Autonomous Vehicle for Gathering Oceanographic Data in Littoral Regions

Engineering Design I

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Executive Summary

Researchers are interested observing how the properties of shallow bodies of water such as rivers and bays change with respect to time and space. Current methods for making oceanographic observations involve fixed stations such as buoys from which measurements are taken and transmitted, and mobile platforms such as boats and ships which can be used to suspend or tow instruments at a specified point in the water column. However, current methods have difficulty providing measurement data at the resolution desired by researchers without considerable investments in time and money. The goal of this project is to design and build an autonomous vehicle for use in gathering this data in littoral regions.

To this end, the Chesapeake Baywatch Team interviewed two customers, CDR Andy Gish and Prof. Joe Smith, both from the U.S. Naval Academy, and worked with them to develop a list of customer requirements that includes the cost of the system, the ability to take samples and make them available to the user, the ability to cover a specified search area in a reasonable time, and the ability to be man-portable and launchable.

In the next step in the design process, the team will develop a number of candidate solutions and select one from among them for detail development.

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1 Problem Definition and Need Identification

1.1 Customer's Problem Statement

The problem statement initially communicated from the customer was:

> *Design and build an autonomous underwater vehicle for use in gathering oceanographic data in littoral regions.*

1.2 What is the problem? What about the current situation is unsatisfactory?

Researchers are interested observing how the properties of shallow bodies of water such as rivers and bays change with respect to time and space. For example, they might be interested in studying how roadway runoff affects the health of the marine life in an estuary. To that end, they would like to measure parameters such as the temperature, pressure, and salinity at different points and times within the estuary and use computational models to complete the picture and draw conclusions from their observations. The problem is, current methods include buoys that can take data over a long time period but only in one location and boats which can take data over a wide area but can't achieve the sampling resolution desired by researchers without a significant time commitment.

1.3 Customer Identification

CDR Andy Gish (Figure 1) of the Naval Architecture and Ocean Engineering (NAOE) Department at the U.S. Naval Academy originally proposed the project and was identified as the initial customer. It should be noted that he is interested in finding a solution on behalf of other researchers but not necessarily interested in the data himself.

Figure 1: CDR Andy Gish, USN, PhD of the NAOE Department initiated this project and has agreed to act as the primary customer[1].

Prof. Joe Smith (Figure 2) of the Oceanography Department at the U.S. Naval Academy was also recommended by CDR Gish as an additional customer and potential source of information.

Figure 2: Prof. Joe Smith of the Oceanography Department conducting field observations[2].

Prof. Smith is a geochemist who according to his faculty webpage studies the "cycling of inorganic and organic constituents in water, soil, and sediments."

Additional potential customers include but are not limited to research scientists (Figure 3), engineers, and students from both government and non-governmental organizations and people associated with the do-it-yourself (DIY) community.

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[1] Profile page, Linkedin, https://media.licdn.com/mpr/mpr/shrinknp_400_400/p/2/000/190/3c4/3adadab.jpg, accessed June 19, 2015

[2] USNA faculty page, https://www.usna.edu/Users/oceano/jpsmith/, accessed June 26, 2015

Figure 3: Research scientists and students conducting field observations from a small surface vessel[3].

1.4 Gathering Information from Customers

With the problem statement in hand and customers identified, the next step in the design process was to gather information from customers. Sources of customer information included customer interviews, complaints, and general research conducted online. The results were compiled and are presented here.

1.4.1 Customer Interviews

Initial interview with CDR Gish

CDR Gish was initially interviewed on June 18, 2015. He mentioned a number of needs and wants during the interview. He was focused primarily on AUVs as the solution to the problem though he mentioned that he would be open to all solutions that met his criteria. Among his primary requirements are the need to measure and record oceanographic data. He stated that specific measured parameters are not as important as the ability to measure *something*. He suggested temperature, pressure, and salinity at several points during the interview. He also mentioned the need to record the position and time at which the measurements were taken and the fact that they needed to be taken simultaneously.

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[3] GEO-CAPE Chesapeake Bay Oceanographic campaign with DISCOVER AQ, Ocean Ecology Science Research Portal, http://neptune.gsfc.nasa.gov/uploads/images_db/geo-cape2.jpg, accessed June 26, 2015

The measurement resolution, that is how close the measurements are taken in space and time, was an open question and is assumed to depend on the gradient of the measured parameters.

CDR Gish stated that the design needed to be autonomous, carrying out its measurements without human assistance. In the case of an AUV, it should return to its initial position if possible. His thought was that the design should store the data onboard for later retrieval, but also mentioned the possibility of using telemetry to transmit data intermittently. He stressed that it should be easy to recover the data, regardless of exactly how.

With regard to the physical size and weight of the system, CDR Gish stated that the design should be able to be handled by two people without the use of special equipment such as a crane or davit. Also, the design should be able to be transported in a small boat such as a RHIB, thus limiting the overall dimensions. When asked if Commercial Off The Shelf (COTS) parts were important, CDR Gish responded by stating that their use was important only insofar as keeping costs down. He stated that the overall production cost for the design should be on the order of $1,000 or less.

With regard to operating requirements, CDR Gish said he would like the system to operate for at least 24 hours on a single charge. He also mentioned that upon full discharge, the design should be positively buoyant so as to return to the surface. The design should also be easy to find once on the surface.

One lesson he learned from previous experience which he offered was that the system, assumed to be dry inside, should feature an overpressure valve as the electronics inside previous prototypes have caused an increase in pressure which discharged unexpectedly upon opening creating a safety hazard.

CDR Gish mentioned biomimicry, or the ability of a design to act like an organism in the natural world, as something he'd be interested in seeing with regard to design propulsion.

He provided several benchmarks, with the assumption being that a glider is the best solution. Gliders are a special class of AUV. They're typically torpedo-shaped and are propelled through the water by changing buoyancy. Gliders traverse a sinusoidal path through the water column by drawing in water, which causes them to become negatively buoyant. They glide forward as they sink toward the seafloor. Approaching the seafloor, they expel the water, causing them to become positively buoyant, and thus rise back to the surface. The profile of a glider is shown in Figure 4.

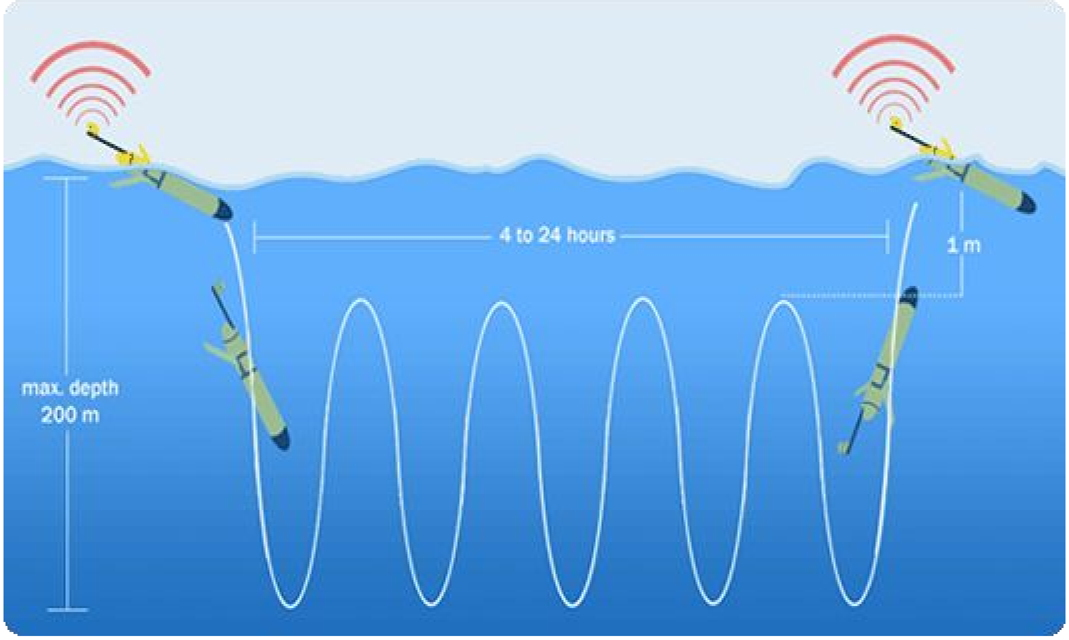

Figure 4: the sinusoidal profile of a glider-type AUV[4].

The benchmark solutions include the Slocum Glider manufactured by Teledyne Webb Research, the Spray Glider manufactured by Bluefin Robotics, and the Sea Glider developed by the University of Washington Applied Research Laboratory. Benchmarks will be discussed in more detail in the Quality Function Deployment Section.

Initial Interview with Prof. Joe Smith

Professor Smith was interviewed on Wednesday, June 24. He also mentioned a number of wants and needs during the interview with the overarching goal of the design being to "build the physical tapestry" of the environment being surveyed.

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[4] Underwater Drones: US Navy to wage new war with sea-powered machines, Before It's News, http://www.marine-knowledge.com/wp-content/uploads/2013/10/gliderdiagram.gif, accessed June 19, 2015

To do this a number of measurements can and are generally made including current velocity, temperature, salinity, pressure, Ph, reduction potential (also known as Eh), and water chemistry parameters. However, he mentioned that a good first goal would be to “map the bathtub” meaning the measurement of the temperature, pressure, salinity and bathymetry (seabed depth contours) in a littoral region.

This information is then used to build an operational hydrographic model of the hydrosphere, which then can be used to help researchers understand the environment in question.

Data sets are generally collected from a small boat in the littoral environment since, in the local area for example, the draft on many research vessels is too deep to get the measurement equipment where the measurements need to be taken. He mentioned buoy data is also used when available and aggregated with measurements made from ships to provide a more complete picture. He gave an example from a recent survey he conducted of the Potomac River in which he took measurements at two depths and at seven locations over six hours from a small boat.

Professor Smith mentioned several other potential customers, discussing them in order of general proximity to a particular body of water. First, people who live and work on the river or bay would be customers, however peripheral, of an environmental monitoring system would help to ensure they have clean water for recreation, fishing, etc. Next, he mentioned researchers who are interested in the basic science to include the processes that occur in the environment. At the highest levels, government organizations including local, state, and federal agencies would benefit from such a design in their efforts to manage waterways as an environmental and economic resource. Uses for the data sets include academic journals, environmental reports, and government studies, depending largely on what the question is and who is asking it.

When asked about sampling rate and spatial resolution he stated that generally, “...you don’t have enough time or money to do the sampling resolution that you need.” However, he mentioned that the 10 m resolution provided by commercial GPS would represent a considerable improvement over current capabilities. He also mentioned several times during the interview that the question one is trying to answer is what drives the requirements. High heterogeneity requires small measurement resolution which drives up the expense and complexity of measurement apparatus. He suggested the ability to survey an area such as the area between the Severn River Bridge (U.S. 50/301) and Trident Light (Figure 5) as being a worthy goal of such a system.

Figure 5: The survey area (shaded in red) suggested by Professor Smith between the Severn River Bridge and Trident Light at the U.S. Naval Academy (Google Earth).

With regard to cost, Professor Smith mentioned that equipment he regularly uses costs approximately $15,000. He also mentioned that the risk of loss is considerable, therefore a cheaper, more easily procured system is a better system.

When asked to describe how an operator might use the system, he mentioned that it should be capable of being launched from a small boat, beach, or pier without the use of a davit or other support equipment. He also mentioned that two people should be able to carry and handle it.

Stating again that the question one wants to answer will drive the operating environment, Professor Smith suggested that a good goal for the project might be to operate in the environment local to the Severn River, year-round. He also mentioned that an autonomous design should have the ability to avoid obstacles such as boats, piers, nets, etc., and that it should provide a means of finding it in the event it cannot return to base.

Speaking specifically to the glider solution suggested by CDR Gish, Professor Smith mentioned that in his opinion gliders are not well suited for littoral operations because the bottom is too shallow and the currents are too swift.

1.4.2 Customer complaints

An autonomous environmental monitoring system is not a commercial product in the sense that one cannot simply drive to a store and purchase one or order one online. Thus, customer complaints specific to this design were unobtainable. However, there are myriad other autonomous systems designed to cover a prescribed area and perform a task. One such system whose reviews were found to be useful was the iRobot *Roomba 880 Vacuum Cleaning Robot* which features many of the desirable qualities of the autonomous environmental monitoring system. First, and perhaps most obviously, it operates autonomously. Also, it is started, performs its function, and returns to a pre-determined location. At $649 on Amazon.com[5], it's also of the same order of magnitude in terms of cost.

A survey of relevant customer complaints include:

- Operation not intuitive
- User inputs to navigation system, specifically, are unclear
- System fault information is difficult to obtain
- Inefficient path
- Obstacle avoidance success depends on obstacle shape
- The system would get "stuck" and stop
- High relative cost for minimum benefit
- System not rugged enough for operating terrain
- Control system support not sufficient (directions and troubleshooting)
- Speed is either too fast or too slow
- Number of battery recharge cycles is too low
- Battery replacement is difficult and expensive (requires a special battery)
- Limited parts support

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[5] iRobot Roomba 880 Vacuum Cleaning Robot for Pets and Allergies, Amazon.com, http://www.amazon.com/iRobot-Roomba-Vacuum-Cleaning-Allergies/dp/B00IO9PBPS/ref=sr_1_1?s=vacuums&ie=UTF8&qid=1435850387&sr=1-1&keywords=roomba&pebp=1435850413363&perid=1Z354MBESP3Q0G1FKERT, accessed July 2, 2015.

1.5 Revised Customer’s Problem Statement.

In light of feedback received from the project customers, the original problem statement was broadened to include all environmental regimes, not just underwater vehicles. The revised statement is as follows:

> *Design and build an autonomous vehicle for use in gathering oceanographic data in littoral regions.*

1.6 Initial Draft of Customer Requirements

Once a basic understanding of the problem was in hand and the voice of the customer was heard, customer inputs were synthesized into a list of customer requirements. Garvin’s Eight Dimensions of Quality[6] were used as an outline for ensuring completeness. The initial customer requirements are included in Table 1.

Table 1: Initial draft of Customer Requirements

Dimension	**Description**	**Kano Class.**
Performance	Must be autonomous	Expecter
	Must measure something at multiple points in time and space*	Spoken
	Measurements must be geolocated and time-stamped*	Spoken
	Must navigate some specified area*	Spoken
	Must make measured data available to researchers*	Spoken
	Must be light enough to be carried by at most two people	Spoken
	Must be launched from a small boat, pier, or beach	Spoken
	Should cost less than $1000 to fabricate and operate*	Expecter
	Should operate for at least 24 hours without interaction	Spoken
	Must be recoverable following loss of power or malfunction	Spoken

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[6] G. Dieter and L. Schmidt, *Engineering Design, 5th Ed., McGraw-Hill, New York, 2013, pg. 82*

Table 1 (cont.): Initial draft of Customer Requirements

Dimension	Description	Kano Class.
Performance	Should measure temperature, pressure, salinity, bathymetry	Spoken
	Could be reconfigurable to measure additional parameters	Exciter
	Should cover an area the size of the lower Severn River	Exciter
	Should return to a specified position	Spoken
	Data should be easy to retrieve	Spoken
	Should avoid obstacles	Exciter
	Operation should be intuitive	Unspoken
	Should communicate fault information	Exciter
	Could feature biomimicry	Exciter
Reliability	Must be able to complete one survey*	Expecter
	Should be able to extricate itself from a confined space	Unspoken
Durability	Should last the school year	Expecter
Serviceability	Should maximize the use of COTS parts	Spoken
	should be plug-and-play	Unspoken
	Should be easy to disassemble and reassemble	Spoken
Conformance	Conform with all government regulations	Unspoken
Conformance	Comply with safety and environmental standards	Unspoken
Aesthetics	Should not look like a weapon	Unspoken
	Should be easy to see and avoid	Unspoken
	Should reflect positively on the Naval Academy*	Unspoken

* Critical to Quality Customer Requirements

Clearly, time and resources do not allow for each of these wants and/or needs to be addressed. However, even as a prioritized list is developed, attention will be paid to trying to meet as many of these as reasonably possible as they help to provide context of the customers’ vision.

1.7 Gathering Information on Existing Products

1.7.1 Overview

Current methods for making oceanographic observations involve fixed stations such as buoys from which measurements are taken and transmitted, and mobile platforms such as boats and ships which can be used to suspend or tow instruments at a specified point in the water column (Figures 6 and 7). Within the last several decades autonomous vehicles have been employed with increasing frequency and success for the same purposes. So far, vehicles have primarily included autonomous surface vehicles (ASVs) and Autonomous Underwater Vehicles (AUVs).

Observations can made from discrete samples, meaning water is collected from specific location to be tested at a later time, or *in situ* sampling, meaning the measurement equipment is used in the field for direct observation.

There are many, many examples of the aforementioned systems, far too many to review and summarize here. Therefore, the survey of existing products will focus on the smallest most inexpensive devices used for oceanographic survey, including examples that do not meet these criteria but are still useful for purposes of comparison.

Figure 6: ATLAS mooring buoy and NOAA research vessel, two current means of gathering oceanographic data[7].

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[7] Online log of the research vessel Ron Brown, http://amma-international.org/implementation/sites/ocean/journal/ronbrown.htm, accessed June 19, 2015

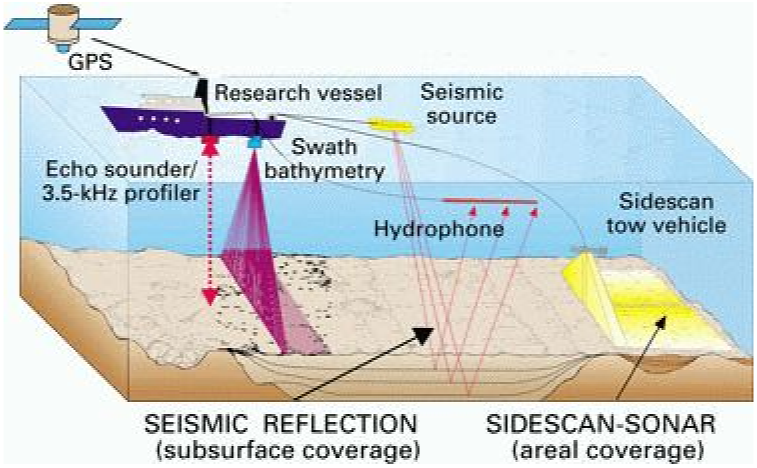

Figure 7: An example of the methods used to conduct oceanographic survey from surface vessels[8].

1.7.2 Product Dissection

During academic year 2015, a previous capstone design team worked on this project. *Team Dreamrider* cleverly called their design the *SeaQPR 2.0* (Figure 8). The primary customer, CDR Gish, vectored the team toward a glider design. Their final product measured nearly 4 ft. long and weighed just over 50 lbs.

The team successfully connected the data acquisition equipment, including a thermometer and pressure transducer. The device was to be propelled through the water using variable ballast provided by eight large syringes.

The team was able to test portions of their design including a check of the battery system's ability to sample and cycle the ballast motors. They also successfully cycled water in and out of the ballast tanks and conducted water-tight tests of the hull to their satisfaction.

Unfortunately, the team did not have enough time to evaluate the design's ability to glide or turn and included these in the Future Work section of their final report.

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[8] Tuah Unggul Resources, Hydrographic Survey Services, http://www.ukurtanah.com/wp-content/uploads/2014/02/Hydrographic-Survey.gif, accessed June 25, 2015

Figure 8: The SeaQPR 2.0, a glider design created by the Waver Rider team of academic year 2015.

Also unfortunate is the fact that the team's final report was not saved to the shared drive and was thus unavailable for further reference. However, Professor Flack, the team's mentor is available should additional information be needed.

1.7.3 Technical Literature

A survey of technical literature was conducted. The information pertaining to the present problem is summarized here.

In their 1993 paper entitled *Autonomous Oceanographic Sampling Networks*[9], Curtain et al. present a system of AUVs and buoys as a possible solution to the four dimensional (three spatial and one temporal) sampling problem. They also included methods for determining the effective survey velocity, estimated power consumed by a single AUV and the total energy required per unit distance of track covered (assuming constant propulsion power). Predicting cooperative autonomous vehicles of the future, they recommended multiple vehicles for covering a single region as a means of reducing the energy required per vehicle.

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[9] Curtain et al., *Autonomous Oceanographic Sampling Networks*, Oceanography Vol 6., No. 3, 1993, pp. 86-94.

In his 2008 paper entitled *Unmanned Surface Vehicles, 15 Years of Development* [10] Justin Manley of Battelle Applied Coastal Environmental Services reviewed the development of Unmanned Surface Vehicles (USVs) from MIT's ARTEMIS in 1993 to the technology of the present, including many of the systems reviewed in the next section. In addition to his review of the technology, Mr. Manley stated that the most significant challenge to the development and commercial availability of USVs is the ability to detect and avoid other surface traffic.

In *The Stingray AUV: A Small and Cost-Effective Solution for Ecological Monitoring*[11]*,* Barngrover et al. discuss their design for a small AUV that features a low-drag stingray hull form (Figure 9). Primarily fielded as a student project and the result of collaboration amongst a number of teams, the design is primarily an educational testbed. However, the hydrodynamic design provides excellent food for thought with regard to an energy saving hull design, and much of the control architecture is listed, including components, which could be useful during detail design.

Figure 9: The Stingray AUV: solid model (left) and carbon-fiber hull design (right)

The paper *Design of an Autonomous Surface Vehicle Used for Marine Environmental Monitoring*[12], was written by Wang, Gu, and Zhu in 2008 and outlines their design of an ASV (Figure 10) used for marine environmental monitoring and hydrologic survey. The design is a catamaran design measuring 2.7 m (9 ft) and is propelled by two propellers. The power supply is a set of lithium ion batteries with a 60 Ah capacity. The paper details the team's

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[10] Manley, Justin E. "Unmanned surface vehicles, 15 years of development." In *OCEANS 2008*, pp. 1-4. IEEE, 2008.

[11] Barngrover et al., *The Stingray AUV: a small and cost-effective solution for ecological monitoring,* OCEANS 2011 , vol., no., pp.1,8, 19-22 Sept. 2011

[12] Wang, Jianhua, Wei Gu, and Jianxin Zhu. "Design of an autonomous surface vehicle used for marine environment monitoring." In *Advanced Computer Control, 2009. ICACC'09. International Conference on*, pp. 405-409. IEEE, 2009.

hydrodynamic considerations and testing as well as the control architecture. Tests demonstrate the ability to patrol at a speed of 1.5-2 m/s (3-4 kts) for 135 minutes.

Figure 10: The two-hull design prototype including ducted propellers (left), and the ASV during testing (right)

In 2009, Dunbabin, Drinham, and Udy wrote a paper entitled *An Autonomous Surface Vehicle for Water Quality Monitoring* describing their design of a 16 ft. long solar catamaran (Figure 11) capable of navigating complex inland waterways while monitoring water quality parameters[13]. In their paper they outline many of the same design and operational considerations desired by the customers of this design including the ability to operate for 24 hours continuously, profile the water column, and return to base autonomously.

Figure 11: the Lake Wivenhoe ASV, a solar powered catamaran design measuring 16 ft.

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[13] Dunbabin, Matthew, Alistair Grinham, and James Udy. "An autonomous surface vehicle for water quality monitoring." In *Australasian Conference on Robotics and Automation (ACRA)*, pp. 2-4. 2009.

Intended primarily as a navigation test platform, the Lake Wivenhoe ASV has demonstrated the ability to navigate autonomously and avoid obstacles such as other water craft and non-navigable shoals.

1.7.4 Consumer and Product Literature

Iver3 Nano AUV. Although the Iver3 Nano (Figure 12) is well out outside the specified price range at around $50,000 USD, it meets nearly every other requirement specified by the customer, and is thus included here.

Figure 12: The Iver3 Nano autonomous underwater vehicle made by Ocean Server[14].

The Iver3 is an autonomous vehicle designed specifically for oceanographic survey and environmental monitoring. It measures 1.7 m (165 in.) long and has a mass of 18 kg (weighs 65 lbs.). The sensor package includes GPS, a pressure sensor, and an internal navigation system (INS). It also features a side scan sonar system capable of seafloor mapping at distances of up to 100 m. On a single charge (267 WHrs, 24 V), it can operate for 5 hours at a survey speed of 2.5 kts depending on the sea current and the equipment operating.

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[14] Iver3-**450-Nano AUV, Ocean Server Products,** http://www.iver-auv.com/iver3Nano.html, accessed July 6, 2015.

The propulsion system features a 36 V brushless DC motor and it can maneuver in pitch, roll, and yaw. It has an integrated wireless data transmission system, 4 GB of memory for control and collection, and a 64 GB solid state drive for data storage.

REMUS 100. Similar to the Iver3 Nano, the REMUS 100 (Figure 13) was specifically designed for environmental monitoring (REMUS stands for Remote Environmental Monitoring UnitS). It is also of similar size with a length of 1.6 m (63 in.) and a weight of 37 kg (80 lbs.). Standard sensors include bathymetry, temperature, water velocity (current), salinity (conductivity), optical backscatter, diver visibility, sidescan sonar, and fluorescence. Endurance is stated at 22 hours at 1.5 m/s (3 kts.) depending on current speed and sensor configuration on a single 1 kWh charge. Propulsion is provided by a brushless DC motor connected to a three-bladed propeller.

Figure 13: The REMUS 100 autonomous underwater vehicle made by Hydroid, LLC[15].

Unlike the Iver3, however, the REMUS was designed to conduct hull inspection, and can therefore hover in position as well as follow along the hull at a set standoff distance. It can also operate in conjunction with up to four other REMUS 100 vehicles. The REMUS 100 features GPS and INS, but navigation input can also be provided via at least two transponders.

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[15] REMUS 100 Brochure, http://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/61E9A8C492C51D50C12574AB00441781/$file/Remus-100-Brochure.pdf?OpenElement, accessed July 6, 2015

Slocum G2 Glider. As previously discussed, the Slocum Glider (Figure 14) is a high-endurance AUV that traverses the hydrosphere very efficiently using a buoyancy engine. The glider is 1.5 m long (60 in.) and has a mass of 54 kg (120 lbs.) depending on the configuration. Standard measurements include currents, conductivity, temperature, depth, turbidity, chlorophyll, backscatter, and dissolved oxygen. It also features a hydrophone for collecting acoustic information. Average horizontal speed is 0.35 m/s (0.68 kts.) using the buoyancy engine or 1 m/s (2 kts.) in propeller mode. There is an optional littoral buoyancy engine available in addition to the deep water system, though it is not clear from the available literature how "littoral" is defined in terms of depth. The deep sea variant can be deployed for periods of up to 12 months, depending on the battery pack configuration and operating environment. The Slocum Glider navigates using a combination of GPS, depth (pressure) sensing, and dead reckoning.

Figure 14: the Slocum G2 glider made by Teledyne Webb Research[16].

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[16] Teledyne Webb Research Slocum G2 Glider Datasheed, http://www.webbresearch.com/pdf/Slocum_Glider_Data_Sheet.pdf, accessed July 6, 2015

Wave Glider SV3. The Wave Glider is a combination float and submarine joined by a tether. The float measures just over 3 m long and the submarine just over 2 m long. They have a combined weight of 330 lb. Because the system is solar powered (rated at 150 W collection rate), it has an advertized endurance of 1 year. Average data collection speed is 0.9 m/s (1.8 kts) with a maximum system speed of 1.5 m/s (3 kts.). The system can carry up to 100 lb of additional payload. It uses a solid state magnetometer in conjunction with GPS to navigate. With regard to communications, the system features Iridium (RUDICS), and 802.11 WiFi, with cellular connection optional. The system shown in Figure 15 costs on the order of $300,000 USD[17].

Figure 15: Liquid Robotics Wave Glider SV3, with only the floating portion shown[18].

MIT SCOUT. SCOUT stands for Surface Craft for Oceanographic and Undersea Testing. The SCOUT is an autonomous Kayak built primarily from COTS parts (Figure 16). The keel length is 3 m (10 ft.). It can operate for approximately 8 hours at a maximum speed of 1.5 m/s (3 kts) drawing from five Absorbed Glass Mat (AGM) lead acid batteries. The system weighs approximately 180 lb. and can be manipulated by two people. The scout has three modes of control: direct, indirect, and fully autonomous. The SCOUTS can also be programmed to operate in a swarm.

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[17] Wave Glider SV3 Specification Sheet, Liquid Robotics, http://info.liquidr.com/specification-sheets?submissionGuid=11c382ee-c4c5-4449-bb07-5bc630ef6a43, accessed June 25, 2015

[18] Liquid Robotics' Wave Glider ASV Collects Typhoon Rammasen Data, Unmanned Systems Technology, http://www.unmannedsystemstechnology.com/2014/07/liquid-robotics-wave-glider-asv-collects-typhoon-rammasen-data/, accessed June 25, 2015.

The vehicle is propelled by an electric trolling motor and steering is achieved using a hobby servo motor. The vehicle is meant to acts as a “pickup truck” allowing the user/operator to install whatever equipment is necessary for the mission. Collision avoidance measures were under development in 2005.

The entire system can be purchased for approximately $500 USD. Unfortunately, the SCOUT is not available for purchase, nor are the plans available to the public.

Figure 16: MIT Scout during operation (left) and in preparation for deployment (right)[19].

1.7.5 Patent Literature

A preliminary patent search was conducted on the U.S. Patent Office website (http://patft.uspto.gov/) using the keywords *autonomous* and *water* or *underwater* and *vehicle* and *oceanographic* and *survey*. The search produced 24 hits including the following:

US patent 8,995,229 awarded to Melvin II et al. in 2015 for a method of determining the position of a submersible vehicle within a body of water which uses a transmitter aboard the vehicle and listening stations distributed through the operating area to locate it. The patent paperwork includes diagrams and flowcharts that might prove useful in the concept generation stage.

US patent 8,397,657 awarded to Guerrero et al. in 2013 for a single robot or system of robots that can be used to venture to a precise location on the seafloor

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[19] Joseph Curicio, John Leonard, and Andrew Patrikalakis, *SCOUT - A Low Cost Autonomous Surface Platform for Research in Cooperative Autonomy*, Marine Technology Society (OCEANS) Conference, 2005 .

(Figure 17). The robots are dropped and move downward trading potential energy for kinetic energy. However, it is unclear how they are intended to return to the surface. Again, though it does not represent a complete solution, the concept of dropping small modules to the floor and having them collect information or take samples directly on the way down may be useful to consider during concept generation.

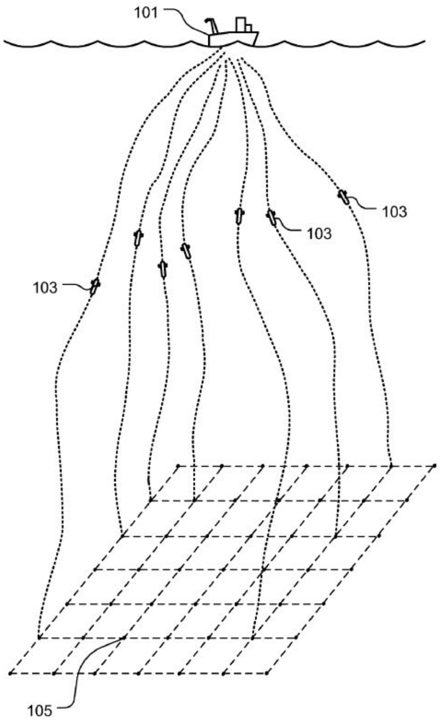

Figure 17: the patent description of *Vertical Glider Robot*, patent number 8,397,657.

US patent 5,687,137 awarded to Schmidt et al. in 1997 for methods and apparatus for adaptive oceanographic sampling. The system includes several stationary tomography (i.e. imaging by sections using a penetrative electromagnetic wave) stations along with at least one underwater autonomous vehicle (Figure 18). The patent is for the specific adaptive algorithm, but the entire system provides some insights for future work.

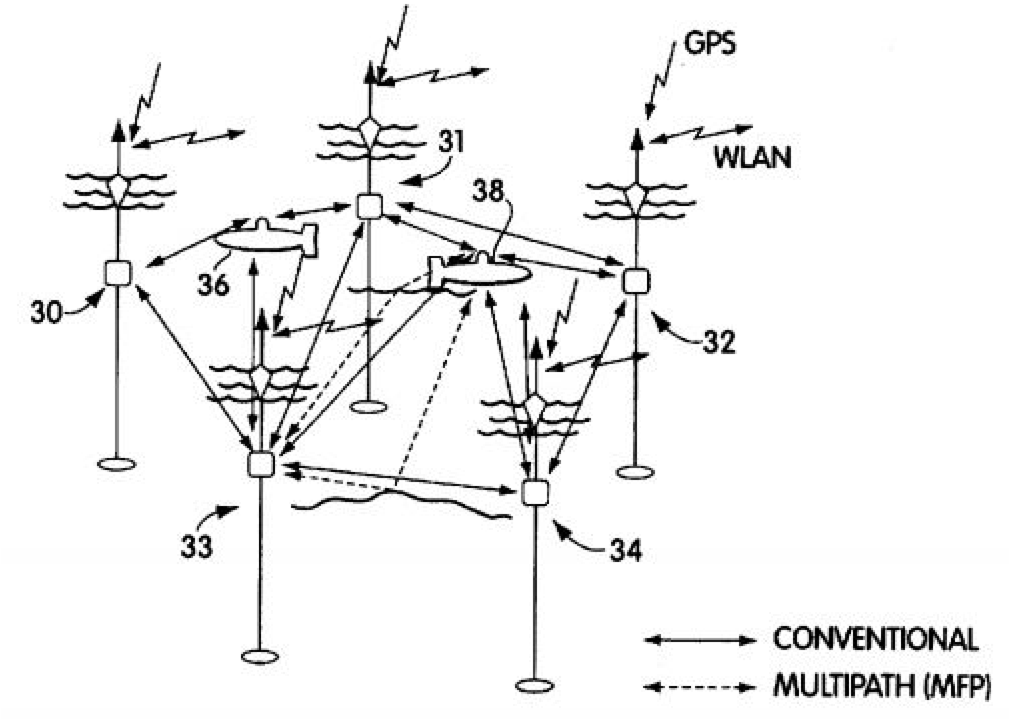

Figure 18: the patent description of *Methods and Apparatus for Adaptive Oceanographic Sampling*, patent number 5,687,137.

1.7.6 Applicable Codes and Standards

There are no prohibitions in the U.S. Code of Federal Regulations specifically regarding autonomous vehicles. It was, however, determined that ASTM Standard volume 15.11 governs unmanned maritime vehicle systems (UMVSs). Unfortunately, the standards must be purchased and as a result were unavailable as of the time of this writing.

Peripherally, Occupational Safety and Health Administration (OSHA) Standard 1926.106 describes the personal protective and lifesaving equipment required when employing such a system.

From a considerable review of local, state, and federal codes and regulations, it’s clear that which codes and standards might apply is based largely on the ultimate form of the design. For example, if a buoy system is used, the state of Maryland has specific requirements for mooring buoys[20] including where they are placed and how they must appear, but it is unclear if there are specific requirements for non-mooring buoys. It stands to reason that if one were to deploy a buoy or a system of buoys, permission would be needed from some local government organization. As another example, if the system uses WiFi to transmit and receive information, it will be subject to the IEEE 802.11 communication standard.

Also, if the design solution includes the use of a surface vessel, autonomous or not, it stands to reason that all regulations applicable to such craft should be observed.

1.7.7 Global, Economic, Environmental, and Societal context

Global. Autonomous vehicles are at the forefront of current technology. They are being used in applications ranging from covering freeway traffic jams and delivering consumer goods to conducting reconnaissance and launching weapons. Water-borne vehicles used for environmental monitoring could potentially be used in every corner of the globe. An effort should be made to ensure the vehicle’s form reflects its benign function to preclude it being mistaken for a weapon.

Economic. The cost of high-tech components has dropped precipitously in the past decade. Computer processors, cameras, navigation equipment, and so much more can now be purchased cheaply online and delivered within days or even hours. How-to tutorials are readily available online. This is the environment in which this vehicle is designed. The primary purpose of this project is to provide a bill of materials and some instruction so that anyone with interest and a nominal budget can have the capability of oceanographic survey.

More broadly, a breakthrough technology in this area has the potential to be widely adopted, thus creating a lucrative business opportunity in support of environmental scientists and conservation groups. Also, considering the significance of waterways like the Chesapeake Bay as a national economic resource, cost-effective wide-scale monitoring could have a tremendous positive impact on the myriad economic interests that rely on them.

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[20] Single Recreational Mooring Buoys, Department of Natural Resources, http://dnr2.maryland.gov/Boating/Pages/srmbuoys.aspx, accessed July 24, 2015

Environmental. As his Uncle Ben tells Peter Parker in the *Spiderman* comics, “With great power comes great responsibility.” The components used to create an environmental monitoring system must be robust enough to withstand the harsh operating environment of the sea. As such, the same properties that allow them to withstand the marine environment make them unlikely to degrade when discarded or lost. Moreover, batteries and other such materials can be harmful to the local environment. Every effort must be made to recover the system, not only for purposes of data recovery and future use, but in the spirit of responsible environmental stewardship.

The impact of a successful system, on the other hand, would be a tremendous boon to environmental conservation efforts and natural science.

Societal. The underlying purpose of this project is to better understand the marine environment in an effort to improve and preserve the health of local waterways. To put it simply, clean water is good for everyone from wildlife to residents who live along the water to the people who earn their living from it. The stated purpose of many an engineering professional group is to better society. An autonomous environmental monitoring system would support that goal directly.

1.7.8 Engineering Models

At this point in the design process no design concepts have been proposed. However, there are some solution-neutral questions that can be answered or at least estimated based on some back-of-the-envelope calculations. These include:

- How far does a vehicle need to travel?
- How much time would it take?
- How much energy would this require?

Considering the previous survey of benchmarks, some designs are propelled constantly (e.g. REMUS 100, Wave Glider, etc.) while others are intermittent (Slocum Glider). In an effort to get an idea of the high end of the power requirement, constant propulsion was assumed with the understanding that a design such as a glider could potentially require less energy.

As a first approximation, the search area was assumed to be the Severn River, south of the Severn River Bridge and north of Trident Light, the white shaded area shown in Figure 19. According to the Google Earth polygon tool, the area encompasses 1.8 km^2 (0.7 mi^2). It was assumed that it would be a single vehicle conducting the survey. It was also assumed that at the time of survey there would be no current through the search area. It is understood that this is not an entirely realistic assumption, but a higher degree of fidelity can be included in later models. A horizontal velocity of 1 m/s was assumed as a reasonable starting point based on the quoted velocities of the benchmark products.

Figure 19: the search area with the Google Earth polygon used to calculate the area, shaded in white.

For the purpose of rough estimation, the search area was reduced to simple rectangles overlaid on Nautical Chart 12280 *Chesapeake Bay: Severn and Magothy Rivers* as shown in Figure 20. The perimeter of the search box was placed at approximately the 10 ft. (3 m) depth line. Assuming a creeping line search pattern (shown using the black, dashed line in Figure 20), the total search distance would be approximately 156 km. At 1 m/s, it would take a little over 43 hours to complete a single survey. Prof. Smith mentioned that the tidal cycle in the Severn River is on the order of 6 hrs. In order to search the entire area in 6 hours, the vehicle would need to travel 7.2 m/s (14 kts.). Or, considered another way, a vehicle traveling at 1 m/s could search along 3600 m per hour. At 10 m spacing between lateral tracks (the highest fidelity of commercially-available GPS), with lateral tracks 500 m long, the vehicle could search 60 m in the direction of advance or 0.03 km^2 per hour. If a swarm of vehicles were used, the search area could be covered in 6 hrs. by 10 vehicles.

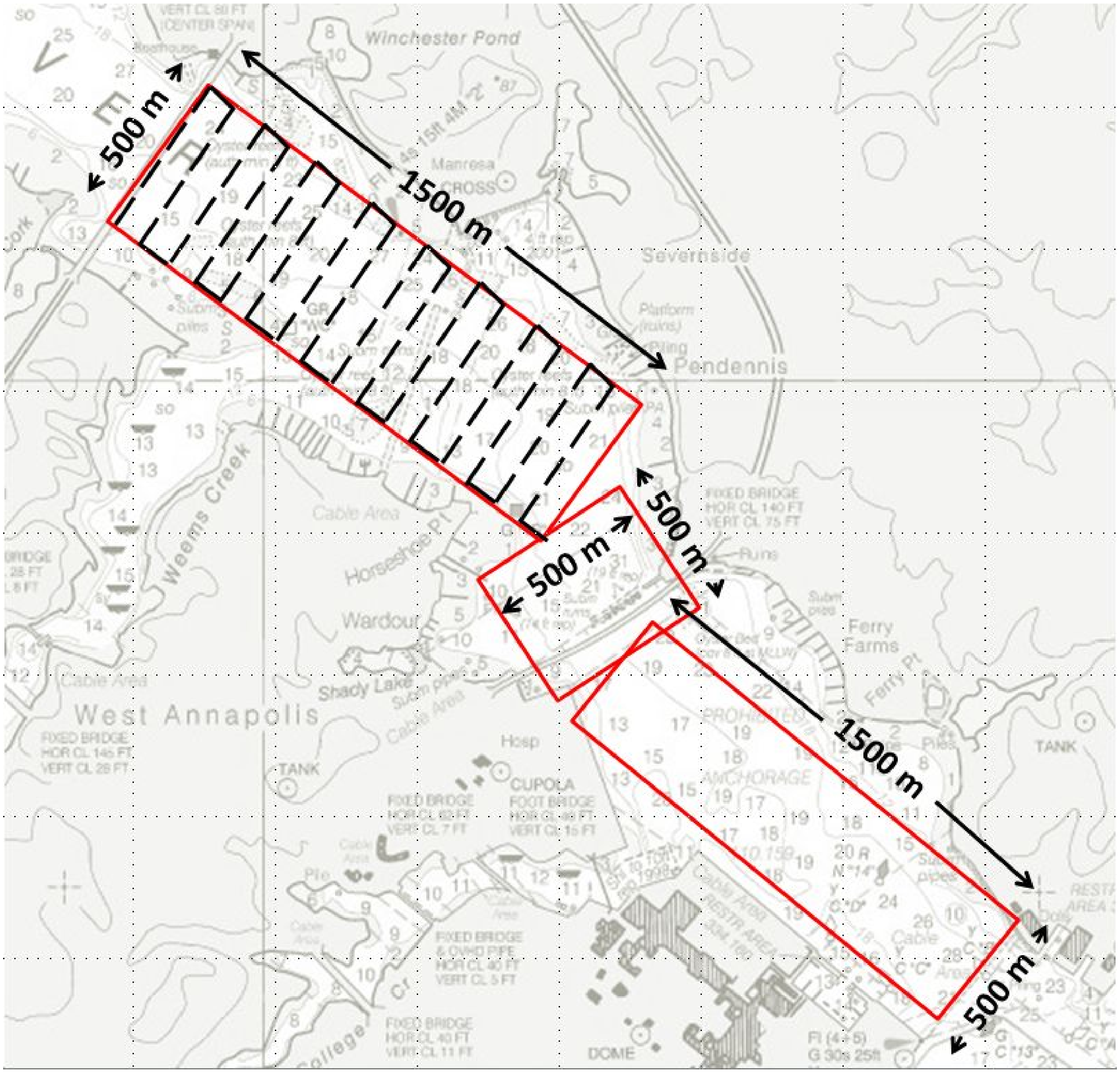

Figure 20: Nautical Chart 12282 *Chesapeake Bay: the Severn and Magothy Rivers* overlaid with approximate search area boxes, shown in red, and dimensioned, shown in black text. The black dashed line in the upper left search box depicts the creeping line search pattern, though is not shown to scale.

As previously mentioned, Curtin et al. also provided an equation to estimate the required search velocity:

$$V_e = A/(2Lt) \qquad (1)$$

Where V_e is the effective survey velocity, L is the resolution, defined as the maximum horizontal distance from any point in the area from the survey track, in this case, L = 10 m / 2 or 5 m. In Equation (1), t is the survey time. For a search area of 1.8 km^2 (1,800,000 m^2), a resolution of 5 m, and a time of 6 hrs. (21,600 sec.), the effective search velocity is 8.33 m/s which is larger but on the same order of magnitude as the first estimation.

The amount of energy required to search the area does depend on the solution, specifically the shape and size of the hull, the speed of the vehicle through the water, the efficiency of the propulsion system, etc. However, a back-of-the-envelope estimation can be made using parameters from the REMUS 100 spec sheet. From Curtin et al., the power required can be calculated using:

$$P = (rDSV^3)/(2h) + H \tag{2}$$

where P is the power required, r is the density of salt water (1025 kg/m^3), D is the drag coefficient (assumed 0.1 for a long streamlined body), S is the surface area (0.9550 m^2, assumed a cylinder using the length and diameter of the REMUS 100), V is the search velocity (8.3 m/s, calculated above), h is the propulsion efficiency (estimated to be 0.7 from Curtin et al.), and H is the hotel load (i.e. power used for functions other than propulsion, in this case assumed 5 W based on proportion of total power quoted on the REMUS 100 spec. sheet). Given these parameters, the required power was 40 kW, a prohibitively high value. It was decided that search speed should be reduced to the value quoted in the REMUS 100 spec. sheet, 1.5 m/s, which yielded a much more reasonable 240 W. The operational power quoted on the REMUS 100 spec. sheet is 45 W, a much lower figure, but perhaps the power conversion efficiency is higher or the drag coefficient is lower for the REMUS.

Also from Curtin et al., the energy required per unit track covered is given by the equation:

$$E = [(rDS)/(2h)](V/N)^2 + NH/V \tag{3}$$

where E is in J/m and N is the number of vehicles used to cover the search area. Using the previous problem parameters, the required energy is 160 J/m. A single vehicle covering the entire search area of 156 km would require 2.5e7 J of energy. Assuming a battery has a capacity of 100 Ah and is operating in a 12 V system, the battery would have 4.32e6 J of energy. Thus six batteries would be required to traverse the search area. The code used to calculate these estimates is enclosed in Appendix A.

These are rough estimates, however, they demonstrate that a solution might reasonably be found using current technology.

1.8 Quality Function Deployment

1.8.1 Customer Requirements

A second interview was conducted with CDR Gish and Prof. Smith. They were shown the initial table of customer requirements (Table 1) to ensure the team properly understood their needs and wants, and asked if they would identify a handful of the highest priority requirements. They were also asked to rank those requirements in order of priority on a scale of 1 to 5 where 1 is least important and 5 is most important. Each of them provided different inputs, but together the team agreed upon the appropriate priority to ascribe to each customers' comments. The revised list of customer requirements are included in Table 2.

Table 2: Revised Customer Requirements

A successful design should:	Priority
Take measurements and make them available to the user	5
Be cheap	5
Cover a specified search area in a reasonable time, autonomously	4
Be man-portable and launchable	3

1.8.2 Customer Assessment of Competing Products

CDR Gish and Prof. Smith were also asked to rank their evaluation of several benchmark designs based on the established customer requirements. Their inputs are included in Table 3.

Table 3: Customer assessment of competing products.

	Prof. Smith			CDR Gish		
Customer Requirements	**REMUS 100**	**MIT SCOUT**	**Slocum Glider**	**REMUS 100**	**MIT SCOUT**	**Slocum Glider**
Take measurements and make them available to the user	5	5	3	5	5	5
Be cheap	1	5	1	1	5	3
Cover a specified search area in a reasonable time, autonomously	5	5	1	5	3	5
Be man-portable and launchable	5	5	5	5	5	5

Benchmarks were rated on a five-point scale with regard to customer requirements. Designs that performed well with respect to a particular customer requirement were given a score of 5. Likewise, designs that performed poorly were given a score of 1. Both customers scored the MIT SCOUT highly indicating that the design team could use many of its features in a new design. Cost was a considerable detractor for both customers for both the REMUS 100 and the Slocum Glider. On the other hand, the SCOUT scored well because of its low cost. It's also clear from the scoring that CDR Gish is interested in technology similar to the Slocum Glider, whereas Prof. Smith is less enthusiastic about it. Each of the benchmark designs scored well with respect to size, giving the design team a clear target size for a new design.

1.8.3 Engineering Characteristics

From these customer requirements, a list of engineering characteristics was developed in order to quantify system performance with regard to customer requirements. These are included in Table 4.

Table 4: Customer requirements and their corresponding engineering characteristics along with the rank of relative importance.

Customer Requirements	Engineering Characteristics	Units	Direction of Improvement	Rank Order
Take measurements and make them available to the user	samples stored/ transmitted	#	↑	2
Be cheap	cost	$USD	↓	1
Cover a specified search area in a reasonable time, autonomously	area coverage	%	↑	5
Cover a specified search area in a reasonable time, autonomously	search area	m^2	↑	3
Cover a specified search area in a reasonable time, autonomously	search rate	m^2/s	↑	3
Be man-portable and launchable	mass	kg	↓	6

In Table 4, *area coverage* likely requires further explanation. Coverage area is defined as the area searched divided by the total area defined. The search area would be the path integral of the search route given the system position resolution (10 m). Another way to think about this would be the *completeness* of the search.

Rank order was calculated using the methodology outlined in Dieter and Schmidt, Section 3.6.2[21]. System cost was determined to be the highest priority of this design, which makes sense in light of the fact that systems are readily available that meet most if not all customer requirements except for the prohibitive cost of most and the inaccessibility of the only affordable option (i.e. the MIT Scout, which is not currently available for purchase, nor are plans available online).

To these engineering characteristics is added a list of constraints, in this case a list of "yes/no" requirements including:

- Operate autonomously
- Conform to all applicable codes
- Comply with safety regulations
- Comply with environmental standards
- Does not look like a weapon
- Reflect positively on the U.S. Naval Academy

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[21] G. Dieter and L. Schmidt, *Engineering Design, 5th Ed., McGraw-Hill, New York, 2013, pg. 99-110*

The last two constraints are included with consideration of the event a prototype is lost and recovered by someone in the surrounding community.

1.8.4 Technical Assessment

The performance of each of the benchmark systems with regard to the established engineering characteristics was determined, when possible, and included in Table 5. Surprisingly, most of the specifications listed on the information sheets do not describe the *goodness* or completeness of search. This is perhaps due to the variability associated with setting different system parameters such as the sampling frequency, search path, etc. As such, the performance of each benchmark design with regard to the engineering characteristics outlined in the previous section was difficult to obtain for all categories. When necessary, a qualitative assessment was made.

Table 5: Technical assessment and target values for each engineering characteristic.

Engineering Characteristic	**samples stored/ transmitted**	**cost**	**area coverage**	**search area**	**search rate**	**mass**
Units	#	$USD	%	m^2	m^2/s	kg
REMUS 100	many	50,000	high	medium	low	37
MIT SCOUT	many	500	high	low	low	82
Slocum Glider	many	100,000	low	very high	low	54
Targets	20,000	1000	50	18,000,000	12	25

1.8.5 Target Values for Engineering Characteristics

The target value for the number of samples was arrived at by taking the estimated track length, 156 km, and dividing it by the expected GPS position resolution, 10 m which yields 15,600 samples. The final value is rounded up from this figure with some margin deemed nominal considering the low cost and space associated with data storage. The cost target figure was taken directly from customer inputs. The coverage area target is an estimate of what might reasonably be considered success with the thought that follow-on projects might improve navigation and maneuvering. The search area target is also taken directly from the customer, as previously discussed. The search rate is the total search area, 1.8 km^2, divided by the estimated time to search as previously calculated for a vehicle cruising at 1 m/s, 43.3 hrs. The mass target was derived from human subject testing during which team members carried weights, kneeled, and held the weights at arms' length to simulate system deployment. Masses above 25 kg were deemed too heavy for the old and infirm (i.e. the faculty). It is recognized that the mass target is considerably lower than the other benchmarks and may be too low to be achievable, despite physical testing.

1.9 Project Management

Table 6 includes all of the project-specific tasks and milestones anticipated at this time. It also includes the person assigned to complete the task and the anticipated date of completion. Near-term tasks are known with higher certainty than those later in the semester or next semester.

Table 6: Project-specific tasks, resources, and completion dates.

Milestone/Task	Person Assigned	Date of Completion
Initial interview with CDR Gish	Lust	6/18/15
Initial interview with Prof. Smith	Lust	6/24/15
Field trip to Northrop Grumman undersea systems	Lust, Stevens	9/3/15
System Requirements Report initial draft	Lust	9/4/15
System Requirements Presentation dry-run	Lust	9/9/15
Individual design concepts complete	Lust, Stevens	10/7/15
Design selection	Stevens	10/8/15
Preliminary Design Report initial draft	Lust	10/12/15
Preliminary Design Presentation dry-run	Lust	10/15/15
TSD Interview	Lust, Stevens	10/22/15
Purchase orders submitted	Stevens	10/19/15
Work orders submitted	Lust	10/19/15
Detail Design Report initial draft	Lust	11/30/15
Detail Design presentation dry-run	Lust	12/3/15

Table 6 (cont.): Project-specific tasks, resources, and completion dates.

Milestone/Task	Person Assigned	Date of Completion
Prototype demonstration in LeJeune Pool	Stevens	2/18/15
Prototype demonstration in College Creek	Stevens	3/3/15
Final Testing	Stevens	3/17/15
Prototype demonstration for customers	Stevens	3/31/15
Final Design Report initial draft	Lust	4/7/16
Final Design Presentation dry-run	Lust	4/14/16
Capstone Day/Final Design Presentation	Lust, Stevens	4/27/15
Final Design Report	Lust	4/28/15

1.10 Budget

The budget for the previous team was initially $3,000 of which $1210 was spent. This is likely an appropriate estimate for this project. The previous team did not build more than one prototype, but the remaining funds would likely have been sufficient to cover them should they had the time. Furthermore, the MIT SCOUT reportedly costs $500 total. This figure surely doesn't account for research and development costs, but demonstrates the approximate total cost of all the components in a working prototype.

Aside from a fact-finding field trip to Northrop Grumman, located in Annapolis, there is no anticipated travel associated with this project. A vehicle from the motor pool will be requested and the excursion will take place between meals, thus no travel funds will be required.

The total budget requested for this project is $3000.

Appendix A - Preliminary Engineering Model of the System

```
%% Engineering Model Calculations
clear; close all; clc

% Calculations for estimating search speed, power required, and energy per
% unit distance track covered

% parameters
A = 1.8 * (1000^2); %search area, m^2
L = 10/2; %search resolution, m
t = 6 * 3600; %search time, s

% calculate the search velocity, in m/s
V_e = A/(2*L*t);

%% Power consumed by AUV
% specifications taken from REMUS 100 spec sheet

% parameters
h = 0.7; %propulsion efficiency (guess)
r = 1025; %density of salt water, kg/m^3
D = 0.1; %drag coefficient (assumed long streamlined body)
d = 0.19; %AUV diameter
l = 1.6; %AUV length
S = pi*d*l; %surface area
H = 5; %hotel load (power used for vehicle functions other than propulsion)
V = 1.5; %AUV velocity, m/s

% calculate the total power consumed, in W
P = (r*D*S*V^3)/(2*h) + H;

C = 1000*3600;  %battery capacity for the REMUS 100, J
T = 22*3600;    %system endurance, s
P_remus = C/T;  %the power consumption, W

% P_remus is 45 W, which is corroborated by their spec sheet.  It's much
% higher than the power requirement calculated above.  Perhaps the drag
% coefficient is lower or the propulsion efficiency is higher.

%% Energy required per unit distance of track covered, E

% parameters
N = 1; %the number of vehicles used to cover the search area

% calculate the energy required per unit distance of track covered, in J/m
E = ((r*D*S)/(2*h))*(V/N)^2 + (N*H)/V;

% to cover the entire track of 156 km, the required energy would be:
```

```
E_total = E * 156000;
% that's a lot!

% calculate the number of batteries required
C_battery = 100; %assume 100 Ah battery capacity, converted to J
V_system = 12; %assume 12 V system
E_battery = C_battery * V_system * 3600; %battery capacity in J
N_batteries = E_total/E_battery;

% to search the entire area, we'd need 6 100 Ah batteries.
```

Appendix B - Agreement of Project Deliverables (Version 1)

Design Project Deliverables
Agreement between
USNA Student Design Team (“Chesapeake Baywatch”)
and Customers
Version 1

The purpose of this document is to clearly communicate expectations with regard to project deliverables between the student design team, faculty advisors, and the project customers. It is not intended to be a contract or any other legally-binding document.

In general:
We, the students, will give our best effort with the time and resources available with the intent of providing the customers with a design that will satisfy the their requirements to the best of our understanding and abilities.

We, the faculty, will do our best to assist the students through the design process including helping them maintain a workable timeline, providing technical assistance when needed, and giving them access to resources as they are necessary and available.

We, the customers, understand that this is a student design project and an educational experience above all. The students must be allowed to make engineering design choices based on their own judgement. Failure, though the students, faculty, and staff will strive to ensure it is avoided, must always be an acceptable outcome.

In detail:
On Capstone Day, Wednesday, April 27, 2015, the team will provide the following:

A working prototype that is capable of autonomously traversing the area of College Creek between the footbridge and the corner of the sea wall as shown in Figure B1. It should be pointed out that this is a much smaller area than stated in the original requirements draft. However, it was agreed by all parties, that the reduced scope would provide a much more realistic chance for success while still providing a challenge and learning experience for the students.

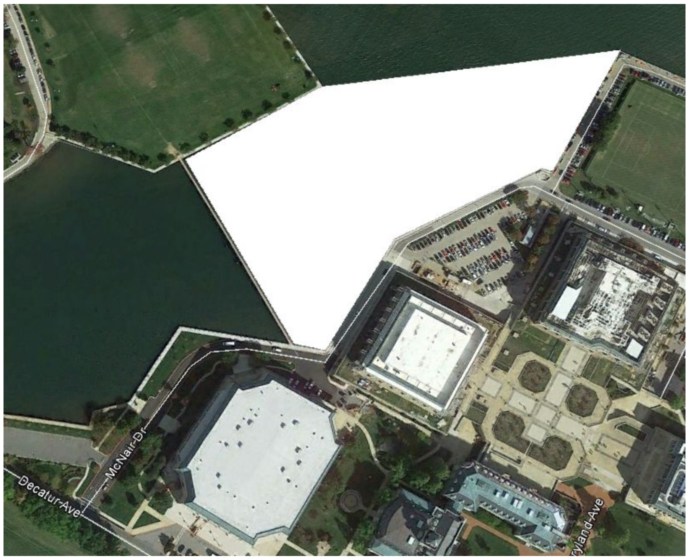

Figure B1: An overhead view of the revised search area including the area downstream of the pedestrian bridge to the line between the adjacent corners of the Hospital Point and Dewey Point seawalls.

The revised customer requirements and their associated engineering characteristics, including targets, are included in Table B1. Target values were calculated using the same analysis used previously, updated for the reduced search area.

Table B1: Revised Customer Requirements and Engineering Characteristics.

Customer Requirements	Engineering Characteristics	Units	Direction of Improvement	Rank Order	Target
Take measurements and make them available to the user	samples stored/ transmitted	#	↑	2	300
Be cheap	cost	$USD	↓	1	1,000
Cover a specified search area in a reasonable time, autonomously	area coverage	%	↑	5	50
Cover a specified search area in a reasonable time, autonomously	search area	m^2	↑	3	33,000
Cover a specified search area in a reasonable time, autonomously	search rate	m^2/s	↑	3	9
Be man-portable and launchable	mass	kg	↓	6	25

Deliverables also include any intermediate prototypes requested as well as a copy of the Final Design Report.

Student Design Team:
LCDR Ethan E. Lust: *Ethan E. Lust, 4 SEP 15*
CDR John D. Stevens: *John D. Stevens, 4 SEP 15*

Faculty Mentor and Technical Advisor:
CAPT John P. Jones: *John P. Jones, 4 SEP 15*
Jacques-Yves Cousteau: *Jacques-Yves Cousteau, 4 SEP 15*

Customer(s):
CDR Andy Gish: *Andrew Gish, 4 SEP 15*
Prof. Joe Smith: *Joseph Smith, 4 SEP 15*

Appendix C - Team Charter

Team: Chesapeake Baywatch

Project Description: Autonomous Vehicle for Gathering Oceanographic Data in Littoral Regions

Name	Team Role	Cell Phone Number
Ethan Lust	Team Leader, Design Comm. Editor	757-636-8727
John Stevens	Safety Officer, Purchaser, TSD Liaison	123-456-7891
J.P. Jones	Team Mentor	USNA Chapel Crypt x1776
J. Cousteau	Technical Advisor	Aboard the Calypso ????

Weekly Meeting Schedule: W6, Rickover Hall, room 229

Conflict Resolution Statement: If there is a disagreement, we'll try to talk it out by identifying the source of conflict and discussing it. If we still can't come to an agreement, we'll bring the issue to CAPT Jones for arbitration. We will work to treat each other with respect, both professional and personal, at all times. Also, LCDR Lust will do whatever CDR Stevens says.

Personal Statements:

"Besides fulfilling the graduation requirement, I look forward to working on a real-world problem in an effort to help someone who needs it. I'm also interested in putting the education earned over the past several years to use. I think the experience of working in a team and also with customers and other professionals will provide valuable insight into the design process and how engineering design in the commercial world works." - Ethan Lust

"I'm just in it for the money." - John Stevens