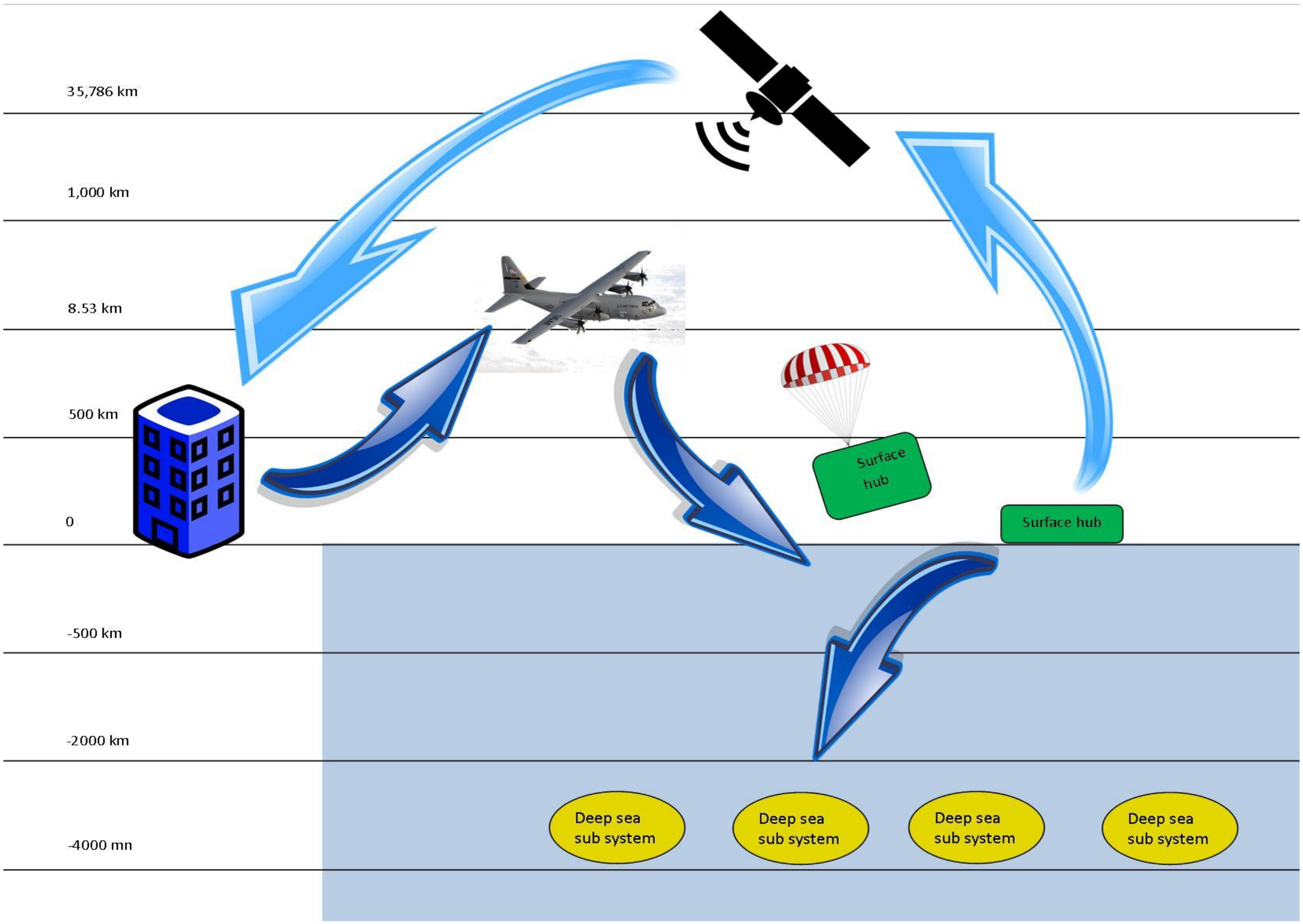


Figure 24: Overall system diagram. Dark blue arrow are transit and light blue arrows are data transfer.

5.6.2. Deployed System Communication Network

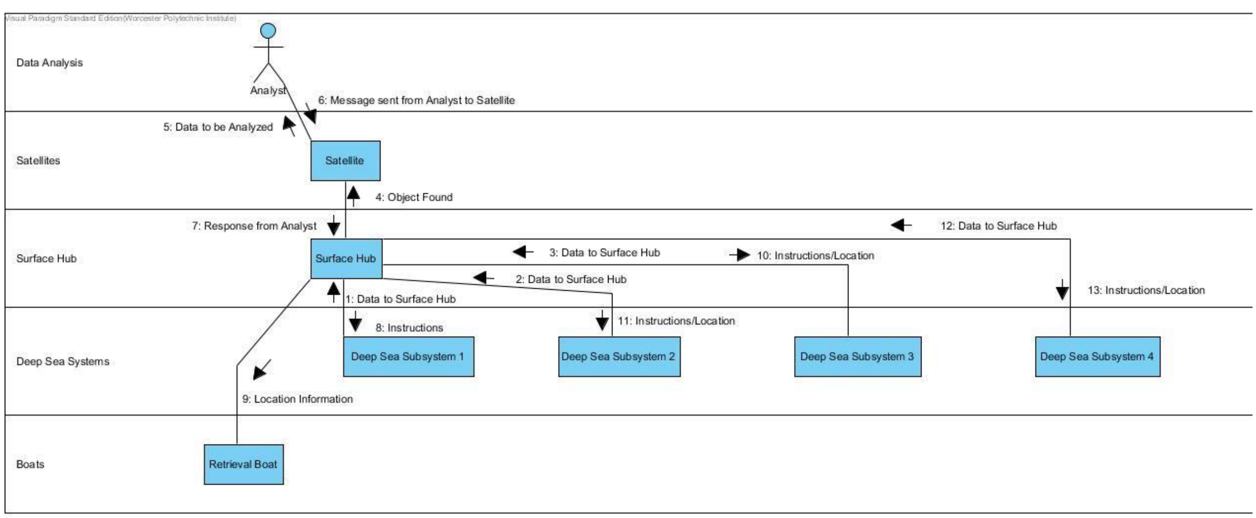


Figure 25: Deployed System Communication Network, shows communication connections and information sent and received

This diagram shows the deployed systems, how they will communicate with one another during a mission, and the type of information they will exchange, from the view of the analyst located at one of the command centers. This communication diagram would begin immediately after system deployment function checks and would continue until the whole system is recovered.

5.6.3. Traceability Matrix

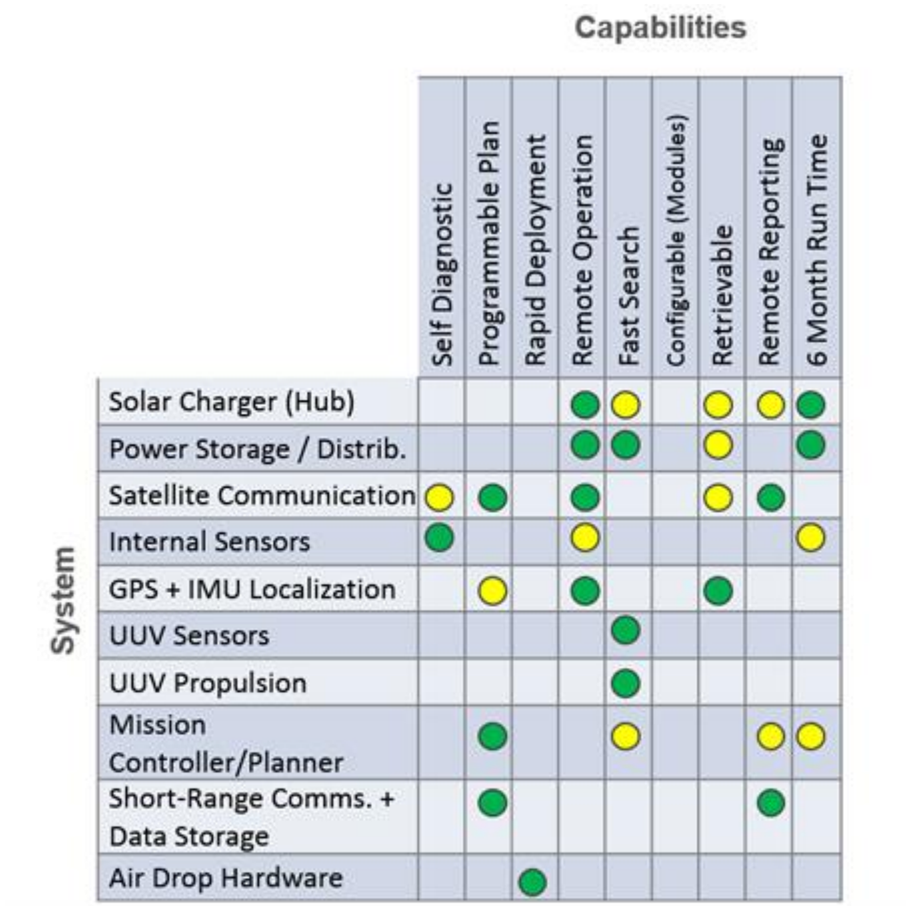


Figure 26: Traceability Matrix that specifies the relationships between the components and capabilities

The traceability matrix in Figure 26 specifies the relationships between the components and capabilities of a system. Some systems support the operation of multiple capabilities. Unlike the house of quality, this shows which capabilities rely on which systems. Here, important dependencies are denoted with green marks, and less critical relations with yellow marks. The communications and power management systems are crucial to many key capabilities of the system. Other systems, like the internal sensors are used for, but not critical to the robustness of the system as a whole. It is important to note here that the search capability is only represented in one column of the traceability matrix, even though it is the most important capability of the system. Other diagrams are more useful for visualizing such critical relationships; the main use of the traceability matrix is to verify that features of the system are all necessary and correspond to a capability.

5.7. Verification & Validation

The following verification and validation tables are based on those found in Appendix A of the *Guide to Reusable Launch Vehicle Safety Validation and Verification Planning* published by the Office of the Associate Administrator for Commercial Space Transportation. There requirements that we are validating and verifying are the Key Performance Parameters (KPPs) and the Operational Requirements (OR) of our system. The identification numbers correspond to the section of this paper where the requirements are discussed in more detail. The primary source for these requirement is the revisited Milestone 1 document in which the team identified the most critical system requirements. The team determined through background research and consensus that the requirements are valid as shown below. Additionally, engineers were assigned to manage each requirement.

5.7.1. Validation Table

The validation table is to make sure that all the requirements are met and that we are building the correct system to meet the needs of the customer. This brings in the critical requirements or KPPs and the operational requirements. If a requirement does not help answer the problem posed by the customer then it is cut. The table has all the requirements that this system needs to be built to answer the problem statement and be a useful system.

Table 5: Validation Table

Requirement ID CR = critical requirement OR = operational requirement	**Requirement**	**Source**	**Validation Status (Y/N)**	**Requirement Owner (Individual)**
CR 1 (Described in section 4.2.4.1)	System shall be able to operate at 4km depth and 401 atms (CR)	Milestone 1 Rev. 2	Yes	Mechanical Engineers
CR 2 (Described in section 4.2.4.2)	System shall find wreckage of aircraft within 6 months given 90% confidence of impact location (CR)	Milestone 1 Rev.2	Yes	Sensor Engineers
CR 3 (described in section 4.2.4.3)	System shall survive autonomously for a minimum of 6 months (CR)	Milestone 1 Rev.2	Yes	Electromechanical Engineers
CR 4 (Described in section 4.2.4.4)	System shall communicate findings (CR)	Milestone 1 Rev.2	Yes	Electricals Engineers
CR 5 (Described in section 4.2.4.5)	The system shall be able to operate in an	Milestone 1 Rev.2	Yes	Ocean Engineers

	ocean environment			
OR 1 (Described in section 4.3.2.1)	System shall withstand a 7G maximum impact with 90% operational capability (OR)	Milestone 1 Rev.3	Yes	Mechanical Engineers
OR 2 (Described in section 4.3.2.2)	System shall scan ocean floor for unnatural objects (OR)	Milestone 1 Rev.3	Yes	Sensor Engineers
OR 3 (Described in section 4.3.2.3)	System shall have a lifespan of at least 5 years with maintenance	Milestone 1 Rev.3	Yes	Mechanical Engineers
OR 4 (Described in section 4.3.2.4)	System shall operate at 3 - 35 degrees C (OR)	Milestone 1 Rev.3	Yes	Electromechanica l Engineers
OR 5 (Described in section 4.3.2.5)	System shall use internal sensors to send status updates every 30 minutes (OR)	Milestone 1 Rev.3	Yes	Electrical Engineers
OR 6 (described in section 4.3.2.6)	System shall navigate ocean environment - dive, surface, 6 DOF (OR)	Milestone 1 Rev.3	Yes	Mechanical and Ocean Engineers
OR 7 (Described in section 4.3.2.7)	System shall be able to recharge its power source in a 25% duty cycle (OR)	Milestone 1 Rev.3	Yes	Electromechanica l Engineers

5.7.2. Verification Table

The following verification table identifies the methods that would be used to verify that requirements are met. The verification methods are similarity (S), analysis (A), testing (T), inspection (I), and demo (D). Similarity refers to relying on the certification and qualifications from other companies if their products are certified under a recognized organization. Analysis and testing would be used to determine if and how well the system carries out its primary function of finding the airplane wreckage in the specified deep-sea region (Section 4). It would be rather difficult to demonstrate and inspect these capabilities. However parts can be inspected for applicability to manufacturing specifications. Analysis of the functionality of each component over the specified amount of time (6 months) will be the best way to determine whether or not the system meets requirement as described in detail in Section 4.4. Finally verifying the mechanical durability of the system during an airdrop (Section 5.4.3) could be accomplished through analysis, testing, and demonstration.

Table 6: Verification Table

Requirement ID **CR = critical requirement** **OR = operational requirement**	**Requirement**	**Verification Method** **A = Analysis** **T = Test** **D = Demo** **I = Inspection** **S = Similarity**	**Measure of Success**	**Requirement Owner (Org/Individual)**	**Status (to be done/in progress/complete)**
CR 1 (Described in section 4.2.4.1)	System shall be able to operate at 4km depth and 401 atms (CR)	A (preliminary design phase) , S (concept design phase) & T (detail	48 hours submerged at depth, no leaks & 48 constant changing	Mechanical Engineers	TBD (to be done)

		design & development)	pressure, no leaks		
CR 2 (Described in section 4.2.4.2)	System shall find wreckage of aircraft within 6 months given 90% confidence of impact location (CR)	A (preliminary design phase)	Analysis done in simulation 90% success rate needed	Sensor Engineers	TBD (to be done)
CR 3 (described in section 4.2.4.3)	System shall survive autonomously for a minimum of 6 months (CR)	A (preliminary design phase), S (concept design phase)	Analysis through calculations and simulation, if they say yes along with the documents agreeing	Electromechanical Engineers	TBD (to be done)
CR 4 (Described in section 4.2.4.4)	System shall communicate findings (CR)	I (detail design & development), S (concept design phase), & T (detail design & development)	At all stages of assembly all items that need to communicate must send 100% of messages 100% of the time	Electricals Engineers	TBD (to be done)
CR 5 (Described in section 4.2.4.5)	The system shall be able to operate in an ocean environment (CR)	A (preliminary design phase),S (concept design phase)	No leaking or severe corrosion is allowed.	Ocean Engineers	TBD (to be done)
OR 1 (Described in section	System shall withstand a 7G maximum	A (preliminary design phase), T (detail	Whole system must survive 7G impact with	Mechanical Engineers	TBD (to be done)

4.3.2.1)	impact with 90% operational capability (OR)	design & development), & D (detail design & development)	90% operational capability		
OR 2 (Described in section 4.3.2.2)	System shall scan ocean floor for unnatural objects (OR)	A (preliminary design phase) & T (detail design & development)	Sensors must show being able to find aircraft parts in silt floor 95% of the time	Sensor Engineers	T BD (to be done)
OR 3 (Described in section 4.3.2.3)	System shall have a lifespan of at least 5 years with maintenance (OR)	A (preliminary design phase), S (concept design phase)	Nothing will be accepted if cannot last 5 years with proper maintenance	Mechanical Engineers	TBD (to be done)
OR 4 (Described in section 4.3.2.4)	System shall operate at 3 - 35 degrees C (OR)	A (preliminary design phase), I (detail design & development), S (concept design phase), & T (detail design & development)	Test in temperature chamber to failure, failure points must be ≥40 degrees C and ≤-2 degrees C	Electromec hanical Engineers	TBD (to be done)
OR 5 (Described in section 4.3.2.5)	System shall use internal sensors to send status updates every 30 minutes (OR)	A (preliminary design phase), I (detail design & development), & T (detail design & development)	Must send update every 30 minutes, do not go more than 60 minutes without ping being sent or heard	Electrical Engineers	TBD (to be done)
OR 6	System shall	A (preliminary	Engineering	Mechanical	TBD (to

(described in section 4.3.2.6)	navigate ocean environment - dive, surface, 6 DOF (OR)	design phase), & T (detail design & development)	model must perform diving, surfacing, and 6 DOF controllability with no failures and within 5 feet of identified location	and Ocean Engineers	be done)
OR 7 (Described in section 4.3.2.7)	System shall be able to recharge its power source in a 25% duty cycle (OR)	A (preliminary design phase) & T (detail design & development)	Recharging must happen 100% of attempts	Electromechanical Engineers	TBD (to be done)

6. System Specification

6.1. Testing Plan

As part of the verification and validation procedures and risk mitigation plans, several tests must be run on both subsystems and the full search system. The aim of these tests is to verify that key performance parameters and critical requirements are met, and catch unexpected issues before a live deployment of the system.

6.1.1. System Tests

The most critical tests are listed below. They each correspond to the KPPs described in section 4.8.3, and are concerned with the system's environmental tolerance and operational reliability. Other tests will involve the reliability of communications systems, on both local (hub to UUVs) and long range Iridium communication, power system charge / discharge rates, verifying remote control features, thermal tests, and others. These additional tests are not directly related to the KPPs, and are not covered in such detail.

6.1.1.1. Component Acceleration Test

Relating to operational requirement 4.8.2.1 and the acceleration survival KPP, every subsystem inside the surface hub and UUVs will be individually shock tested at 14G's, double the expected deceleration from an air-to-water drop. This includes each power, communications, propulsion system, etc. The success criterion for this test is that the subsystem can function unimpaired after being exposed to the acceleration on at least 3 orthogonal axes. Interruption of functionality during the test (e.g. system power resetting during an impact) does not constitute a failure, as long as the functionality is restored following the acceleration. Each subsystem passes or fails this test independently.

6.1.1.2. Full System Acceleration Demo

Also related to operational requirement 4.8.2.1, the full deployable system, including the surface hub and UUVs will be assembled and packaged as they would be for a live deployment. This payload will be launched into a body of water at the same angle and speed expected from an actual airdrop. Following that, the system will attempt to initialize a search where it landed. In a successful test, the system will be able to start a search with at most a 10% performance degradation over the nominal search rate. This rate as calculated as the fastest rate the power, propulsion, and sensing subsystems will allow a given area to be thoroughly searched.

Afterward, inspection of the hardware must confirm that it is in-tact enough to operate for an estimated 6 additional months.

6.1.1.3. Environmental Test

To verify the critical and operational requirements (Section 4.4.5 & 4.8.2.6 respectively) that the system must operate in saltwater, a hub and one UUV will deployed in a saltwater tank exposed to the sun for one month. For one month, the hub and UUV will simulate the operations of a live deployment. The mechanically tethered UUV will drive its thrusters and collect sonar data for an expected dive time, return to the hub, report the sonar data, and recharge using the hub’s solar charger. The test requires that after one month of operation, the UUV and hub’s subsystems have withstood the environmental effects, and still function unimpaired.

6.1.1.4. Cyclic Pressure Test

To verify the UUVs meet critical requirement 1 (4.4.1) and operational requirement 2 (4.8.2.2) that the system can operate at depths of 4km, a UUV will be enclosed in a temperature-controlled pressure vessel. The UUV will be fixed in place, but will test its sonar equipment, and run its thrusters for the duration of the test. The water will be kept at 3 degrees Celsius, and the pressure inside the vessel will be cycled from atmospheric pressure to 503 atm, which corresponds to a depth of 5km. In one test, the pressure will go from atmospheric to 503 atm, and back 75 times. After the test, the recorded sonar and self-diagnostic data from the UUV will be analyzed to check that it didn’t experience any interruptions. The UUV will also be inspected for leaks or damage afterward.

6.1.1.5. Wreckage Discovery Test

Requirement 4.4.2 states that, “System shall find wreckage of aircraft within 6 months given 90% confidence of impact location”. There may not be a known plane wreck in the Indian Ocean to demo this capability on, but a real shipwreck, preferably in the Indian Ocean and near the maximum operating depth of 4km will be selected for a live demo. This wreck should be roughly as easy to find as a recently crashed plane. The system will be deployed from a manned ship within a 7-day searchable radius of the known shipwreck. Operators with no knowledge of the wreck’s precise location will run a search in the area. In a successful test, the operators will be able to identify and report the location of the wreckage. This is primarily a test of the UUV search performance, not hub or satellite functionality, which are covered in separate tests. Analysis of the search data will also help estimate requirement “90%” probability of identifying wreckage.

6.2. Utilization and Support

The system is expected to last 5 years before needing hardware upgrades. Annual maintenance, as well as post-deployment maintenance will be regularly performed. These two procedures are described below.

6.2.1. Annual Maintenance

For the annual maintenance the complete system will undergo a full inspection and as necessary replacement or upgrade of parts. The following is a high level inspection list:

- Check battery charge / discharge rate and capacity

- Remove thrusters and check maximum thrust and water tightness of the motor with the motor fixed underwater
- Inspect the hull inside and out for barnacles and remove them
- Repaint and re-coat the hull if any scratches go through the paint to metal.
- Inspect the gaskets on all pressure-sealed parts, and pressure test those parts
- Replace the charging connectors if they are corroded at all

6.2.2. Post-Deployment Maintenance

These are some high level inspection procedures to be performed once a system has been retrieved by a crew at the end of the full mission.

- Thoroughly rinse all saltwater off and out of the UUV and hub
- Inspect each module for damage or leaks. Replace or repair as necessary
- Remove barnacles attached to the hulls

6.3. Retirement and Disposal

At the end of the 5-year life cycle, there will be an analysis of which components are reusable, upgradeable, replaceable, and which should be sold or discarded. Out of date components could be discarded or donated to academic researchers. The only component with a difficult disposal procedure will be the lithium polymer batteries, which need to be turned into an authorized recycler.

7. System Impact Analysis

7.1. Technological Impact

Digital technology has come a long way in the last 30 years since underwater vehicles have been used and developed for deep sea research. In order for vehicle systems like this to be viable, there are certain existing technologies that have to be integrated and tweaked for our mission. Current sensor technology is limited by the power density required to image a specific area. Additionally, new thrusters that aren't as prone to saltwater corrosion are also coming onto the market. Underwater mapping is currently a multi-process ordeal that requires at least 4 properly surveyed acoustic buoys that need to be moved as the search area progresses ("Km.kongsberg.com", 2015). With the plethora of inexpensive sensors and smaller, cheaper, faster computing processing power, and batteries having increasing power density, multi-vehicle systems can now be smaller and more efficient at covering specific areas.

Ultimately, vehicle speed is dependent on factors such as hydrodynamic shape and energy density. With the current designs, vehicles are not easily maneuverable (such as they cannot easily) and are limited by the amount of power required to power larger thrusters (in order to go faster).

7.2. Market

A smaller market besides emergency response could be that of academic research. Geological researchers are interested in monitoring underwater fault lines and underwater volcano activity. Marine biologists are interested in studying the biological life at the bottom of the sea and the ocean currents behind all of that. Underwater archaeologists could also benefit from higher resolution sea floor grid-mapping because the more mapping means better understanding of the seafloor and geographic history of ancient civilizations.

A larger market share is probably that of oil and gas. As oil rigs are increasingly offshore in fairly remote or inaccessible locations, it is dangerous to monitor functionality through manned missions. There are pipeline inspections and oil rig inspections that need to be performed.

7.3. Defense Impact

Many navies around the world very care about high resolution of the sea floor. For many of the technologies that are now available, it is possible to target underwater threats from another ocean/part of the world entirely. Smaller vehicles allow for targeted searching and better maps of the sea floor, which could be invisible to surface craft and allow for reconnaissance missions in remote areas.

7.4. Earth Environmental Impact

Our systems appears to have very little to no impact on the environment that it will be working in. In fact due to the sensors that our system could be equipped with, we could potentially obtain secondary environmental data, as long as the primary objective of finding the aircraft is not affected at all. We do have the possibility of losing a part of our subsystem but the concern with that is minor. Our current disposal plan is to either donate our systems to schools/research institutions or use it as an artificial reef. Therefore if it ends up on the bottom of the ocean it can provide homes for any type of fish that may be down there. The batteries are the most concerning of potential environmental issue but with the new style of Lithium ion polymer

(LiPO) batteries they are being made to be less toxic if a leak occurs. But due to the new flexible shell that the batteries are starting to have it should be protected against leaks. Due to the size and components our subsystems will be made of there is little concern for negative environmental impact.

7.5. Societal Impact

This system could bring about good working relationships between governments and civilian companies that could lead to more positive relations between the countries. The main human issue that is always at the forefront is trust. However as long as our company is upfront about what we are doing and our systems are completing their missions within the parameters defined by the countries that ask for the help of these systems, relations should grow stronger. Another big benefit of finding the downed aircraft within 6 months instead of the normal 1 to 2 years it takes now, is it could bring comfort to the families of the people lost. Another major benefit is by finding the aircraft sooner, the crash investigation can begin sooner and then the cause for the crash can be discovered sooner. If the cause for the crash is something that could have been prevented, or is a flaw in the aircraft system, then finding it sooner can help prevent the issue from occurring again, thus potentially saving hundreds of lives.

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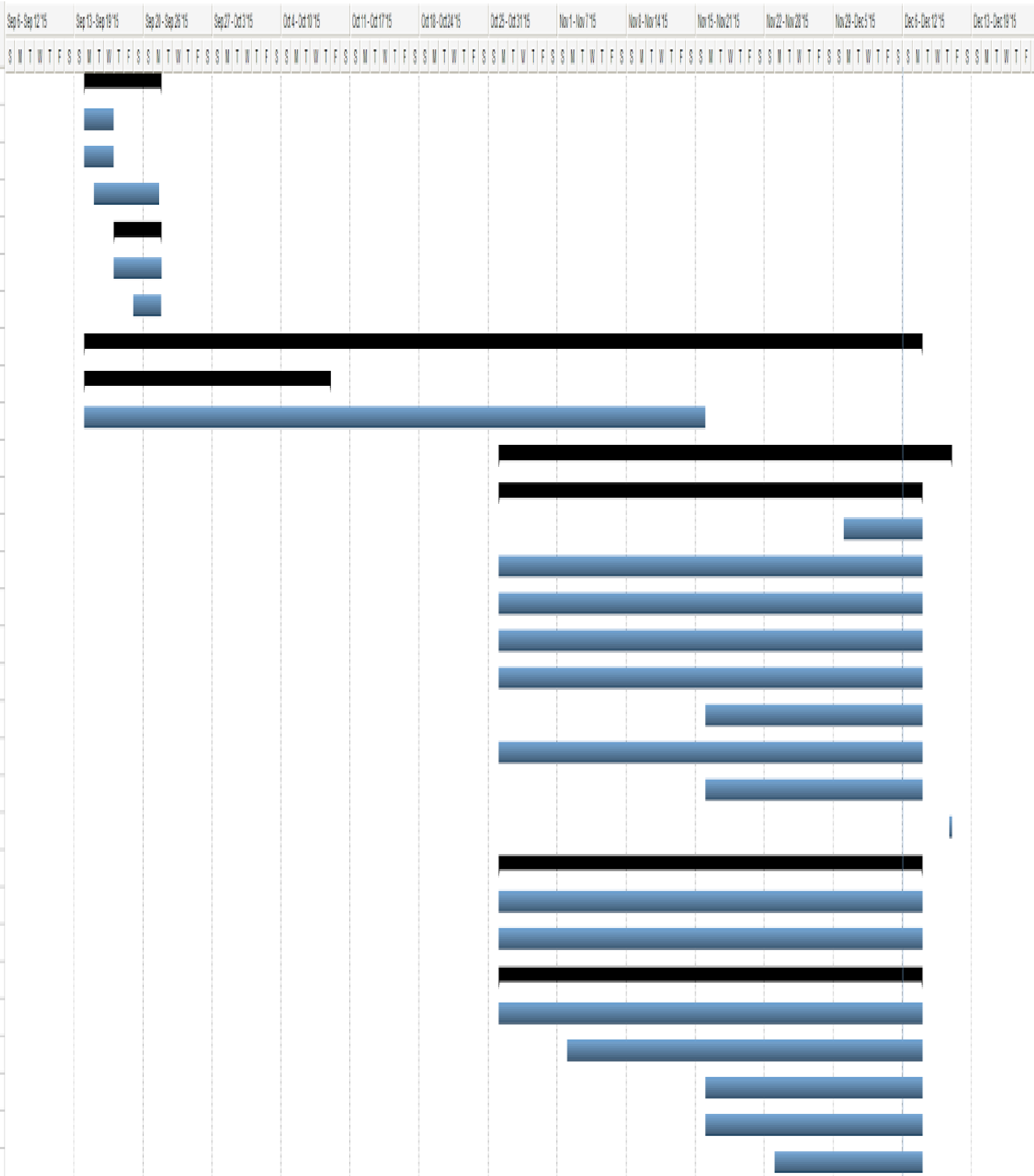
8.1. Appendix 1: Gantt chart

We realize this Gantt Chart is difficult to read so please refer to the link provided. It does require a google account.
https://www.smartapp.com/gantterforgoogledrive/index.html?fileID=0B3K6cJ9DH0F9SGsyMHI4WXVGQUE

		Name	Duration	Start	Finish	Predecessors	Resources
1		**Brainstorming**	**23.63d?**	**09/14/2015**	**09/21/2015**		
2		Problem Identification	9d?	09/14/2015	09/17/2015		
3		Problem Definition	9d?	09/14/2015	09/17/2015		
4		Identify System Response to Problem	19.75d?	09/15/2015	09/21/2015		
5		**Define our System**	**14.63d?**	**09/17/2015**	**09/21/2015**		
6		Formal Definition	14.63d?	09/17/2015	09/21/2015		
7		Does our System answer the Problem?	8.5d?	09/19/2015	09/21/2015		
8		**Administrative Tasks**	**255d?**	**09/14/2015**	**12/07/2015**		
13		**Milestone 1**	**75d?**	**09/14/2015**	**10/08/2015**		
31		Re-Evaluate and Expand on Milestone 1	189d?	09/14/2015	11/15/2015		
32		**Finalization**	**138d?**	**10/26/2015**	**12/10/2015**		
33		**Paper Finalized & Uploaded**	**129d?**	**10/26/2015**	**12/07/2015**		
34		Executive Summary	24d?	11/30/2015	12/07/2015		
35		Conceptual Design	129d?	10/26/2015	12/07/2015		
36		Preliminary Detailed Design	129d?	10/26/2015	12/07/2015		
37		Projected Work Break Down Structure	129d?	10/26/2015	12/07/2015		
38		Project Plan	129d?	10/26/2015	12/07/2015		
39		Budget and Financial Feasibility	66d?	11/16/2015	12/07/2015		
40		Potential Problems	129d?	10/26/2015	12/07/2015		
41		Appendices	66d?	11/16/2015	12/07/2015		
42		Final Product	1d?	12/10/2015	12/10/2015		
43		**Milestone 2**	**129d?**	**10/26/2015**	**12/07/2015**		
44		System Functional Analysis	129d?	10/26/2015	12/07/2015		
45		Synthesis Allocation of Design Criteria	129d?	10/26/2015	12/07/2015		
46		**System & Subsystem Analysis**	**129d?**	**10/26/2015**	**12/07/2015**		
47		Trade off Analysis	129d?	10/26/2015	12/07/2015		
48		System Synthesis and Definition	108d?	11/02/2015	12/07/2015		
49		System & Product Design	86d?	11/16/2015	12/07/2015		
50		System & Product Model Development	86d?	11/16/2015	12/07/2015		
51		System Prototype Test & Evaluation	45d?	11/23/2015	12/07/2015		



8.2. Appendix 2: System Detailed Structural Diagram