Designing, Building, and Managing an Autonomous Boat and its Transatlantic Crossing Attempt

A Major Qualifying Project

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Acknowledgements

At its conception, the Scout project was a big challenge undertaken by a small group of teenagers. Without the support of friends, family, and other supporters, this project never would have seen the successes that it did. I would specifically like to thank the “Scout moms” for their endless patience, the neighborhood engineers for their excellent advice that often went ignored, Tom Schindler for his heroic 24 hour push to get the Scout tracking website online before the launch, and the media outlets that spread news of the Scout project across the world.

I would, of course, like to thank everyone who followed this project as it developed. Your enthusiasm, comments, and donations kept this team going through countless setbacks. To Mike Mills and Jamestown Distributors, thank you for supporting the Scout project before it was cool to do so. I hope that the Scout team is one day able to return this gesture.

I would finally like to acknowledge Quinn Harper, Hobbins, Ryan Muller, Andy Chew, and anyone else who came by the garage to help with the project at any point in time.

Matt Franklin- I hope that you know this project wouldn’t have happened without you. As for the core Scout team, I’m just happy that we’re all still alive after spending so many hours in the garage with each other. I’m sure that you’re all looking forward to the next project as much as I am.

I would like to thank Professor Adrienne Hall-Phillips for supporting the Scout project and its use as an MQP. I hope that I reflect some of her wonderful passion and enthusiasm in this report.

Authorship Statement

The entirety of this report was written by Dylan Rodriguez.

Abstract

Scout was a 13 foot long boat designed by myself and several of my friends to navigate without a crew on a 3,500 mile journey from Rhode Island to Spain using only solar power and onboard processors to complete the crossing; the boat was not to receive any input from us once it left the shore. The project received significant media attention and was closely followed by tens of thousands of curious onlookers. Although Scout was built by a group of young college students solely for fun, execution of the project led us to begin investigation of ways that autonomous boats could be used in marine research applications. The purpose of this project is to study the entirety of the Scout project, examine potential uses of products similar to Scout, and present recommendations for future autonomous surface vessel development.

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Executive Summary

The Scout project was an endeavor undertaken by a group of young college students which began in 2010. The goal of the project was to build a solar powered boat capable of navigating its way from Rhode Island to Spain, all with no interaction between the boat and shore. Although the Scout project was designed just to be a fun way to inspire an audience with creative engineering, a number of individuals have approached the Scout team with queries concerning Scout's ability to complete a number of missions with real-world applicability. This report examines some of the potential uses for a platform like Scout and studies the potential implications of adopting autonomous boats as tools for research.

As autonomous boats can be designed to require no crew or fuel, they are ideal for long distance missions, missions that require data collection in dangerous environments, or repetitive missions that would otherwise have to be completed by expensive manned vessels. Although the technology necessary for autonomous surface vehicles to be developed exists, few of these vessels have been developed and brought to the commercial market. This report closely studies the Scout project and uses lessons from the project to develop recommendations for future development of autonomous vehicles designed for marine data collection and task based mission performance. These recommendations are then put into context of a next generation Scout vessel which is being designed and built by Scout Technologies Incorporated, the company started by the original Scout team to further research and develop commercially feasible autonomous products.

1: Introduction: The Backstory

During one of the dark nights of the winter of 2010, Dylan Rodriguez and Max Kramers, two young college students whom had been friends since kindergarten, were working on experimental rocket-launched airplanes in Max's garage. Max had returned to Rhode Island from his internship in Spain for Christmas vacation, and the two had a conversation about their plans for the coming months and the fact that they wanted to communicate more. As a joke, Dylan suggested fitting Max's A-Class catamaran with computers and motors so that it could sail itself across the Atlantic Ocean and deliver bottled messages to Max. Although the boys settled on using Skype to communicate with each other, both continued to consider building an autonomous boat to send across the Atlantic.

By early spring of 2011, Max and Dylan had built an early prototype of a small solar powered boat that could navigate around a local pond. They realized, however, that a boat capable of crossing the Atlantic would require a sturdier hull, more capable electronics, and highly refined programming that could function for thousands of miles while traversing rough Atlantic seas. As hurdles were identified, additional students and friends joined the team to expand on the skills and resources of the initial team members. The final team was comprised of Dylan Rodriguez, a Management Engineering student at WPI, Max Kramers, a Mechanical Engineering student at URI, Dan Flanigan, a Civil Engineering student at Bucknell University and Naval Architecture student at Southampton University, Brendan Prior, a liberal studies student at Endicott College, and Michael Flanigan, an Aerospace Engineering student at the University of Notre Dame. Sponsorship for composites and other construction materials was secured through Jamestown Distributors, a marine supply distributor based in Bristol, Rhode Island. The partnership with Jamestown Distributors allowed Scout to be built with carbon fiber; this meant that Scout was stronger and about fifteen pounds lighter than it would have been if the team used fiberglass, a less expensive alternative to carbon fiber, for construction. The cost of electronics and the remaining expenses were covered by money raised from a fundraising drive and from the team members themselves. Figure 1 shows the final product of the Scout project.

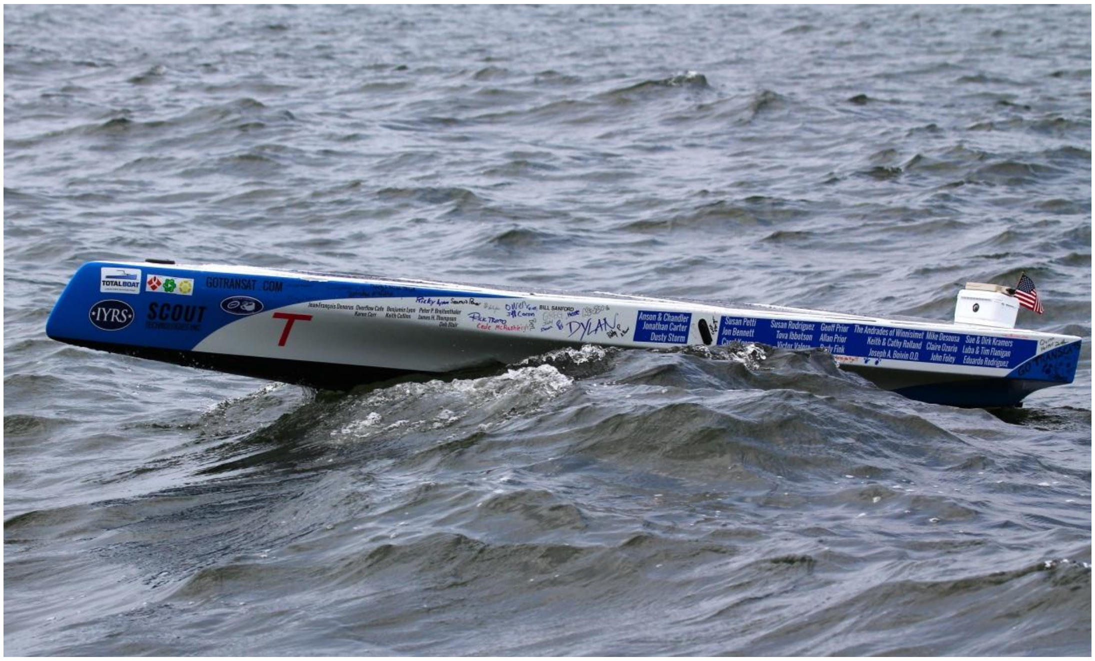

Figure 1: The product of the Scout project (Rodriguez, 2013).

In August of 2013 the team launched Scout, the most current iteration of the project. Scout is a thirteen foot long boat which closely resembles an aircraft carrier in its design. Solar panels on the deck drive an electronic motor below the waterline to propel the vessel, and onboard batteries store charge to allow the vessel to run overnight and in inclement weather. Scout carries a number of scientific sensors aboard, and transmits position and sensor data to a database via the Iridium satellite constellation as it completes the crossing.

The remainder of this paper will discuss how the Scout project was developed into my Major Qualifying Project. I will then discuss the importance of this topic, a background on autonomous surface vehicles, and an overview of current market leading products and systems that could be complemented or replaced by autonomous surface vehicles in the future. I will review how Scout was built, the goals and design of her mission, the story of her launch, and data collected by the platform. I will conclude with a review and analysis of the results of Scout's mission and will offer closing recommendations for the future development of related technologies.

As this project was completed by a group of students from different colleges across the country, in this paper, the word "team" refers to those students introduced in the backstory. Except for the limited contributions made to the communication system software by Ryan Muller, I am the only student from WPI who functioned as a team member on this project, and did so between when we started the project in my freshman year at WPI and when we launched it in the summer of my senior year.

1.2: How Did This Become My MQP?

While watching coverage of Hurricane Sandy during the fall of 2012, I was intrigued by a statement made by CNN's senior meteorologist, Chad Myers. Myers was projecting the path of the hurricane, and voiced, "the computers are not perfect because there's not much data in the ocean. There's no one in the ocean putting up weather balloons for us to know which way weather is blowing [….] we need more data out there. We don't have it." (CNN, 2012). It was at this point that I realized the potential value of an autonomous sensor platform that could be deployed to study developing weather systems and other subjects of scientific interest alike, although the team had discussed potential uses of autonomous platforms like Scout loosely in earlier conversations. After additional research and further discussions with scientists and experts in fields that have in the past used water-based platforms to collect data, we found a significant and valuable market in marine data collection that was not being satisfied with existing technologies (M. Kaltofen, personal communication, October 5, 2012)[1]. For this reason, the team decided that the potential uses for autonomous surface vessels warranted further investigation.

1.3: Why is This Topic Important?

Current marine data collection systems include manned research ships, satellite constellations, floating and submerged buoys, and other well developed tools that supply the world's scientists with a tremendous amount of data every day. However, for many marine research projects these sensor systems are inadequate for collecting the types of data required for appropriate synthesis by environmental scientists (K. Pryor, personal communication, October 13, 2012). Some of the limitations of these data collection systems are technical constraints which often can be solved only by further research and development of enabling technologies. Other limitations, which can be more easily rectified, are difficulty of access to certain areas of the world's oceans, high transportation and equipment costs, and commercial viability of developing solutions designed to rectify these issues (Pawlak et al., 2011)

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[1] Marco Kaltofen is a researcher at Boston Chemical Data Corporation and a research fellow at Worcester Polytechnic Institute. He has worked with autonomous boats for mission-oriented projects in the past, including oil mapping and pollution indexing. His field of work involves data collection from a variety of platforms, and he has identified a number of strengths and weaknesses of a number of land and water based systems.

The aforementioned issues can reduce the amount of data that can be collected from our oceans with traditional data collection methods and can lead scientists to use other technologies that are more readily available but may be less suited to a particular task. Governments and environmental organizations have recognized these issues and are continuously funding new efforts designed to collect more data that can be shared between organizations (Le Traon, 2011). Many fields of science rely on accurate and current environmental measurements to make accurate predictions, assessments, and plans, some of which have impact on international trade, aviation, weather forecasting, and the global environmental future. New data collection products designed to collect information from the oceans are needed in order to ensure that forecasts, projections, and records dependent on this data can be supplied with the most appropriate data possible (Grosky, Kansal, Nath, Jie, & Feng, 2007).

While many marine data collection systems can be improved upon, an entirely new system that has potential to solve many problems presented by the other technologies might be the best channel to investigate. One such system involves the use of autonomous boats equipped with sensors designed to collect and transmit data to ground based platforms. These oceangoing vessels can be built to endure months on the open ocean while navigating complex preprogrammed routes and collecting data from integrated sensors along the way (Fahimi, 2009). Although a few autonomous data collection vessels have surfaced over the last several years, they are limited in their efficacy as their low speeds, poor modularity, high cost, and lacking user interfaces serve as a barrier to their effective and widespread use. A new generation of leading edge autonomous vessels has the potential to redefine many current scientific processes, including the methods with which storms are tracked, oil spills are mapped, wave height and length are indexed, and pollution is measured on a global scale. Unlike traditional manned boats, autonomous boats can be deployed quickly with sensors and equipment designed specifically for a particular mission, and they can stay offshore for months at a time while transmitting the data they collect back to shore (Manley & Willcox, 2010).

2: Background

To understand how an autonomous surface vehicle (ASV) can impact the marine data collection environment, we first must gain an understanding of current data collection purposes, technologies and methods. We must also study the types of data that are collected by current methods in order to understand how this data is used and why it is useful to scientists and the general public. Although many different systems are used to collect different types of data for many purposes, there are a few missions that ASVs are particularly well suited for; those will also be investigated here.

The existing field of marine data collection devices can be categorized as units designed to measure scientific water properties, units designed to measure biological information about organisms living in the water, and units designed to collect environmental measurements.

2.1: What Data is Collected, Why is That Data Useful?

A number of data types are common to many oceanic data collection projects. While some of these projects span a number of months, years, or decades, such as global temperature recording, others situations in which oceanic data is sought are more time sensitive, and include potentially toxic algal blooms, hurricanes and other weather events, and oil spill mapping. This variety of data types collected by various oceanic sensing devices makes the sensor platform market very broad, and different data capture mediums often have extensive strengths and weaknesses.

2.1.1: Water Property Measurements

Water property measurements include scientific measurements of indexes such as salinity, fluorometry, dissolved oxygen, hydrogen sulphide, thiosolphate and sulphur, pH, total alkalinity, total dissolved organic inorganic carbon, and carbon dioxide partial pressure. Although most of these measurements require different sampling methods and sensors, many are commonly collected (Grasshoff, Kremling, & Ehrhardt, 2009). While these measurements are often collected by manned vessels due to the complexity of ensuring ideal water samples, buoys have become much more popular vehicles of scientific sensor instrumentation. Satellite platforms are largely incapable of collecting these types of data (Staff, 2007b).

Water property measurements can be used for a large number of research and environmental projects. For example, oxygen levels, salinity levels, and pH levels are common metrics used to identify the suitability of water to support life. A number of other sensor types are used to identify particular components of water composition specific to a particular issue under study and can be mapped to better indicate causes or effects of particular metrics.

2.1.2: Biological Data

Biological data measurements include the assessment of nutrients, levels of phytoplankton, and the use of fluorometric sensors to determine levels of Phycoerythrin (marine cyanobacteria) (Staff, 2007a). This data is used to predict oceanic biological activity and is typically collected by in situ sensors attached to buoys or by analyzing water samples taken from manned ships (Kampel et al., 2009). Data collected by biological sensors, especially data concerning nutrient concentrations and phytoplankton, is important because as phytoplankton feed from nutrient rich water, their population can grow out of control and produce harmful algal blooms that produce toxic compounds, putting sea life and humans at risk. Early warning of harmful algal bloom formation allows scientists to predict where those blooms will form, where they will move to, and how they will affect those areas. Advanced notice enables coastal decision makers additional time to stage resources, warn at risk populations, and respond to the events (Anderson, Glibert, & Burkholder, 2002).

2.1.3: Environmental Data

Environmental data consists of measurements of the environment surrounding the platform that do not fall into the other categories. These measurements include air temperature, barometric pressure, wave height, wind speed and direction, photographic observation, radiation measurement, turbidity, and air quality indexing ("NDBC- Moored Buoy Program," 2013). As there are a number of types of environmental data that can be collected, this data can be used in many different ways. Environmental data can be especially useful for weather forecasting as the range of RADAR can be a limitation when forecasting the formation and movement of offshore weather systems. Temperature, wave, radiation, and wind data each have particular uses. These metrics are often collected and processed by multiple platforms and offered in its raw form, as data collected from different platforms can be afflicted by various nuances. For example, data collected from satellites is limited by a number of factors, including issues such as sample depth (satellites are unable to sample the temperature of water five or more meters below the surface), time of day restrictions (visible spectrum imagery is only available during daylight hours) and atmospheric variables beyond the scope of the satellite payload’s corrective capacity (Lu, Ramsey, Rangoonwala, Suzuoki, & Werle, 2012). Satellite data is often calibrated with data collected by in situ sensors to remove biases introduced by the atmosphere above the subject. If the in situ platform reports measurements regularly, the biases of the satellite platform can be corrected in real time with the most recent data (Venkatesan, Shamji, Latha, & Mathew, 2013).

2.2: How is Oceanic Data Collected?

In pursuit of collecting data from the ocean, scientists and researchers deploy different resources configured with sensors specific to the particular mission. Obvious considerations involve the cost of the resource, the efficacy of the system, its timeliness in delivering results, and accessibility of the environment where the samples must be taken.

2.2.1: Water Property Data Collection Platforms

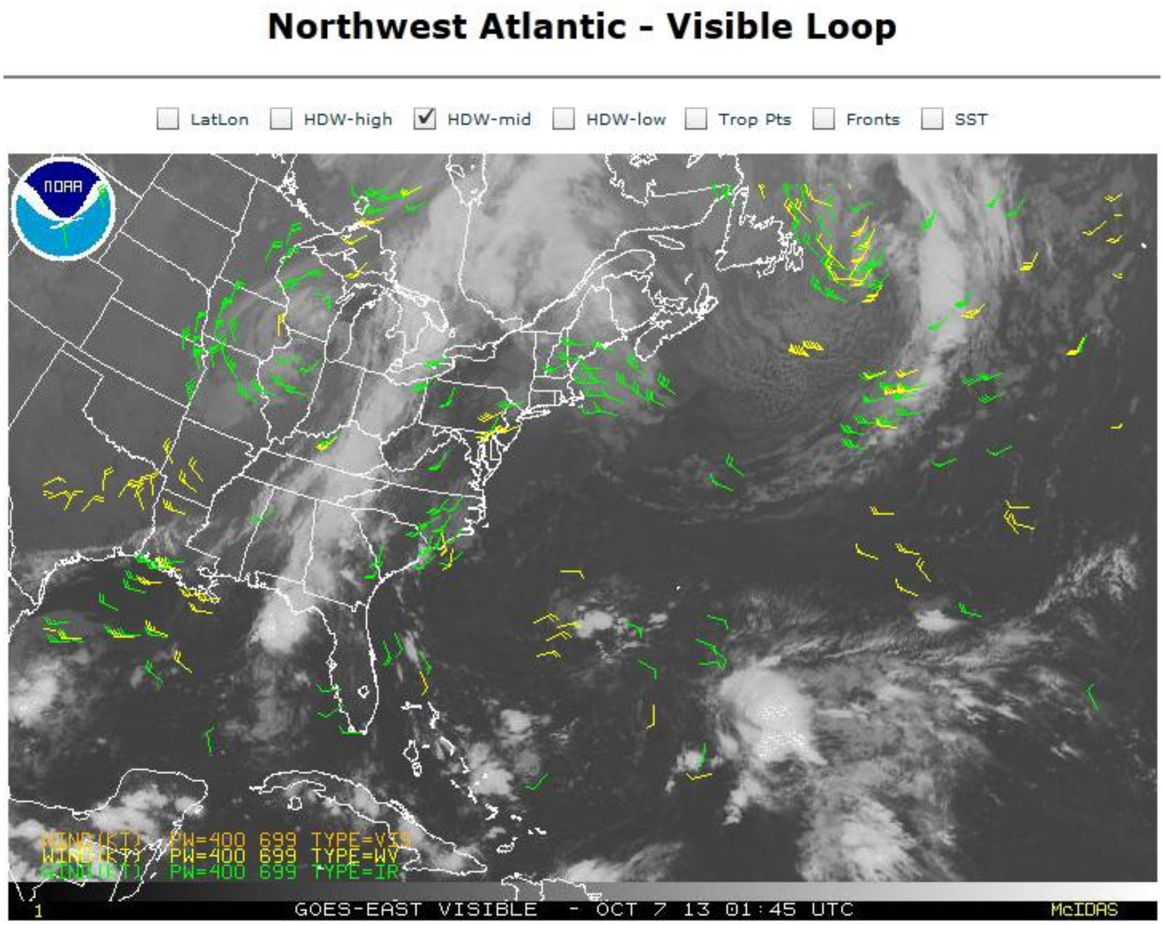
Water property data collection platforms typically consist of buoys and research ships. As many elements of this category are particular compositional characteristics indistinguishable from space, contact based measurement techniques, such as manual sampling and the use of buoys, is the most effective means of collecting the data. If automated sampling platforms are used, solid state sensors are fitted to the unit to allow for nearly instantaneous reading and storage of sensor data.

2.2.2: Biological Data Collection Platforms

Sensors are readily available to measure a number of biological metrics. The type of data collection platform depends on the type of data that will be collected, although satellite based platforms have been proven to be often ineffective tools for many biological measurements (Kampel, Gaeta, Lorenzzetti, & Pompeu, 2007). For oceanic research, laboratory analysis of water samples or contact based “in situ” measurements are usually preferred by the scientific community, depending on the purpose of the sample collection and the constraints that dictate the sample's study. For example, in situ measurements can be taken and transmitted in less than a minute, while laboratory analysis requires a physical sample of the water and requires an appropriate amount of time to transport and process the sample. For this reason, in situ measurements are most commonly used to collect data from remote or difficult to access platforms, from areas where the variable under study changes rapidly, or from a number of locations that would be too numerous to sample regularly. Laboratory analysis is often used in cases where precision and accuracy is particularly important, such as when measurements of a sample are used in court or when particularly small variations in derived measurements are significant.

2.2.3: Environmental Data Collection Platforms

Oceanic environmental data is primarily collected by buoys and satellite based platforms. Each platform has a number of strengths and limitations. For example, although satellite based imagery platforms can allow for wind speed and direction to be mapped, they rely on a "tracer" to be present, often in the form of a cloud or water vapor mass which is tracked between image frames taken over time ("Derived Motion Winds," 2013). These systems work well to establish a projection of the movement of large scale weather systems, but have a difficult time mapping information regarding the winds in narrow altitude bands (the GOES system categorizes winds in three ranges: 0-10,000 feet, 10,000 to 23,000 feet, and 23,000 to 50,000 feet ("Toggle Overlays Explained," 2013). In addition, and visible in Figure 2, wind direction and speed data derived from these satellite images can be sparse, especially in areas with little cloud cover or heavy high altitude clouds that obscure traceable cloud formations underneath them.



☐ LatLon ☐ HDW-high ☑ HDW-mid ☐ HDW-low ☐ Trop Pts ☐ Fronts ☐ SST

Figure 2: Wind speeds and directions calculated from GOES visible imagery (HDW-mid displayed) (National Weather Service, 2013)

2.3: Autonomous Surface Vehicles and Data Collection

Autonomous surface vehicles (ASVs) are boats designed to travel without a crew. Because autonomous surface vehicles operate on the surface of the water, they are best suited for certain types of measurements and data collection methods. Scientists are turning to developing technologies to lower costs and collect otherwise inaccessible data, and autonomous watercraft are being included in this shift to increasingly advanced and hands-off data collection equipment (Marzuola, 2002). These platforms can be designed to collect a large amount of data from a number of sensors that interact with the environments above and below the waterline. It can then be hypothesized that ASVs may make good data collection platforms, especially if a particular unit can be outfitted with in situ sensors that can function without maintenance and provide accurate data for the duration of the platform's mission. As most common data types are separated into water property measurements, biological measurements, and environmental measurements, an autonomous surface vehicle would only prove to be an effective platform for collecting data if it could prove more effective than current collection means.

2.3.1: Water Property Measurements

ASVs have an advantage in regards to their capacity to collect water property measurements because these metrics change often and an ASV could be configured to repeat a particular mission in order to maintain the usefulness of the most recent set of data. Unlike moored buoys, ASVs often have shallow drafts, meaning that sensors cannot usually be located at a depth of more than about twenty feet due to the structure of the unit. The advantage that ASVs have compared to buoys, however, is their capacity for modularity and on-the-job repurposing. One ASV could potentially be outfitted with a battery of solid state in situ sensors and undertake a week long, 500 mile mission; those same sensors would only collect data from one static location if they were mounted on a buoy during that time. As ASVs are modular, the unit could serve different purposes seasonally, or be pulled from low priority missions when a more time sensitive survey must be taken. This modularity could also lend ASVs to be borrowed and loaned between organizations to support high priority missions.

2.3.2: Biological Measurements

A number of biological activity indicators can be easily measured by an ASV. Some simple metrics include chlorophyll counts and fluorometry data, both of which can be used to assess the concentration of suspended phytoplankton in the water. ASV data collection in the biological measurement field is particularly interesting because ASVs could be used to further investigate potential algal blooms with higher data point resolution. As some biological measurements can only be conducted in a laboratory, the ideal ASV may have a water sample collection system or other means of taking and storing water samples that would be transported to a lab for further analysis. With this method, a number of issues plaguing traditional water sample practices could be avoided, especially in regards to the cost, complexity, and number of man hours involved with collecting ideal water samples (Grasshoff et al., 2009).

2.3.3: Environmental Sensors

As an autonomous surface vehicle travels on the surface of the water, it is useful not only for measurements underwater, but for measurements above water as well. Above-water measurements that can be taken with simple solid-state equipment include air temperature, barometric pressure, wave height, wind speed and direction, photographic observation, radiation measurement, turbidity, and air quality indexing. As a modular ASV can accommodate a number of sensors and configurations, one platform could potentially collect a large and varied amount of data on a mission hundreds or thousands of miles long. As discussed earlier, some types of data, such as wind speed and direction, cannot be collected via satellite as accurately as they could be collected by an ASV or weather buoy. As weather buoys do not cover the ocean with significant resolution, it is possible that the potential of ASVs to provide calibration data to satellite platforms studying otherwise uncorrelated parts of the ocean could increase the accuracy of particular datasets collected by satellite, as well as yield discrete measurements that could be used independently to examine the environment studied by the ASV.

2.3.4: Additional Sensors

Because of the modular nature of a properly constructed ASV, additional sensors specific to a particular research field or application could be installed on the platform with little effort. This capacity for expansion means that autonomous surface vessels have a tremendous breadth of applicability, allowing the end user to customize the product to their specifications and specific sensor payload. For example, scientists looking to measure water salinity to investigate its effects on shellfish could fit the unit only with the salinity and other water property sensors that would be useful in their investigation.

2.4: Existing Autonomous Vehicles Used for Data Collection

A small number of autonomous surface vehicles designed for use as autonomous data collection platforms exist today; some are available on the commercial market, while others are still in development. Several autonomous surface vehicles have been launched by hobbyists. As the objectives of ASV platforms are often similar (collect sensor data and transmit it back to shore,) the differences between the platforms, and their current positions in the commercial market, are what differentiate the products to potential clients and create value for particular missions. Not discussed here are Autonomous Underwater Vehicles, which resemble small submarines or torpedoes and are being used for numerous research projects today.

2.4.1: Wave Glider- Liquid Robotics

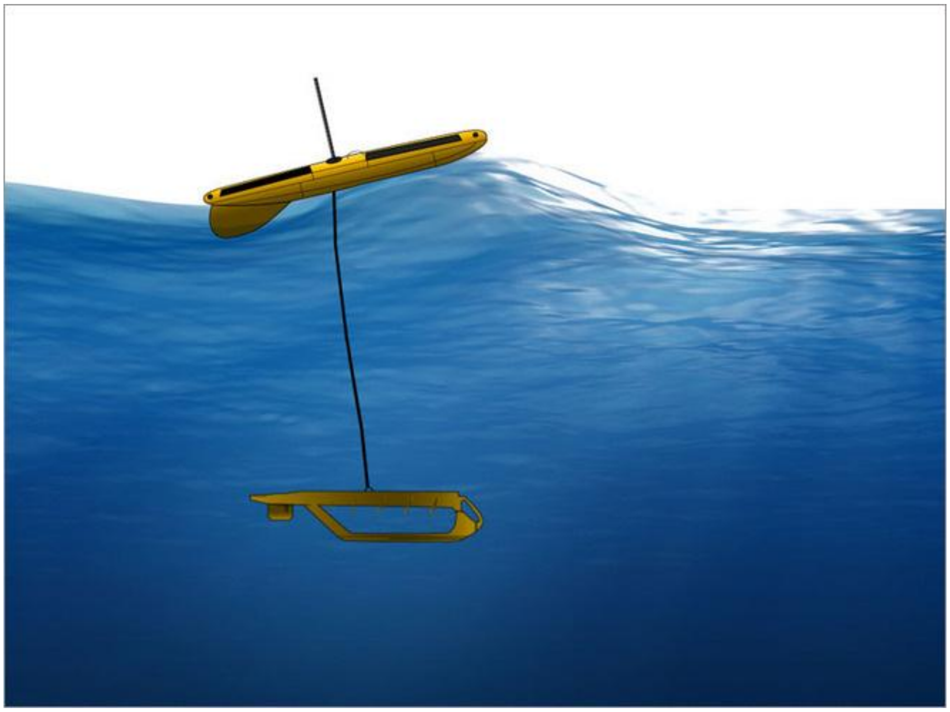


Figure 3: The Liquid Robotics Wave Glider: computer rendering (Robotics)

Wave Glider is a platform developed by Liquid Robotics, a company operating out of Sunnyvale, California, which has been funded by a number of rounds of venture capital investment totaling more than $81,000,000 ("Crunchbase: Liquid Robotics," 2013). The company's first product, the Wave Glider (pictured above in Figure 3) is a semi-autonomous platform that is propelled by wave power and can be outfitted with a number of sensors and payloads, often designed for scientific data collection purposes. While the Wave Glider has a virtually unlimited source of propulsion and can travel 24 hours a day, its maximum speed is reported by Justin Manley and Scott Willcox, two company employees, to be 2.25 nautical miles per hour in ideal sea conditions. Manley and Willcox state that the expected "long mission average” speed of the platform is about 1.5 knots (1.73 mph) which excludes it from a number of missions that require autonomous platforms with higher, more predictable speeds. Liquid Robotics allows customers to either buy “time” on a Wave Glider at a rate of between $1,000 and $3,000 per day, or purchase a Wave Glider outright, with a purchase price starting at $300,000.

The Wave Glider platform has had some success in the commercial market and has Liquid Robotics has deployed approximately 130 units as of August of 2012. Liquid Robotics has not made detailed information about their customers public, but plans to use its military and security strategic advisory board to expand into the security market ("Liquid Robotics: About Us," 2013).

2.4.2: Roboat

Figure 4: Roboat under sail (“Roboat: Home,” 2013)

Roboat is an autonomous sailboat built by a research team from Austria that has had great success in international ASV competitions, particularly in the World Robotic Sailing

Championships, where the team has won four times. Although the 3.75 meter boat is not currently designed for commercial applications, the large size of the vessel enable it to handle missions that smaller platforms, such as the Wave Glider, could not accomplish due to its lack of buoyancy and cargo space. The Roboat website lists a number of potential applications that its creators believe to be feasible uses for the platform, including CO2 neutral cargo transport, data collection, and even advanced autopilot solutions for exhausted or otherwise incapacitated skippers ("Roboat: Home," 2013). As the Roboat project is not yet a commercial venture, its marketability may be difficult to determine, but its ability to carry payloads of significant weight and bulk, as well as the plentiful solar power available to the onboard systems, makes Roboat an interesting and potentially valuable platform in the developing ASV market.

2.4.3: Saildrone

Figure 5: A prototype Saildrone on a test mission ("Saildrone," 2013)

Saildrone is an ASV designed by a team of engineers that have had intentions of commercializing the project since its inception. The unit’s sole source of propulsion is its wingsail, and production models will be 19 feet long with a mast height of 20 feet. Saildrone LLC claims that the platform can attain a maximum speed of 14 knots (16 miles per hour) and an average speed of 4 knots (4.6 miles per hour.) Like the Wave Glider, Saildrone is designed to carry customizable payloads and sensors as dictated by customers, and data can be collected onboard and transmitted back to shore. The higher average speed of the Saildrone, however, means that the product can complete a mission more than twice as fast as the Wave Glider, which could be a significant selling point as many missions, such as monitoring specific weather events, are time sensitive.

So far, Saildrone LLC has only built prototype units which are not available for purchase today. The company has not published an estimated market date for the product, but does plan to use the units in a number of experimental studies in 2014. These trial missions include shark tracking off of the coast of California, buoy replacement in cooperation with NOAA, and an ocean acidification study ("Saildrone," 2013). Although the Saildrone does have certain advantages over Waveglider and buoys, those advantages need to be weighed against its large size. As the price of this product has not been released it is difficult to compare the cost benefit ratio of the unit to another product, such as the Wave Glider.

3: Methodology

As the Scout project was an experimental venture undertaken by a team of college students with limited resources, it was constrained in several ways and presented a number of challenges unique to the project. As Scout moved from the design phase to the various stages of construction, features were added and removed, structure designs were modified and reworked, electronic system designs revised, and thousands of lines of code were written. While Scout was designed primarily for the task of traveling from Rhode Island to the shores of Spain, it was also fitted with environmental sensors designed to take readings along the way and transmit them back to shore based systems.

3.1: Goals of the Scout Project

The Scout project was designed to produce an autonomous electric motorboat that will navigate under its own power from the coast of Rhode Island to Sanlucar de Barrameda, Spain. Sensor systems fitted to the platform were designed to record data which was then sent along with diagnostic information to shore every twenty minutes. The platform was also designed to record video clips that are stored onboard for later retrieval. A backup tracker mounted to the deck was able to be remotely activated in the case of primary system failure.

3.2: Design

Scout was designed to be as inexpensive, light, and seaworthy as possible with the resources that were available to us. As Max had considerable marine design experience, he designed the boat to be built from carbon fiber and Divinycell marine grade foam in a thirteen foot long hull resembling the form factor of an aircraft carrier. Max’s design was dependent on the configuration of the solar panels, the amount of power that would be available to the motor, the weight of the systems that would be onboard, and a number of other factors not directly related to the platform’s performance in the water (for example, Scout needed to be easily transportable by car). Sponsorship by Jamestown Distributors allowed Max to use materials and construction techniques that may otherwise have been prohibitively expensive.

The design of Scout’s electronic systems was complicated by the fact that Scout would be powered solely with solar power and would need to function independently for months. I designed the electrical systems using as many “off the shelf” components as possible in hopes of simplifying the system and reducing the number of potential points of failure. An example of this was the solar charge controllers- the devices designed to manage the charging of the batteries. Instead of designing and building these complex units from scratch, we bought the controllers online and integrated them into our systems.

Although we tried to use as many off the shelf products as possible, I still had to design and build some electronic components to connect systems and enable the functionality that we were expecting from Scout. Figure 6 shows an early version of the motherboard designed to facilitate the connection of various subsystems to Scout’s central processor. While we had previously created a ratsnest of terminals and wires in the electronics box on Scout, this board allowed us to use standardized connectors to simplify the integration of subsystems which increased the ease with which the system could be inspected and gave us more confidence that it wouldn't fail prematurely. Circuit boards and electronic components were usually purchased with cost being the primary deciding factor in the purchase decision.

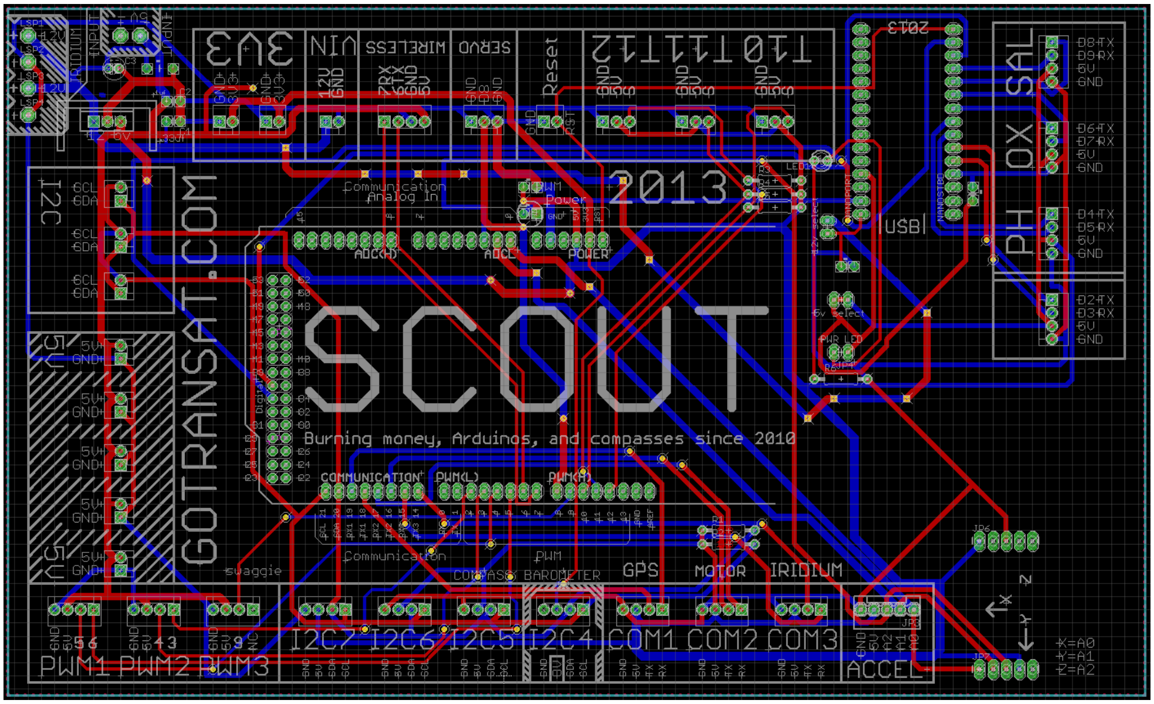


Figure 6: Scout printed circuit board (Rodriguez)

Scout's software was written in the Arduino integrated development environment and was designed to be simple, reliable, and predictable. Because Scout would be spending months at sea, we knew that it would have to be completely independent of us as the platform would be inaccessible; we would not be able to fish it from the sea for repairs if it failed in the middle of the Atlantic. We eliminated many features that would have been nice to have but could potentially interfere with the main functionality of the unit, and designed the remaining systems to be as simple (and as easy to debug) as possible.

3.3: Strategy

As Scout is comprised of a number of subsystems, we found it easiest to build many of the systems in parallel and combine them as we moved forward. For example, work on the software and electronic systems took place in tandem with the physical construction of the boat. As most of the team did not have significant electronic or software experience, the priority of those team members was to support the team members doing that work. This focus of the team significantly increased the number of hours that the resident and visiting team members working on software and electronic hardware could spend contributing to those components of the project and improved the efficiency of those team members when they were working, which was a critical component of the strategy of the team. These support roles ranged from making lunch to covering a team member who sometimes worked on Scout instead of going to his real job.

In addition to supporting the critical components of the project, the strategy implemented by the Scout team focused on maximizing the use of the resources available to it. In many cases, this meant identifying potential issues early on and consulting friends or other acquaintances to identify ways to move forward. If a particular issue became obstructive to the completion of other parts of the project, the team would whiteboard a series of potential solutions to the problem and attempt these solutions, in order, until the issue was fixed. For example, an issue with the battery charging system was solved early in the process, but had the initial potential solutions not worked, we would have ended up replacing the LiFePO4 batteries with heavier, less efficient sealed lead acid batteries to mitigate the issue.

3.3.1: Social Media and Connecting to our Audience

One goal that the Scout team members had concerned our parents and neighbors; namely the fact that sometimes all of the Scout team members would disappear from the neighborhood community for days at a time while working on Scout. At the beginning of the project, the Scout website was a simple static page that was updated once or twice a month. When the team started to put more hours into the project, we similarly put more time into maintaining our public appearance, both online and with traditional news media sources. Figure 7 shows an example of a post that I published on the Scout Facebook page in order to share an unsolicited analysis presented by Scout follower Jörg Dietrich, a research scientist at the University Observatory Munich.

Scout- The Autonomous Transatlantic Robot shared a link.
September 12, 2013

Will Scout crash into Portugal? Jörg Dietrich offers analysis and a neat graphic that will update in real time as Scout travels towards her destination (wherever that may be!)

Analyzing Scout — Transatlantic Autonomous Robot
www.usm.lmu.de

2,542 people saw this post

Figure 7: The "will it crash?" post on the Scout Facebook page

In the last months of the project, the Scout team maintained a website, a blog, a Twitter page, and a Facebook page. As I had the most experience with website development, I ended up managing the website and the rest of the project's online presence. Parents were emailed instructions on how to receive the latest messages posted to Twitter as text messages to their phones so that they would have some idea of what their kids were up to. By the end of the project, Scout's Twitter page had 300 followers, the email list had 325 email addresses in it, and the Facebook page had over 2,200 subscribers. The team's intent was to use these communication channels to keep the parents and the public up to date on the project. These updates were particularly useful for events, such as long distance testing. For example, Figure 8 shows a series of tweets posted to update the project's Twitter followers during the failure of one of Scout's navigation lights that were fitted for the duration of a long distance test occurring at night.

Scout Transatlantic @ScoutTRANSAT · May 30
1:42am. Discussion regarding failing replacing nav lights on scout.

Scout Transatlantic @ScoutTRANSAT · May 30
Emergency backup lighting system developed. Sending a team of three out to install while two remain on Astraea pic.twitter.com/5irHJUtAAU

Scout Transatlantic @ScoutTRANSAT · May 31
Light refit a success, scout continuing to glide along at 2.8kn. Emerging from sakonnet river, 1.28 miles to mouth. pic.twitter.com/Fs3b7um5U3

Figure 8: A series of updates on the Scout Twitter page, posted during an offshore test.

3.4: Data Collection

Scout was fitted with several sensors designed to collect data as she crossed the Atlantic. These sensors include sensors used for navigation, a barometer, a voltmeter attached to the motor battery, a dissolved oxygen sensor, a salinity sensor, a pH sensor, and three temperature sensors (water, air, and internal.) As the team didn't have the resources to buy and install expensive sensors, the sensors chosen were the most economical units available on the market. The data from these sensors is transmitted every twenty minutes by Scout and stored in a database onshore. While more accurate, feature rich sensors could be fitted to a Scout platform in the future, these were chosen as a proof of concept to illustrate the value of an autonomous platform in regards to data collection over long distances in the Atlantic.

3.5: Analysis

While the Scout project carried sensors onboard only as a proof of concept, a number of analyses can be performed on the data received from the platform. There are a number of additional results of the project that can also be studied.

3.6: Specific Applied Efforts

As the Scout project was a collective effort undertaken by friends, it presented its own challenges, both technical and managerial. Unlike in a commercial environment, there were no set hours, no job titles, no compensation, and no money available to hire consultants. I found that this created two areas of concern: managerial challenges and technical challenges.

3.6.1: Managerial Challenges

The average age of the five Scout team members at the beginning of the project was 18.2 years old, with the youngest member being fifteen and the eldest being twenty years of age. Focusing a team of teenagers to achieve a project of considerable technical difficulty requires an understanding of the group's relationships with each other and with the project itself. As the project developed over the next two and a half years, although the abilities and responsibilities of each team member changed, the momentum of the team and the project grew to an incredible level, creating a work environment that was truly remarkable. In the summer of 2012, for example, all Scout team members had full time (40 hours/week) jobs, yet the average time commitment to the Scout project, per team member, was 82 hours per week.

Although the team never sat down to discuss the establishment of individual focuses or responsibilities, team members rose to fill whatever positions they believed they were best suited for. For example, the fact that none of the other team members had any electronic design or software experience meant that I was best suited for tasks related to those components of the project. It also meant that if I wasn't able to complete a task in this field, I would find someone who knew how to do it and find a way to compel them to do so. Most of us had some experience working with composites, but Max was by far the most knowledgeable in that field, and so the design of the structures and laminate schedule were handled by Max. Dan, Mike, and Brendan also had particular strengths gained from past experience that helped identify where they could contribute the most value to the team.

The concept of leadership in this project was fascinating because of the fact that the project required knowledge and resources beyond our means, thousands of man hours of work during weekends and summers, and financial investment by all of the team members. As I fell into a leadership role for the project, I understood that the motivation of the team members would play a huge part in the success or failure of the project. My focus was to give Scout the best chance at success on her mission as possible, and oftentimes that meant sleeping for four hours a night or forgoing sleep to help another teammate with a particular task. This team was incredibly self-motivating and self-sufficient, and each team member made their own sacrifices to spend the amount of time working on Scout that they did. My greatest contribution in regards to my leadership of the project was most likely the fact that although everyone else did take time off from the project for sailing races, travel, or other engagements at one point or another during the summer, I was always there, working with whoever was left. Because the team was so close knit, I had unnecessarily worried that the loss of one of the team members for even a week could demotivate the remainder of the team.

3.6.2: Technical Challenges

As the Scout project is a technical project that involves microcontrollers, long distance navigation, motors, solar power, and communication over a satellite network, it presented a number of technical challenges. Most physical challenges, such as hull construction, solar panel mounting, or composite component manufacture, could be overcome simply by applying more time to that task. Many software and electronic system challenges, however, could not be solved solely by committing additional time to that issue. For example, as the satellite communication unit that we chose for Scout was designed to be integrated into systems by professionals, I experienced tremendous difficulty in integrating the unit into Scout's onboard computer system. At the time, there was no better product available on the market that was suitable for the purpose, so the only option that we did have was to continue trying to integrate this product. I contacted a friend, Ryan Muller, who then commuted during the weekends in a series of 240 mile round trips to the garage in order to help overcome some of the more complex software issues that we were facing with that integration issue. Access to Ryan became a key resource for the success of the project.

A technical challenge in the electronic development aspect of Scout that was particularly daunting was the isolation of electrical noise created by the motor controller from the rest of the system. During testing, we found that electrical noise was generated on the power bus when Scout's drive motor was propelling Scout through the water. These spurious signals interfered with the rest of Scout's systems, particularly the servo motor used to control the rudder. In-house debugging determined the source and means by which the interference was affecting the rudder control system, but a quick consult from Dr. Greg Jones[2], a neighborhood friend and Scout supporter, produced a solution that was implemented and determined to be effective.

Another technical challenge encountered by the team was developing a bilge pump activation system to sense water in the boat and trigger the bilge pump. The initial plan was to use a commercially available bilge pump float switch, but after testing a standard unit from Jamestown Distributors, the team wasn't pleased with its performance; it took two or three

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[2] Dr. Greg Jones: A neighbor and electrical engineer who is a professor at the University of Rhode Island and works at the Naval Undersea Warfare Center in Newport, Rhode Island.

inches of water in the bottom of the hull for the switch to activate. While such a switch may be adequate for large boats where a few inches of water are inconsequential, Scout is sensitive to such amounts of water in her hull. Team members examined other products carried by Jamestown Distributors, but found that no float switch carried by the company would activate the bilge system with less than two inches of water in the hull. Two of my other team members, Mike and Brendan, had led the switch search, and decided that if an ideal bilge pump switch could not be found, they would make one. The system that they developed was not a traditional float switch; it instead used carbon rods which would trigger a relay when they were bridged by water. Although it took two team members an afternoon to design, build, and install the system, this solution significantly reduced the amount of water in her bilges that Scout would transport across the Atlantic.

A number of interesting innovations were developed to solve problems that were difficult to simulate and test. One significant example concerns the possibility of a memory leak on the navigation processor. Such an issue could, over a period of weeks or months, slowly fill the memory available to the unit until it crashes, reducing Scout to a floating message in a bottle. We knew, however, that if we reset the unit automatically each day a memory leak would never crash the processor, and if it did, the problem would be fixed on the next reset of the system. We designed an automatic reset system into the electronics and software and it visibly and successfully rebooted the unit a number of times in the transatlantic attempt; without this system, Scout's navigation system would have failed as early as five days into the journey.

Other challenges that we encountered while designing Scout's systems included mechanical issues, such as the potential for Scout to encounter seaweed, plastic bags, or other sea debris that would get wrapped around the keel or propeller and impede Scout's travel through the water. Upon consideration and simulation of the issue, we found that programming Scout to motor backwards for a minute every few hours would free most debris from the keel and propeller.

3.7: Methodology Analysis

Scout sent 2,285 transmissions from its launch on August 23, 2013 to its disappearance 76 days later on November 6, 2013. During the mission, some values transmitted from Scout appeared to be errant, and suspected onboard software issues would occasionally stop the reporting altogether. Because of timeline restrictions, several diagnostic data fields that were planned to be implemented in the system were stripped from the final code because they hadn't been fully tested before launch; this data could have been useful in understanding the failures of the onboard systems.

Although some of the data received from Scout was corrupted or otherwise unusable, we did collect a significant amount of data that can be studied to learn more about what Scout experienced on her trip. Analysis of this data can certainly help improve the design of future Scout platforms and provide a basis for future research.

3.7.1: Voltage

Scout was fitted with a voltage sensor connected to the motor battery. The power distribution system was designed to charge this battery to a maximum of 13.8VDC and allow it to discharge to around 10 volts at night, at which time the system would shut down the motor until the battery could be recharged the next day. As Scout's hull is a displacement hull, it takes an exponentially higher amount of power for it to move faster; slower speeds are significantly more efficient. An optimal speed would be one that would keep Scout moving forward around the clock.

As there were no electrical current sensors in the system, we can study the voltage of Scout's motor power bus to gain a basic understanding of how Scout was handling power.

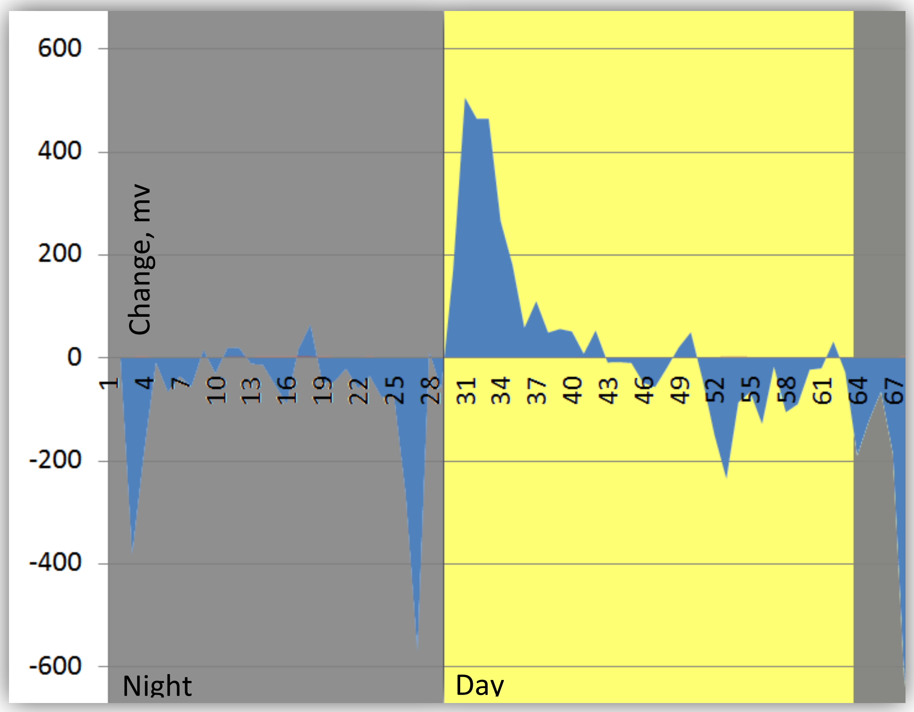


Figure 9: Selected Scout voltage changes

Figure 9 depicts the change of the voltage of the main power bus on Scout. Change on the Y axis indicates a rise or fall in motor system voltage over a 20 minute period. Figure 6 shows that in this case, the battery was discharged during the night (gray: packet 1-30) and started to charge around packet 30 (yellow: 9:13am EST.) The voltage then increased rapidly from packets 31 to 35, and leveled off over the afternoon. We can see that at a certain point in the afternoon (around packet 52) the power coming in from the solar panels wasn't enough to maintain the bus voltage so it began to slowly dip, and at packet 64 (7pm) the solar panels weren't providing any power which is indicated by a significant dip in the system voltage. This graph can be thought of as motor use trying to push down and the solar power pushing up; at night the motor will win and deplete the power reserves, and during the day the values will move above the X axis as power is stored in the system.

Because Scout's batteries had a very flat charge/discharge curve, and because the voltage measured on the bus isn't an accurate battery status indicator, voltage data is limited in its usefulness. An ideal power management system would include current sensors to measure electrical current as it flows in and out of various system components. In this way, a more accurate map of power flow could be generated and studied. Figure 10 shows a colorized representation of Scout's system voltage over the first two days of its mission; green means that the battery was full or that the system was charging, yellow indicates that the system was discharging the battery, and orange indicates a low voltage situation.

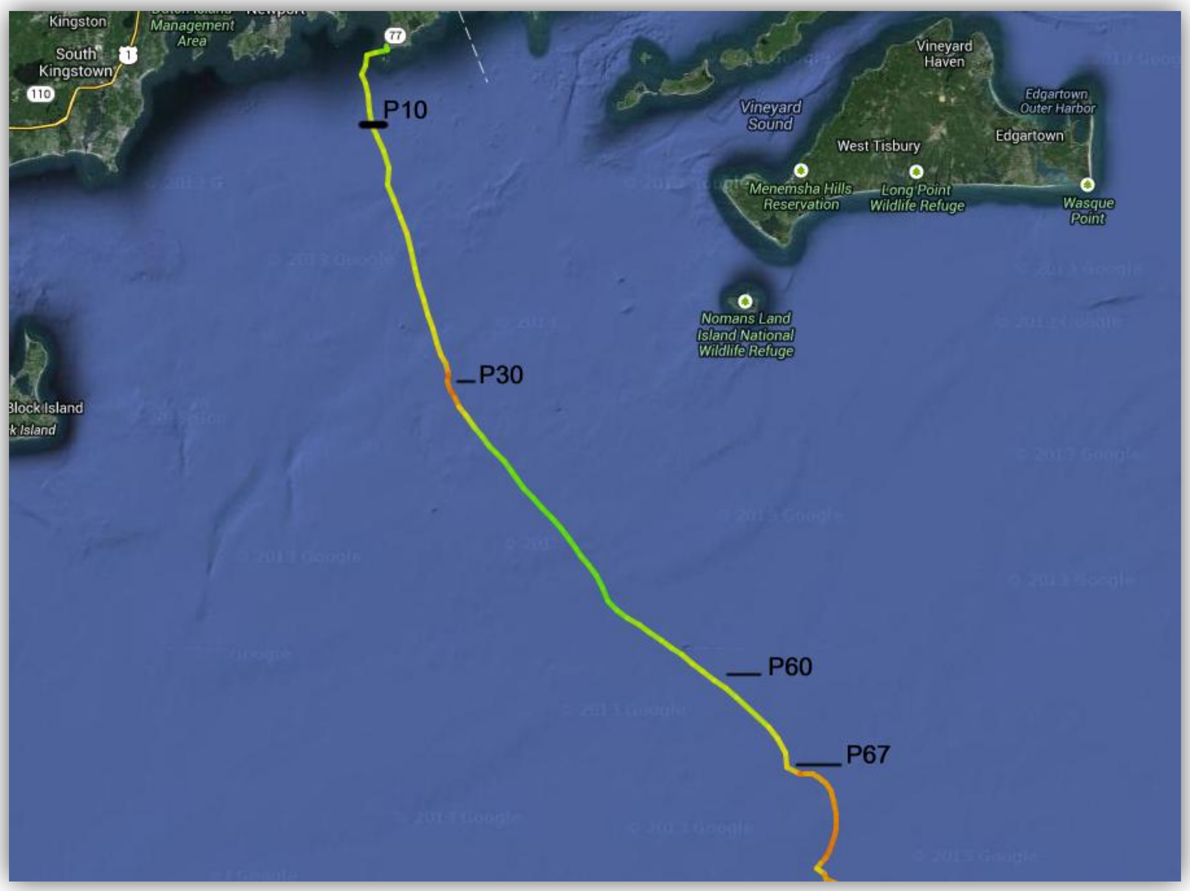


Figure 10: Colorized representation of system voltage

3.7.2: Scout's Speed

Scout was designed to travel for approximately 20 hours a day at around 2.5 nautical miles per hour (4.6 km/h). Scout's speed was measured by using the speed over ground as reported by the GPS, but this measurement style would often provide values that varied significantly between transmissions. For example, Scout's speed while surfing down a wave could be reported as 7 km/h, while the next measurement may be taken while Scout is climbing a wave at .5 km/h. Averages taken over longer periods of time smooth out these variations. While we did build a function into Scout's code to mitigate this issue by taking a speed measurement every minute, averaging twenty minutes' worth of measurements onboard, and sending the averaged speed back to shore, a programming error precluded this function from returning useful data.

To get a better idea of Scout's average speed, we can simply find the distance that Scout travels in a 60 minute period and map those values (distance/time.) If we average Scout's speed in this manner over the duration of the mission, we find that Scout averaged about 3.2 km/h. A visual representation of these different speed calculation methods is presented in figure 11.

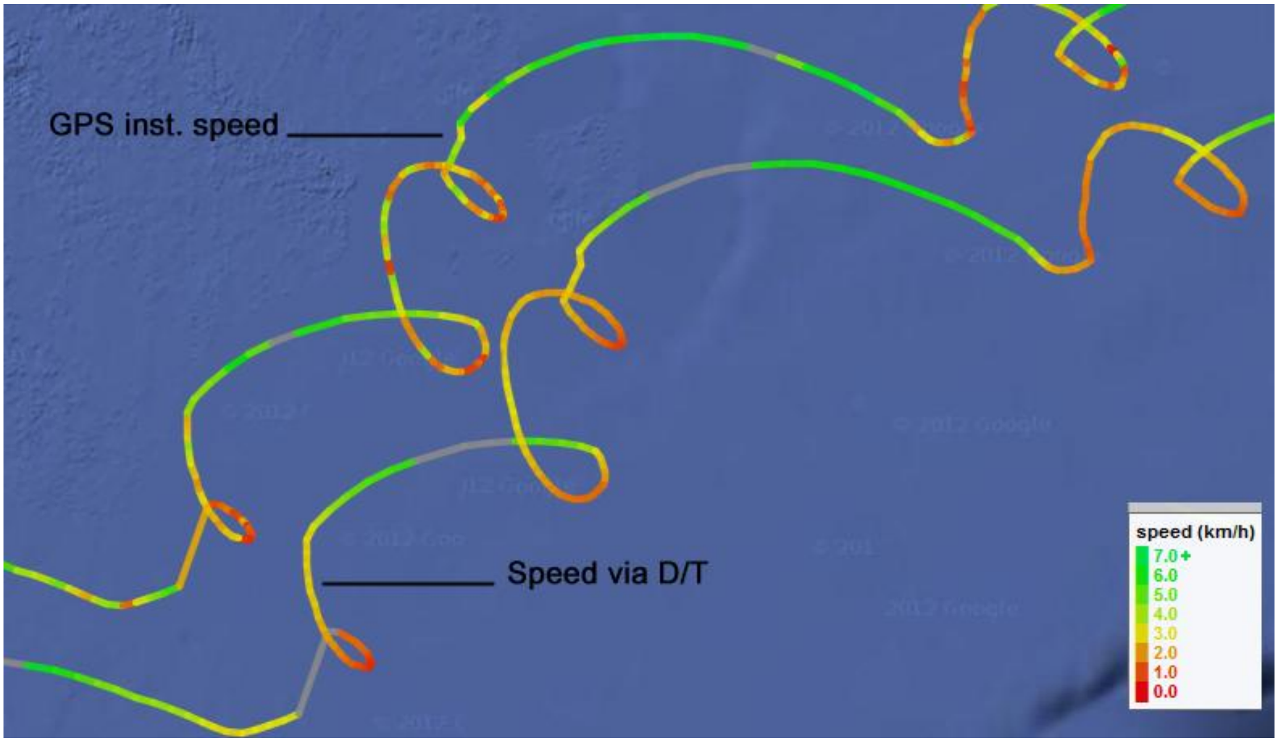


Figure 11: Scout's speed calculated by GPS and distance/time. Readings from the GPS vary more significantly than D/T measurements, probably due to the way GPS calculates speed.

To increase Scout's average speed in the future, considerations such as additional solar panels, a more efficient propeller, and better power handling systems may provide significant speed gains. Additionally, careful consideration of the normal running speed of Scout can make a significant difference in its overall average; displacement hulls are more efficient at slower speeds, so power is conserved if Scout runs at lower speeds for longer amounts of time.

Analysis of the data shows that Scout was “sleeping” for about 23 percent of the time that she was in the water; reducing her speed would also reduce the platform’s time in standby mode, which would increase the distance that she could have traveled with the same amount of power.

4: Results

The Scout Transatlantic attempt generated significant quantities of data that can be analyzed to better understand her performance. Significant amounts of unquantifiable data were also generated, as this was the first time that an autonomous boat had traveled more than sixty miles offshore. This information included the public's perception of autonomous long distance vessels, best practices for system design, project management strategy, and ideas for future development.

4.1: Launches

The Scout Transatlantic team launched Scout three times; the first two attempts ended in the near-shore retrieval of Scout, while the third attempt ended when the vessel's tracking units failed. The list of waypoints did not change between attempts.

4.1.1: The First Launch

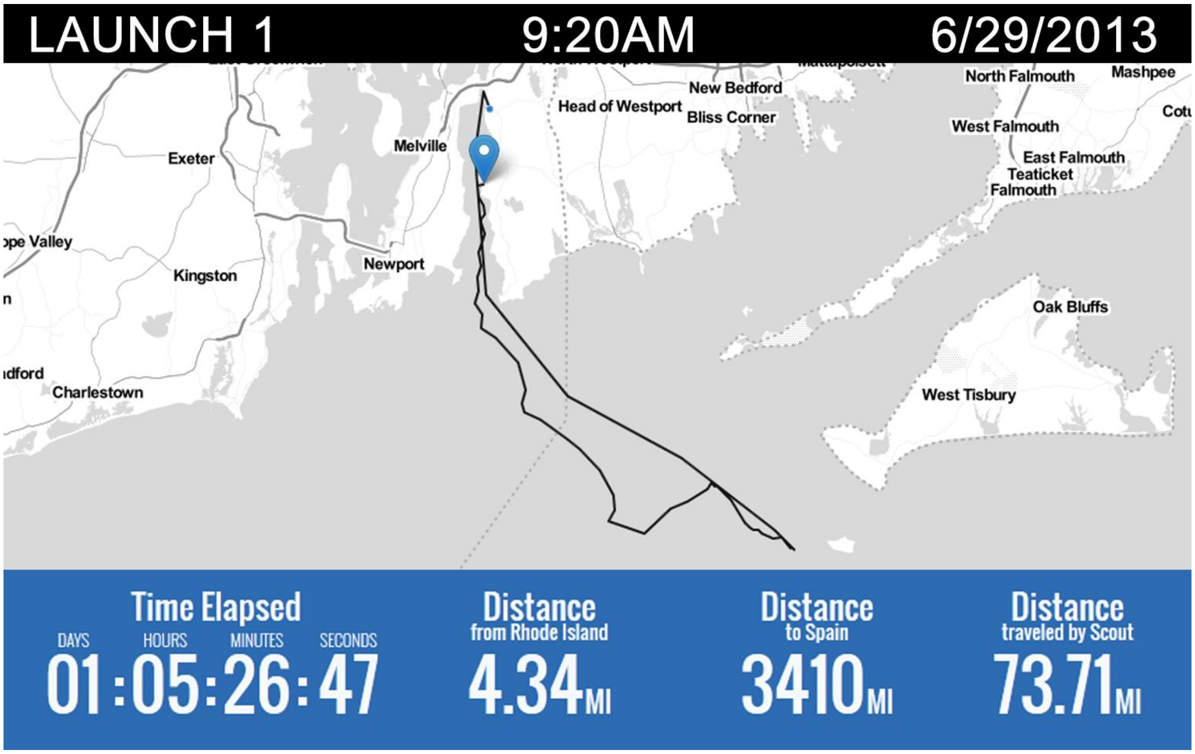


Figure 12: Scout's first launch track

Scout was first launched from Fogland Beach, Tiverton RI on June 29, 2013 at 9:20AM. Scout had been scheduled to be staged at the beach at 6AM that day, but the team was not prepared to launch at that time despite many team members having worked on the vessel for the 24 hours leading up to the event. This launch was designed to be attended by all Scout team members and publicized in advance to encourage media representatives and Scout supporters to attend. Figure 12 shows the actual track of Scout on this first mission.

The launch day events were streamed live to viewers via the Scout website and started with the sealing of Scout’s forward hatch, which was the access point for the battery charging system. This took place while breakfast was being grilled and boats were being staged off the shore of the beach. Other final preparations, such as group photographs and extending the opportunity for supporters to use markers to sign the hull, took about an hour. Once the vessel was ready to go, the five Scout Transatlantic team members walked the boat into the water where it was followed south by a small motorboat. When Scout reached the middle of the Sakonnet River, the small motorboat tasked with tracking Scout docked with a larger sailboat, *Astraea*, which took over tracking Scout. *Astraea* was to follow Scout about twenty nautical miles offshore to ensure her safe passage, but was forced to turn back shortly after nightfall after losing visual contact with the boat.

Due to significant fog and a poor forecast for the rest of the week, the Scout team recovered the boat after her second day at sea. Scout had run out of battery power and was floating in the direction of an uninhabited island; rather than risk the loss of the boat on the shores of the island, she was retrieved and brought back to the garage.

4.1.2: The Second Launch

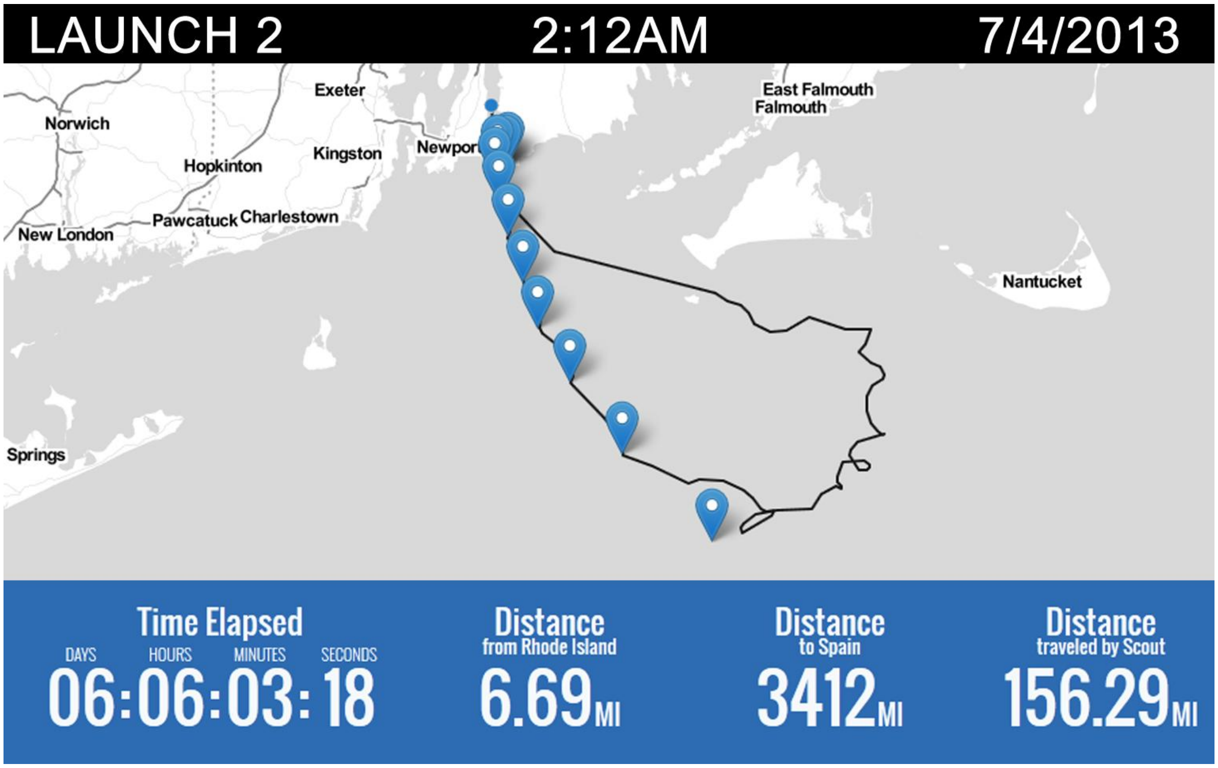


Figure 13: Scout's second launch track

After cleaning and recharging Scout, Max, Dylan, and Tom brought her to Sakonnet Point, Little Compton RI for the second launch on July 4, 2013 at 2:12AM. While the first launch had taken place during the day in order to allow for spectator and media attendance (and the specific date being chosen not by analysis of a weather window but by the availability of all 5 team members) a daytime launch was less efficient in regards to the optimization of the platform's power budget, and the particular day of Scout's first launch happened to be fraught with terrible weather. A midnight launch would allow Scout to use the power stored in her batteries for the first leg of her journey and start the morning with a nearly discharged battery pack. As Scout's solar panels generated more power than the motor used, this additional power would then be put back into the battery pack. If Scout had been launched during the morning with a full battery, the solar panels would generate more power than Scout could consume, and that extra power would be burned off as heat. Figure 13 shows Scout's actual track on this second launch attempt.

In stark contrast to the previous launch, the only attendees at this attempt were the three teammates. Max and Tom paddled Scout past the rocks that peppered the shoreline and returned with news that Scout had vanished into the night. After a short celebration, the first data packet came through the tracking system and showed Scout to be making excellent progress on the first leg of her journey. All three team members spent the night napping in twenty minute intervals, as a transmission was received from Scout three times per hour.

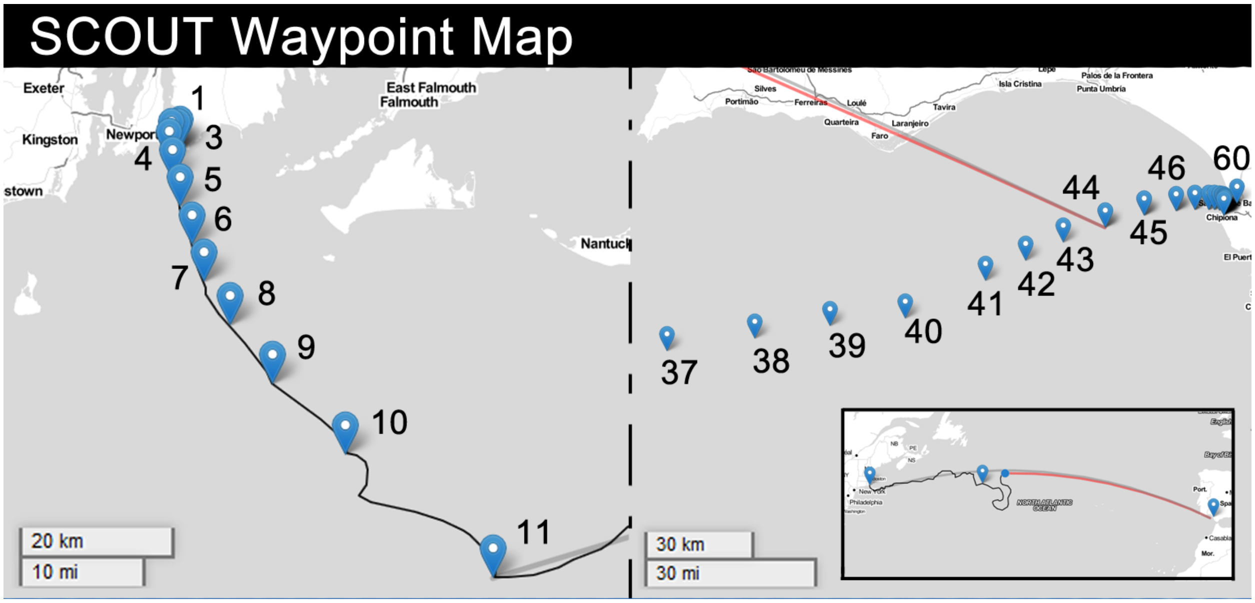


Figure 14: Map showing Scout waypoints

Scout experienced excellent weather during the first launch, and had no trouble hitting the first ten waypoints. Figure 14 shows the arrangement of the waypoints near Rhode Island and those near Spain. After satisfying the tenth waypoint, Scout started behaving erratically and reported in each data transmission that it was pointing in seemingly random directions. Her speed had slowed considerably, and although her voltage reports indicated that she was burning power, the lack of forward progress indicated to the Scout team that the boat was probably spinning in circles, either due to rudder failure or something getting wrapped around the keel. Max, Dylan, and several parents and neighbors mounted a second rescue mission, which was enabled by one generous Scout supporter who volunteered his motorboat for the rescue mission.

When Scout was retrieved from the second launch attempt, she was found with her rudder hard over, motoring in tight circles. The boat was pulled out of the water and transported back to the garage, where the rear compartment housing the rudder steering system was cut open. Upon inspection it was discovered that components in the rudder servo motor had overheated, either due to random failure or from the forces on the servo being too large.

4.1.3: Third Launch

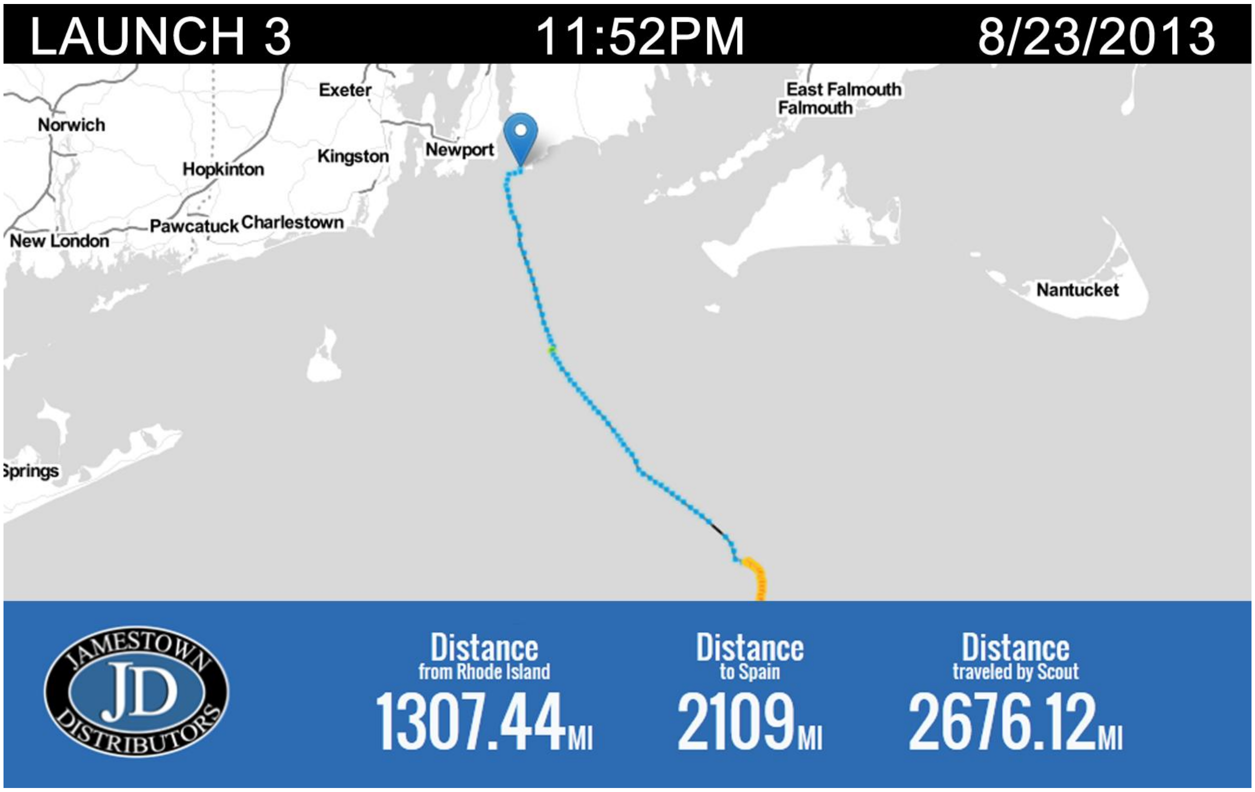
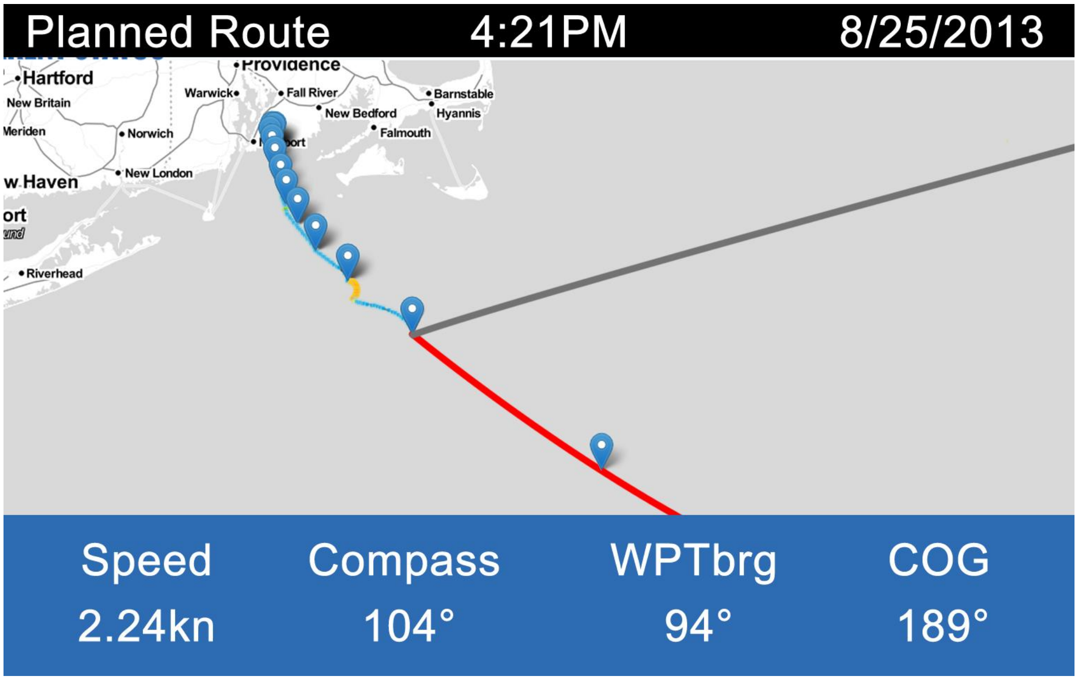


Figure 15: Scout's third launch track

After the failure of the second launch, the Scout team spent a month and a half testing servo motors and considering new designs for the steering system. A significant number of redesign options were discussed and considered, and the team decided to install a better quality servo of the same size and torque into the rudder control system. Optimal changes to the rudder system would have involved a complete redesign built around a worm gear drive system, but such an alteration would have required significant mechanical and software changes that the team didn't believe could be completed in time for another launch attempt that summer. The third launch took place at Sakonnet Point, which was the same site used for the second launch. On August 23, 2013 at 11:52PM, a crowd of supporters watched Max and

Tom swim Scout off the beach and into the night. The beginning of Scout's track for the third launch is displayed above in Figure 15.

Scout quickly surpassed her previous records, and due to an excellent weather window that the launch was planned around, she deviated from her intended path very little. The excellent progress would not last, however; on August 25 at 4:21PM Scout spun off to the east much more dramatically than had been planned. This change of course was the result of a bug in Scout's software that was designed to make sure that the boat would never try to navigate to a waypoint that was west of her position; this error meant that instead of taking a southerly route in the middle of the Gulf Stream current, she would navigate in a straight line between waypoint 11 and waypoint 37, the latter of which was about 2800 nautical miles away. This new course is displayed in figure 16.



Planned Route 4:21PM 8/25/2013

Speed 2.24kn

Compass 104°

WPTbrg 94°

COG 189°

Figure 16: Scout's planned route (red) and the new route calculated by Scout's computer (gray).

As Scout didn't transmit the waypoint it was seeking, at first it was anyone's guess where Scout's new course would take her. The software bug caused Scout's computer to skip a number of waypoints, but it wasn't possible to figure out how many were skipped by just reviewing the code. Transmissions from Scout, however, reported the bearing to the next waypoint. By loading Scout's code on a spare microcontroller and asking Scout what course she would set if she was at a particular position, I was able to triangulate the unknown waypoint. A visual representation of the math performed to identify the new target waypoint is shown in figure 17. Figure 18 shows the output of the microcontroller which identified the target waypoint.

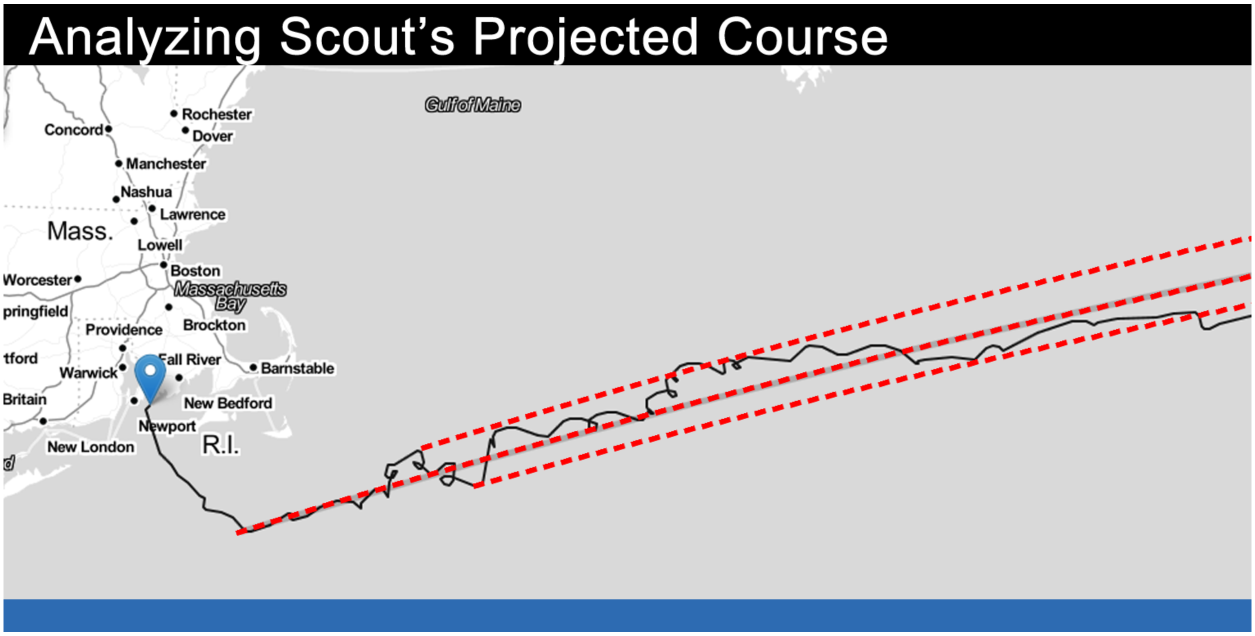
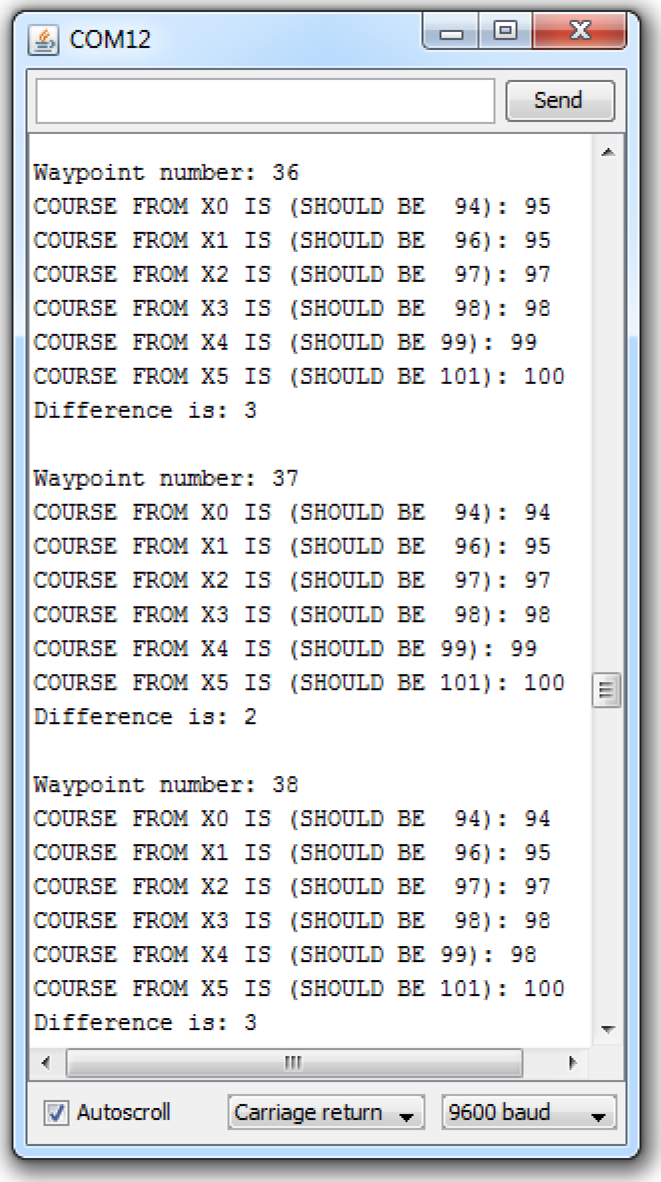

Analyzing Scout's Projected Course

Figure 17: With some manipulation, Scout's software returned what Scout's course would be from a number of different points on her track.

Scout's course change occurred only two days after the third launch in a series of unsuccessful transatlantic attempts; it was widely believed by the public that Scout was disabled or spinning in circles once again, and many thought that this launch would end in yet another rescue attempt. By calculating the waypoint that Scout was headed towards, we were able to confirm to Scout followers that the boat wasn't motoring in a random direction, that it wasn't damaged in any way, and that although the project had shaken free of our grasp, we still understood what it was doing and why it was behaving so.



```
Waypoint number: 36
COURSE FROM X0 IS (SHOULD BE  94): 95
COURSE FROM X1 IS (SHOULD BE  96): 95
COURSE FROM X2 IS (SHOULD BE  97): 97
COURSE FROM X3 IS (SHOULD BE  98): 98
COURSE FROM X4 IS (SHOULD BE 99): 99
COURSE FROM X5 IS (SHOULD BE 101): 100
Difference is: 3

Waypoint number: 37
COURSE FROM X0 IS (SHOULD BE  94): 94
COURSE FROM X1 IS (SHOULD BE  96): 95
COURSE FROM X2 IS (SHOULD BE  97): 97
COURSE FROM X3 IS (SHOULD BE  98): 98
COURSE FROM X4 IS (SHOULD BE 99): 99
COURSE FROM X5 IS (SHOULD BE 101): 100
Difference is: 2

Waypoint number: 38
COURSE FROM X0 IS (SHOULD BE  94): 94
COURSE FROM X1 IS (SHOULD BE  96): 95
COURSE FROM X2 IS (SHOULD BE  97): 97
COURSE FROM X3 IS (SHOULD BE  98): 98
COURSE FROM X4 IS (SHOULD BE 99): 98
COURSE FROM X5 IS (SHOULD BE 101): 100
Difference is: 3
```

Figure 18: X0 through X5 are GPS coordinates selected from Scout's track; the software runs each set of coordinates through the navigation algorithms as if Scout is navigating to that waypoint.

Managing the project's public side would become a significant endeavor; once followers began to accumulate, the team found that it took significantly more time to update the website, Twitter account, and Facebook group than it had imagined. In cases like the skipping of the waypoints, quickly updating followers became an important part of following Scout's travels. As seen in figure 19, most updates directly addressed the project's audience and were designed to be understood by the average curious onlooker.

Scout- The Autonomous Transatlantic Robot
August 26

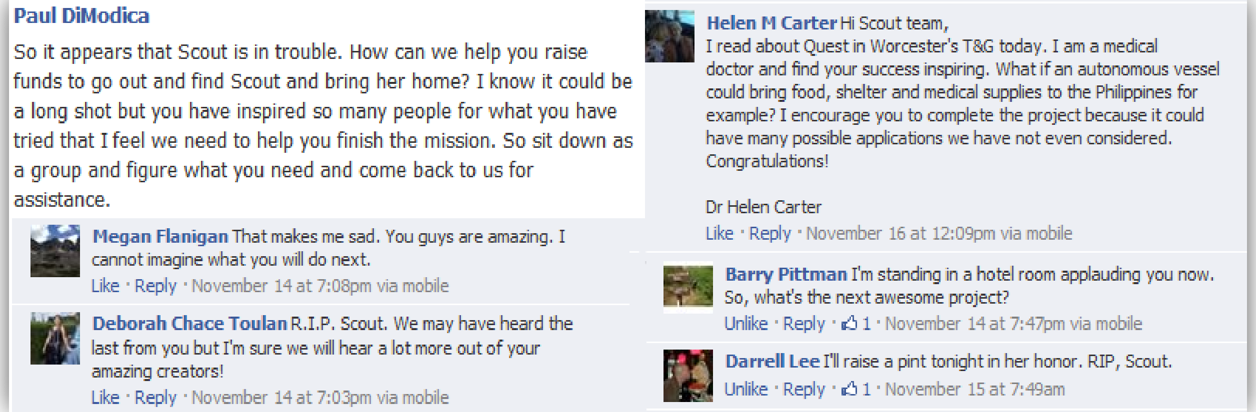
SCOUT Navigation Update-
Many of you have noticed Scout's new course which will bring her far north of waypoint 012 which should have been Scout's next target. If you look at the tracking page, you will see the 'waypoint' direction indicator which displays data sent from Scout to us; this field shows what course Scout wants to navigate. Right now, the arrow on that display seems to be pointed righ... See More

Figure 19: The Facebook post informing followers of Scout's unplanned course alteration

After Scout's course change, she traveled about 850 nautical miles without significant incident. On September 28, however, Scout stopped sending transmissions from her primary satellite transceiver. The backup tracker, activated three days later, indicated that Scout was no longer navigating under her own power and was instead simply floating in the ocean. Although Scout made about 250 nautical miles of progress towards Spain during this period of floating, this progress was simply because of favorable winds and currents. Thirty nine days after the primary tracker went offline, the secondary tracker followed, and Scout was lost at sea.

4.1.4: After Scout Disappeared

By the time that Scout's backup tracker went offline, the tracking website had been loaded 760,000 times by 61,000 unique visitors, and the average visit duration was more than fifty minutes. Thousands of people had followed the project from start to finish, and thousands more were referred by friends or news media. As can be seen in figure 20, even after the boat was lost the team continued to respond to inquiries by news organizations and well-wishing followers.



Paul DiModica
So it appears that Scout is in trouble. How can we help you raise funds to go out and find Scout and bring her home? I know it could be a long shot but you have inspired so many people for what you have tried that I feel we need to help you finish the mission. So sit down as a group and figure what you need and come back to us for assistance.

Megan Flanigan That makes me sad. You guys are amazing. I cannot imagine what you will do next.
Like · Reply · November 14 at 7:08pm via mobile

Deborah Chace Toulan R.I.P. Scout. We may have heard the last from you but I'm sure we will hear a lot more out of your amazing creators!
Like · Reply · November 14 at 7:03pm via mobile

Helen M Carter Hi Scout team,
I read about Quest in Worcester's T&G today. I am a medical doctor and find your success inspiring. What if an autonomous vessel could bring food, shelter and medical supplies to the Philippines for example? I encourage you to complete the project because it could have many possible applications we have not even considered. Congratulations!

Dr Helen Carter
Like · Reply · November 16 at 12:09pm via mobile

Barry Pittman I'm standing in a hotel room applauding you now. So, what's the next awesome project?
Unlike · Reply · 👍 1 · November 14 at 7:47pm via mobile

Darrell Lee I'll raise a pint tonight in her honor. RIP, Scout.
Unlike · Reply · 👍 1 · November 15 at 7:49am

Figure 20: Messages from Scout followers

While many of these messages were from curious recreational followers from around the world, the team received several notes from people intrigued by the potential uses of a product like Scout. These suggestions ranged from shipping goods across oceans to environmental applications and transporting food and supplies to areas affected by natural disasters. While we had only considered the use of a Scout-like platform for environmental research, it was intriguing to see the variety of potential uses for vessels like Scout that our audience came up with.

4.2: Analysis of Scout's Transatlantic Attempt

As Scout's navigation relied only on preprogrammed commands and information that it could gather from its sensors, the systems that we developed and implemented on the platform had direct and measurable effects on Scout's progress. Metrics that we can use to determine the successes and failures of particular systems include cross track error (XTE), deviation from Scout's target speed, and navigation system inaccuracies.

4.2.1: Cross Track Error

Cross track error, often abbreviated as XTE, is the distance of a vessel from the shortest path between two points. In Scout's case, XTE represents the distance of Scout from the invisible line connecting the waypoint most recently satisfied by Scout and the next waypoint that Scout wants to satisfy. In marine navigation, cross track error is used as a metric of deviation from the mathematically ideal path that the vessel should take. Minimizing XTE was not a specific focus of the Scout project, as reducing XTE has the consequence of increasing the power consumed per mile traveled (if Scout was programmed to try to stay as close to the imaginary line connecting two waypoints as possible, it would consume a significant amount of power in its efforts to counteract intermittent forces acting upon it, such as wind and current.) As Scout's mission was to cross the Atlantic, we programmed Scout to have a high tolerance for XTE while keeping potential obstacles in mind (our intention was to keep Scout clear of all landmasses while allowing her to drift north and south with the tides and wind; in this way, as much of Scout's scarce power resources as possible would be committed to moving her east. By programming Scout to increase the magnitude of her rudder correction based on Scout's deviation from her ideal course, we attempted to control the cross track error. This software module went largely untested, as even in our supervised 45 mile test mission there was not enough distance between waypoints to properly simulate Scout's tolerance for XTE.

4.2.1.1: Cross Track Error: What Actually Happened

As Scout's XTE allowance was designed to depend solely on the distance between the waypoint previously satisfied and the next waypoint to be satisfied, waypoint distances were the primary means of varying the XTE allowance along Scout's mission. Scout's XTE between each of the first ten waypoints satisfied was minimal; Scout was often less than one nautical mile away from her ideal course. As the first eleven waypoints were close to shore (less than 40 nautical miles away) the waypoints were plotted less than ten nautical miles apart from each other. Once Scout left the US economic exclusive zone (territory extending 200 miles from shore) the navigational waypoints were positioned about 200 nautical miles apart, in order to allow for a significant north/south drift. The effects of these more widely spaced waypoints, however, were unable to be assessed due to the waypoint bypass error described earlier, as Scout only navigated to waypoint 11 before bypassing more than 20 mid-ocean waypoints and setting a course for waypoint 37, which was less than one hundred miles from Spain.

Because waypoint 37 was more than two thousand miles away, the Scout Transatlantic team immediately became concerned that Scout would calculate a high tolerance for cross track error and allow a collision with the Canadian coast. Another effect of the waypoint bypass error was the potential for collision with Portugal, as the calculated course to waypoint 37 cut through the middle of the country. Jörg Dietrich, a research scientist at University Observatory Munich and enthusiastic Scout supporter, created and published an auto-updating image (included here as figure 19) on his website that indicated Scout's cross track error in respect to the straight-line course between waypoint 11 and waypoint 37.

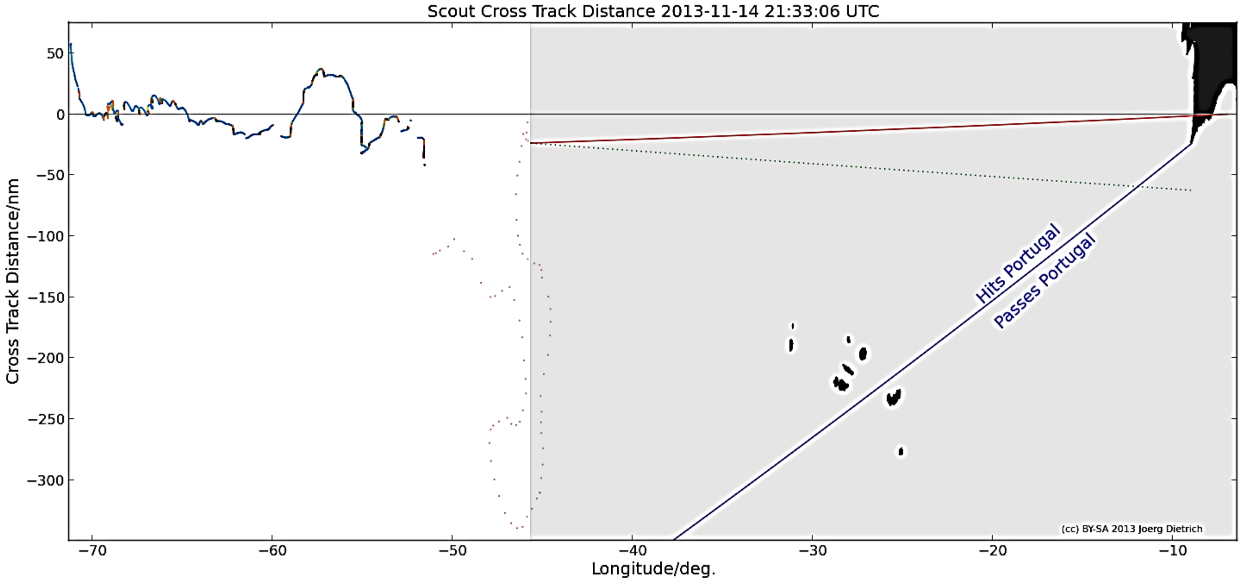


Figure 21: Scout's cross track error distance. XTE = 0 plotted in gray, current bearing plotted in red (Dietrich.)

As indicated by Dietrich's image, Scout maintained a cross track error of around 50 nautical miles or less for the duration of its powered travel. An interesting side effect of Scout's navigation system going offline is an opportunity to see what type of XTE could have been expected from Scout if it disregarded XTE control completely. In the figure above, the segment of Scout's mission traveled under power is indicated by a solid line; the dotted path that begins at -50 degrees of longitude shows Scout as she drifts at the mercy of the wind, waves, and currents. It is obvious that Scout's track deviation was much higher in her unpowered state than it was during the powered component of her journey; the maximum XTE while Scout was navigating under power was about 300 nautical miles less than its maximum XTE when it was floating. Based on this data, we can assume that, had Scout's navigation system remained online and barring any other influences, Scout would have maintained a cross track error of sixty miles or less for the duration of its trip to Spain.

In the graphic above, the gray and red lines are set to converge on waypoint 44, which was the waypoint that the Scout team initially stated was Scout's target following the auto incrementation software error. After the aforementioned calculations were performed, waypoint 37 was confirmed to be Scout's target and is indicated in Dietrich's graphic as a gray dashed line. It is likely that, if the graphic were corrected with this new data, the calculated XTE would be smaller than reported in the graphic's current state.

4.2.2: Speed and Efficiency

All displacement hulls have a "hull speed" which is a mathematically calculable speed, which is the approximate speed at which the hull can travel before becoming trapped in the trough behind the wave created in front of the boat as it moves through the water. For Scout, Max calculated the hull speed to be approximately 4.8 nautical miles per hour. This speed, however, does not represent the most efficient speed for Scout to travel at, which is an important consideration for a mission as long as Scout's transatlantic attempt.

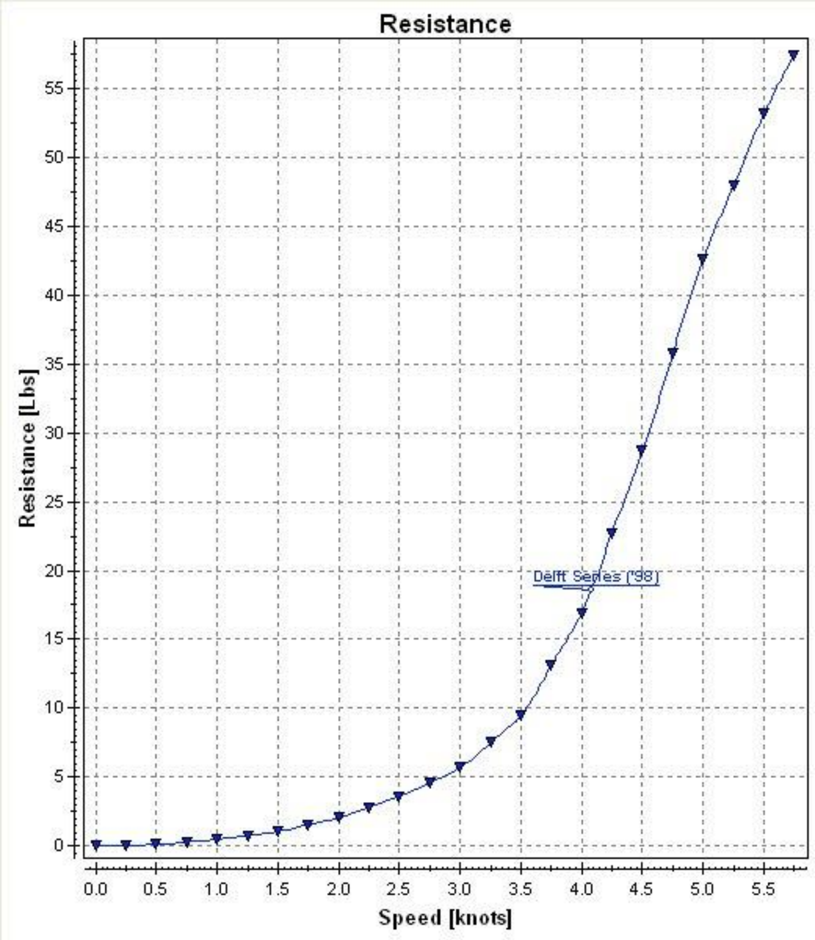


Figure 22: A graph demonstrating the relationship between speed of a hull and the resistance on that hull (Watkins).

Figure 18 demonstrates the relationship between speed and resistance; although this graph was not designed for the Scout project, the values are likely similar (Scout was 13 feet in length, while this graph reflects values for a 9 foot long hull.) As travel at high speeds requires a significantly higher power expenditure to speed ratio, Max selected a relatively low cruising speed of approximately 2.5 knots for Scout to maintain during her attempt. This figure was supported by the power budget calculations that I performed, which involved estimations of daily power intake, standard conversion and battery charging related losses, and power output to speed ratios supplied by Max. While relatively simple, these calculations were time consuming as extensive testing (particularly concerning the power losses experienced between the panels, batteries, and motor) was performed to minimize the errors in the calculations.

While performing these calculations, we found that a cruising speed of 2.5 knots was slightly higher than what Scout's system could sustain, but the relatively small amount of onboard power storage (constrained by our budget) meant that on particularly sunny days, if Scout was traveling at speeds below 2.5 knots, more power would be collected than would be consumed by the boat's systems. In this case, once the batteries were fully charged, any additional power would be burned off as heat and wasted. In order to use all of the power that Scout would collect even on long, particularly sunny days, we set Scout's cruising speed to a speed that was greater than the system could support on an average day.

4.2.3: Navigation System Inaccuracies

As Scout made all course calculations on an onboard ATmega2560 processor, and because the navigation system did not have to produce extremely accurate or precise courses, a number of assumptions were made in the construction of the navigation functions used to set Scout's course.

4.2.3.1: Hardware Constraints

The ATmega2560 processor used by Scout had 256KB of flash memory, 8KB of SRAM, and operated at 16MHz. As this processor was in charge of collecting GPS, compass, and environmental sensor data, controlling motor speed and rudder angle, and determining what course Scout should follow, the team sought to minimize the processing requirements of each module. The GPS position data, for example, was only checked once every few minutes, as there was no need for Scout to receive exceedingly frequent position updates. Environmental sensor polling was offloaded to a secondary processor that handled the collection and packetization of that data, and functions developed specifically for use during the testing phases of the project were removed altogether.

4.2.3.2: Software Constraints

Because Scout's course to the next waypoint was recalculated several times per minute, integer math (faster than the more accurate floating point math) was used wherever possible. In addition, we used a spherical model of Earth, instead of the more accurate but processor intensive ellipsoid model, as the additional accuracy of the ellipsoid model wouldn't contribute to improving Scout's navigational performance (Scout's compass is only accurate to several degrees, so there is no need for any function to return navigation data more precise than one or two degrees.)

4.2.4: Navigation and Communication System Failure: Public Management

After Scout's backup tracking system failed on November 6th, the Scout team decided to wait for a week before updating Scout's website with a message stating that Scout was lost at sea. The full update is attached as appendix i. Although the termination of the project was announced on November 14th, the Scout team committed to paying for another three months of data service for both tracking units in case either unit came back online.

4.3: The Media: Publicity for Scout

When the Scout project began in 2010, it was supposed to be a simple venture that would take three or so weeks to build and launch. As the project progressed, numerous prototypes and rounds of testing consumed thousands of man hours of labor. While interaction with the media was rare in the early stages of the project, by early summer of 2013 the media coverage of the Scout project began to accelerate at a dramatic pace. While the first news articles appeared strictly in local newspapers that had known of the project for years, it was those articles that prompted larger publications to look into the Scout project and contact the team. As the project gained momentum in the press, Scout team members would periodically leave work or take days off to interview with newspapers, online news sources, and television stations, often taking reporters on boat rides during testing or on tours of the Scout garage workshop. Over the duration of the Scout project, GoTransat.com was loaded more than 750,000 times. The following are some examples of some of the publicity the project received during the third launch. Links to all media pieces are in appendix II.

4.3.1: NPR: A Day in the life of Scout

One reporter, named Dave Schneider, drove from New York to Tiverton, Rhode Island to spend two days covering the final preparations leading up to the final launch at the end of August. Dave had an extensive background in technology and was reporting for both IEEE Spectrum magazine and National Public Radio, so the Scout team tremendously enjoyed Dave’s continued presence in the workshop as he was able to get a better understanding of the team’s work processes than other reporters that had spent shorter amounts of time in the project environment. The unique component of the Scout project that Dave focused on was the nature of the Scout team and the story of how five college students were able to work together to produce an autonomous surface vessel that could have far reaching applications if developed further in the future. Dave not only saw programming, composite work, and troubleshooting, but was also able to witness underlying components of the project missed by other reporters, including rapid prototyping, whiteboarding sessions, meal preparation, last-minute software modifications, and driveway repair, all of which contributed to his familiarity with the team and his understanding of team roles and relationships. Included in Dave's interviews was a member of the "Girl Scouts," an anti-Scout group comprised of girlfriends, sisters, and neighborhood friends who lovingly opposed the project due to the amount of time that the Scout team spent isolated in the garage. Dave seemed to particularly enjoy the Girl Scouts' point of view, especially the humorous website that reflected the group's opinion of the project. By spending such a long time with the Scout crew, by understanding the motivations and culture of the team, and by attending a launch event in person, Dave was able to produce the most comprehensive radio segment and print article that covered the project to date.

4.3.2: WPI: The Daily Herd

Upon return to WPI, I was contacted by Jim Wolken, who oversees the production of WPI's Daily Herd. Jim thought that fellow students, staff, and faculty might enjoy an article published on the Daily Herd website, which is a page maintained by WPI as a news and informational resource for its community members. Jim and I met to discuss the project, and he published an article titled "World Record Set!" on September 5th at which point Scout was 300 miles out to sea. Jim had planned to run subsequent stories as Scout made its way further across the ocean, but Scout failed before the next article was penned. The Daily Herd article is available in Appendix ii: Media Links.

4.3.3: MAKE Magazine

MAKE Magazine is a favorite of hobbyists, DIY geeks, and engineers worldwide. Andrew Terranova, a writer for MAKE, contacted the Scout crew in late August to interview some of the team members for an article that he was writing for MAKE. Andrew's article, titled "Transatlantic Drone Takes to the Sea", was an excellent recap of the project from start to finish and covered many components of the project in great detail. The article was viewed by a large audience on MAKE's website, and drove more than 7,000 visitors to the Scout tracking page.

After Scout's failure, Andrew contacted us again to discuss what had happened to the boat and how we were feeling about the project at that point in time. This second article, titled "Scout Transatlantic: When is a Failure not a Failure?" was an excellent reflection of the team's attitude towards the failure of the project, and offered followers great insight in regards to the team's future plans and ambitions. Perhaps most importantly, when Andrew and I were talking on the phone, he asked me why we built Scout. My immediate answer was "we found through this project that we love capturing peoples' imaginations with creative engineering", and although it did take years of work, the Scout project showed us that creative engineering can certainly capture peoples' imaginations. Both MAKE Magazine articles are available in Appendix ii: Media Links.

5: Discussion, Recommendations, and Implications

The Scout project served its intended purpose as a fun way to inspire people through creative engineering. Along the way, all team members learned a tremendous amount about engineering, teamwork, friendship, and project management. The media identified this as well; MAKE Magazine published an article in the months that followed Scout's disappearance and titled it *“Scout Transatlantic: When is a Failure not a Failure?”* A consistent theme in articles published after Scout’s failure was the fact that although Scout was gone, the failure of the project opened more doors than it closed.

In regards to the impact of the Scout project on other ASV development, the Scout team continues to receive inquiries about the project via email, telephone, and Facebook. In some cases, the person sending the message is a middle school student, a fellow college student, or an older fellow who is simply curious about some of the particulars of the Scout project. Others get in touch to ask technical questions in hopes of building their own autonomous boat for fun, and the occasional message will be some type of request for custom ASV development. While none of those encounters have yet produced a marketable product, the market for autonomous surface vessels is growing, and the fact that engineers with decades of experience in their field will get in touch with some college kids, hoping that they can offer him assistance with his or her project, serves to illustrate the unique nature and infancy of the ASV market.

5.1: Recommendations

Although the Scout project was designed to be a fun venture with limited practical potential, a significant amount of knowledge regarding the construction of autonomous surface vessels was realized over the duration of the Scout project. Especially exciting are the potential contributions that the Scout project can make to the development and implementation of autonomous surface vehicles in marine research applications.

Members of the Scout team have already begun designing a next generation platform designed to collect research data autonomously. Although still under development, this platform would address a number of weaknesses and potential areas of improvement identified by the Scout project. These areas of improvement are outlined below in the form of a next generation platform based on the Scout project. This Scout Recon platform is just one hypothetical implementation of some lessons learned from the Scout project. Figure 21 shows the Scout Recon form factor, which includes additional solar panels, navigation lights, a mast for radio, satellite, and sensors, and a new two-hull design.

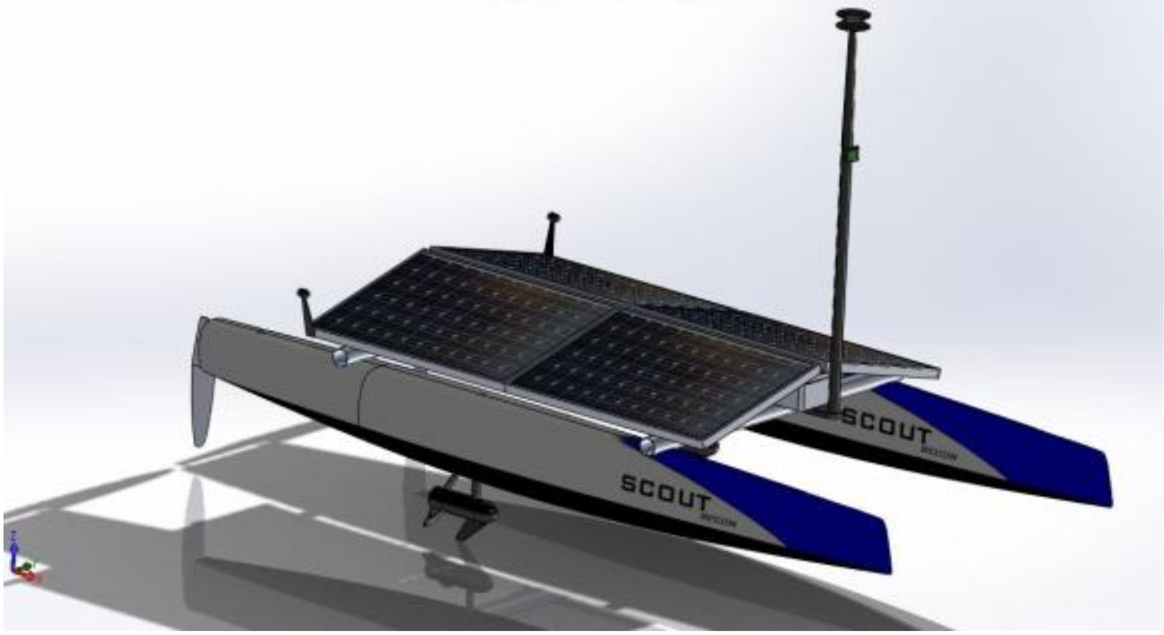


Figure 23- A theoretical next generation Scout Recon platform

5.1.1: Power Management

Scout's systems were not designed to change the speed of the motors based on the amount of power available to the boat. This is an important improvement that would be easy to add in a next generation platform. By identifying the amount of charge that is in the batteries, the amount of current that is coming from the solar panels, and the current speed of the platform, a next generation ASV could more use power more efficiently and travel further per unit of absorbed power. Predictive power systems could go even further and anticipate future power inflows, adjusting motor speed accordingly. Efficiency gained by improved power handling systems would only increase as more solar panels are added to the system (the above Scout Recon platform is one meter shorter than the unit used for the transatlantic attempt and carries twice as many solar panels. Max's calculations, using the same course and sunlight data from the Scout Transatlantic attempt, approximate Scout Recon's average speed at 7.7 km/hr, compared to Scout Transatlantic's average speed of 3.1 km/hr. Some of these gains are a result of the higher efficiencies produced by an improved power control system.)

As the Scout project focused on crossing the Atlantic at a low financial cost, we sought to simplify the power control systems as much as possible, even though we sacrificed some functionality to do so. We also did not transmit detailed power flow information to shore. With further development, reliable power control systems could easily be implemented, and two way communications between shore and the platform would optimally allow for archived power flow data to be transmitted to the shore station on request.

For the Scout project, we selected LiFePO4 batteries to store power collected by the solar panels. Although LiFePO4 batteries are durable, do not easily burst into flame like their lithium ion counterparts, and work with standard lead acid battery chargers, these batteries have a very flat voltage discharge curve. This curve means that even if a voltage sensor is connected to the battery, it is difficult to gauge the battery status from that voltage data. As identifying the charge status of the battery would be necessary for advanced power system control, a battery with a steeper discharge curve would be a necessary component of the next generation power system.

Other improvements to the power handling systems would include optimized solar charge controllers, current sensors on all relevant buses, and programming designed to maintain the most efficient speed of travel while considering battery status, time of day, predicted power capture for the rest of the day, and overall navigation status.

5.1.2: Tracking and Communications

A system to display and receive data from an ASV is one of the more visible and important components of the project. The specifics of an ASV tracking system depend on the particular mission and platform at hand.

The Scout tracking system was programmed by Ryan Muller and Tom Schindler, with a significant amount of it completed in a heroic 24 hour push made the day of the first launch. While the Scout tracker was a great success, having been loaded over 700,000 times across all three launches, improvements were constantly being made over the course of the project. For example, weather layers were added to the map, the color of data points was changed to reflect the power state of Scout at that point, and the total number of points visible to viewers was reduced once page load times began to increase.

In an improved tracking system, additional layers such as ocean currents, cloud cover, and wind speed and direction would be available, regardless of the ASV's purpose. More specific improvements, such as power profile graphs, waypoint alteration functionality, or two way communication support, would depend on the specific ASV.

A related area for potential improvement is the transmissions sent by Scout to shore. Scout's data packets were cost constrained; the team designed the data transmission packets to be heavily compressed and carry as few fields as possible. A production unit should be designed to efficiently package and transmit all of the relevant collected data to the client. Because two-way communication wasn’t permitted on the Scout Transatlantic attempt (if the team contacted Scout from shore, the platform would no longer be fully autonomous) a number of useful functions were not built into the software. A Scout Recon vessel wouldn’t be constrained by the requirement to be fully autonomous, so with this platform waypoints could be changed while the mission is underway, transmission intervals could be altered, sensors could be enabled or disabled, onboard settings could be changed, or the unit could be called home prematurely. With proper development and testing, such functions could create significant value to potential clients.

5.1.3: Construction

The physical construction of a Scout Recon unit would be different from the Scout Transatlantic construction in that fiberglass would be used instead of carbon fiber, molds would be constructed in order to simplify and accelerate the process of building the hulls, and the overall form factor would be a catamaran instead of a monohull.

Although carbon fiber is the best material available for construction of this type of vessel due to its strength and lightness, it is expensive and can be easily replaced with fiberglass, which is cheaper, weaker, and heavier. The difference between carbon and fiberglass construction of a Scout Recon vessel would be about eight pounds. Although eight pounds is a relatively large percentage of the 150lb estimated weight of the vessel, it is not much in regards to absolute weight, and can be offset by using carbon fiber in areas where the additional strength it provides outweighs the cost difference.

A Scout Recon platform would be built using machined hull molds. These molds would allow the rapid production of a number of identical hulls, and would considerably cut down on the amount of labor that would need to be invested in each hull. This type of production also allows complex features to be built right into the mold, instead of having to be crafted and integrated at a later point in time. Construction using molds also reduces the amount of fiberglass and epoxy resin that need to be used in construction, which reduces weight and construction cost.

The Scout Transatlantic craft was designed to be a monohull, as the Atlantic is home to huge seas, wild storms, and other conditions that could cause the boat to capsize. A lead bulb mounted on a solid carbon keel was designed to right the boat if it flipped over. Although a catamaran doesn’t have this self-righting capability, Scout Recon units are designed for use in regions with relatively calm seas. The significant advantage to the catamaran form factor is that overall length can be reduced by one meter while solar panel surface area can be doubled. These advantages made a catamaran the right choice for near-shore operations; offshore operations taking place in particularly windy or wavy seas would be best performed by an ASV with a self-righting mechanism, such as the Scout Transatlantic vessel.

5.1.4: Implications for Researchers

Autonomous surface vehicles have tremendous potential as tools for research. While different research projects may require ASVs with different capabilities, a standardized vessel designed with modularity in mind may be able to be of use to researchers who could benefit from data that the platform can collect. The Scout project is one of the first publically visible projects that made data collected from an ASV available to the public. Of course, none of the data collected by Scout was of particular value to any scientist or researcher, but the user-friendly graphical interface of the tracking system, the level of participation that the public had in the project, and potential for future generations of similar ASVs may be encouraging to those hoping to pursue researchers and scientists as potential data-by-ASV clients.

5.1.5: Implications for Practitioners

Although a detailed study of ASV applicability in practical applications is beyond the scope of this evaluation, improvements to the capabilities of ASVs in general could revolutionize the marketability and adoption rate of those platforms. The development and release of ASV navigation standards by the US Coast Guard and other agencies that regulate US waterways would serve to assure developers and manufacturers of ASVs that their platforms wouldn't be put on the market only to be deemed illegal by legislation that is enacted months later. Development of industry standards could help ASV developers build systems that are compatible with each other, which could allow for ASVs to be loaned between organizations, rented, or easily expanded while growing the market for ASV parts and modules. Basic improvements, such as standardization of modules and connectors, could reduce the proprietarity of the market today, as there are no ASV industry standards that can be referenced and considered by manufacturers.

ASV Application	Example	Recommendations
Mission Specific	Radio repeater Buoy substitute Oil boom towing Defense	-Design specific to the task (could include modularity requirements, large batteries or onboard generator for applications that require large amounts of power, cameras, specialty radio gear, etc.) -Custom programming/ database to enable desired functionality
Data Collection	Oil spill mapping pH Salinity Environmental data etc.	-Capacity for long distance missions -Flexibility for different sensor modules -Onboard data storage -Possible water sample collection apparatus -Database designed to receive and store large amounts of data -Other recommendations depending on type of data collected

Table 1: Recommendation matrix for mission specific and data collecting ASV platforms

5.2: Conclusion

The Scout project was designed to inspire an audience through creative engineering. The fact that the project was conceived and executed by a group of college students during weekends and vacations only served to add to the media's interest in Scout's story, which brought the attempt to the attention of tens of thousands of people around the world. Although in many ways Scout satisfied the team's goals and objectives, the project failed to complete its original mission of being the first autonomous surface vessel to cross the Atlantic autonomously. The Scout team, however, believes that the potentially revolutionary future of autonomous surface vessels will benefit from all attempts to further the industry, and for that reason we are proud to put their names on the most visible ASV failure in history.

Appendix

Appendix i: A Message to Scout Followers

The following message was posted on Scout's Facebook page updating followers of the backup tracking system failure.

Posted on October 2, 2013 at

https://www.facebook.com/ScoutTransatlantic/posts/586824671382096

Hello all-

We'd like to update everyone about where Scout is today. The truth of the matter is that we've lost her a few days ago, and we don't think that we'll hear from her again.

Scout was launched from Sakonnet Point, Rhode Island on August 23, 2013 at some ridiculously early time of the morning (at Scout headquarters, we referred to these hours as "business hours.") Scout set off into the night like an invisible rocket that traveled at around 2 knots, transmitting her position and other data back to us every 20 minutes. We all have fond memories of waking up in the middle of the night to see what Scout was up to.

The last time we heard from this main tracking system was on September 28th. After that system went offline, we had some drinks because it was the weekend and the tracking service provider wouldn't pick up the phone until Monday, sent them Dan's credit card number, and had the service activated by Tuesday to find Scout 95 miles to the south. Thus began a series of loopy tracks ("Go home Scout, you're drunk" commented one Scout follower) totaling about a thousand miles that lasted a month and a half.

On Wednesday, November 06, 2013, at 4:01:27 PM, we received the last transmission from Scout. The backup tracker, a completely independent unit operating on the Globalstar satellite network, quietly failed before the next scheduled (4:01AM) message was transmitted. It has been exactly eight days since she vanished, and we think that this is as good of a time as any to put Scout to rest.

Although the chances are that we will never hear from Scout again, our database is ready to accept an incoming message, the satellites watching over Scout will send us an email if they spot her (while Dan's credit card lasts), and you can all be assured that we'll all get tattoos of Scout's position if she ever does transmit to us again. But as much as we have been captivated by Scout, this is probably the right time to let her go. We all have a number of projects to catch up on, and we're always looking for the next one.

The real benefit of setting today as an end date is that you'll be able to pencil it in on your Scout Supporter plaques! If you haven't received yours yet and you were a $30+ Kickstarter supporter, it should be on its way soon. http://www.gotransat.com/images/scoutplaque.jpg

A massive thanks to all for making this project possible and for helping us keep an eye on Scout over the last few months. We hope that you've had a good bit of fun watching this tiny boat try to take on the Atlantic; we certainly had fun building her.

Cheers!

The Scout Crew

Appendix ii: Media Links

A number of articles, videos, posts, and broadcasts covered the Scout project. The list below links the media that is available online.

Source	Title	Date
Make Magazine	When is Failure not a Failure?	01/28/2014
	Transatlantic Drone Takes to the Sea	08/27/2013
IEEE Spectrum	Robotic Boat Hits 1000 Mile Mark in Transatlantic Crossing	09/27/2013
Here and Now (WBUR)	Solar Powered Boat Makes Unmanned Transatlantic Journey	9/25/2013
Technophiles Podcast	Scout Transatlantic	9/13/2013
Interesting Cool	The Second Scout Hangout!	10/09/2013
Habrahbr.ru (Russian)	Морской робот Scout проплыл самостоятельно более 1600 километров	10/03/2013
BBC Radio:	http://downloads.bbc.co.uk/podcasts/fivelive/pods/pods_20130903-0402a.mp3	
WPI Daily Herd:	World Record Set!	09/05/2013
Sakonnet Times	From Tiverton- A Slow Boat to Spain	06/04/2013
	Scout Sets Distance Record, Copes with Atlantic Storm	08/28/2013
	Confused Scout Gets Early Rescue	07/01/2013
	Tiny Scout Setting Off for Spain Saturday- Follow Along	06/24/2013
Providence Journal	RI Sailing Buddies Build Solar Powered Robot Boat for Trip to Spain	06/02/2013
	Unmanned, Solar Powered Boat Faltering in 2nd Bit to Cross Atlantic from RI	07/09/2013
	Autonomous Vessel Scout on its Way to Spain Again	07/05/2013

	Lack of Sun Prompts Retrieval of Solar Powered Vessel Launched from Portsmouth	07/03/2013
	Solar Powered Boat, Scout, on its way to Spain	06/09/2013
	Solar Powered, GPS Guided Vessel Departs for Spain - Again	07/06/2013
Hackaday	An Autonomous Boat Across the Atlantic	08/03/2013
FastCoLabs	A Student Built Autonomous Drone Boat is Crossing the Atlantic Right Now, and You Can Track it Online	08/03/2013
New England Boating	Mini Solar Powered Boat Sets Distance Record	08/31/2013
Toshiba News:	Students' Robotic Solar Boat on Transatlantic Trek	07/06/2013
Solar Power Today	Solar Powered Boat Aims for First Autonomous Transatlantic Surface Voyage	06/04/2013
Entertainment. Verizon.com	Students' Robotic Solar Boat on Transatlantic Trek	07/06/2013
Huffington Post	Scout, Robotic Solar Boat, on Transatlantic Voyage Thanks to Group of College Students	07/10/2013
Earth Techling	Students' Robotic Solar Boat on Transatlantic Trek	07/06/2013
SolarNavigator	Transatlantic Scout	
Tiverton Patch	Robotic, Unmanned Boat Now 240 Miles from Home	09/04/2013
	Autonomous Boat Returns to RI After Unsuccessful Voyage	07/10/2013
	Support Grows for Scout, the Autonomous Transatlantic Robot	07/11/2013
	Tiverton's Unmanned Robotic Boat Remains Lost at Sea	12/06/2013
ProBoat Radio	Scout- the Autonomous Transatlantic Robotic Boat	09/11/2012
BlogTalk Radio	Scout- The Autonomous Transatlantic Boat	09/11/2012
Now.msn.com	After 2500 Miles Atlantic Scout Ocean Drone Missing Sea	
Bluebird-Electric	Scout Transatlantic @ 30 Days	

Appendix iii: Project Websites

Scout Transatlantic Facebook page (facebook.com/ScoutTransatlantic)

The Scout Facebook page was used to keep Scout followers up to date on the project. This page was particularly active during the final launch. Followers frequently sent us private messages regarding specific topics and often posted comments, links to articles, and other content on the public page.

5,200 people saw this post

Scout- The Autonomous Transatlantic Robot shared a link.
October 9, 2013

"Whatever happens to Scout, it's obvious that there are young people out there with a sense of adventure and the desire to try something new, figure things out, actually build things and make it all work. I find it encouraging that these characteristics are alive and well, at least in Tiverton."

Scouting New Territory
www.windcheckmagazine.com

WindCheck is a monthly magazine devoted to sailors and powerboaters in the Northeast. Every issue features those who race, cruise and learn to boat in the region.

2,181 people saw this post

Scout- The Autonomous Transatlantic Robot
October 6, 2013

Scout continues to move east, albeit slowly. The team has been analyzing position reports and weather conditions on our breaking news pad. For anyone who missed the link feel free to follow along here: http://gotransat.com/breaking

Scout- The Autonomous Transatlantic Robot shared a link via Dailymotion España.
October 9, 2013

A DRONE IS HEADING FOR EUROPEAN SHORES VIA THE ATLANTIC
www.dailymotion.com

A group of students living in the USA constructed a self controlled drone,...

1,653 people saw this post

Scout- The Autonomous Transatlantic Robot shared a link.
October 8, 2013

Live chat has started! Come join for the conversation!
http://youtu.be/nBS1AwJlct8

InterestingCool.com Presents Scout Team Update
www.youtube.com

InterestingCool.com Presents Scout Team Update

2,041 people saw this post

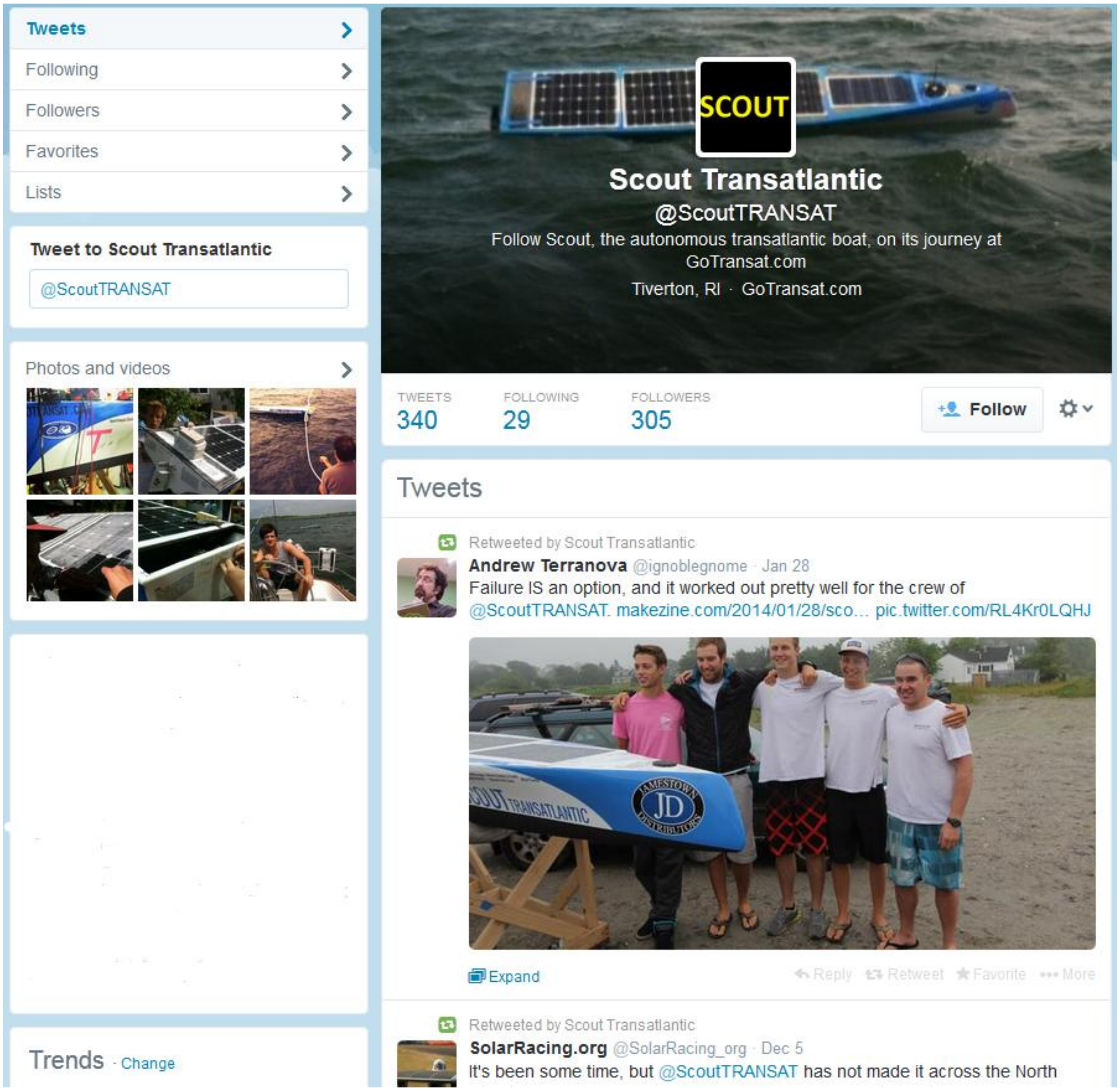
Scout- The Autonomous Transatlantic Robot shared a link.
October 7, 2013

Just a reminder about tomorrow night's 8:30pm live chat at http://tinyurl.com/plq6pd4 hosted by Bret from http://interestingcool.com/ - Feel free to ask any questions about Scout either here, or at the Google+ link!

On a Scout note, it's still up in the air as to whether Scout is motoring or fully adrift. We are monitoring weather conditions closely to try and correlate the two. It is a surprisingly dynamic problem!

Scout Transatlantic Twitter page (Twitter.com/ScoutTransat)

The Scout Twitter page was used to host content in a less formal format than the Facebook page. Tweets were often written on location, unlike Facebook posts or email updates, which were more carefully put together. The Twitter page was of particular use during Scout testing, as it provided a good medium for near-live updates of that particular test.



Scout Transatlantic
@ScoutTRANSAT
Follow Scout, the autonomous transatlantic boat, on its journey at GoTransat.com
Tiverton, RI · GoTransat.com

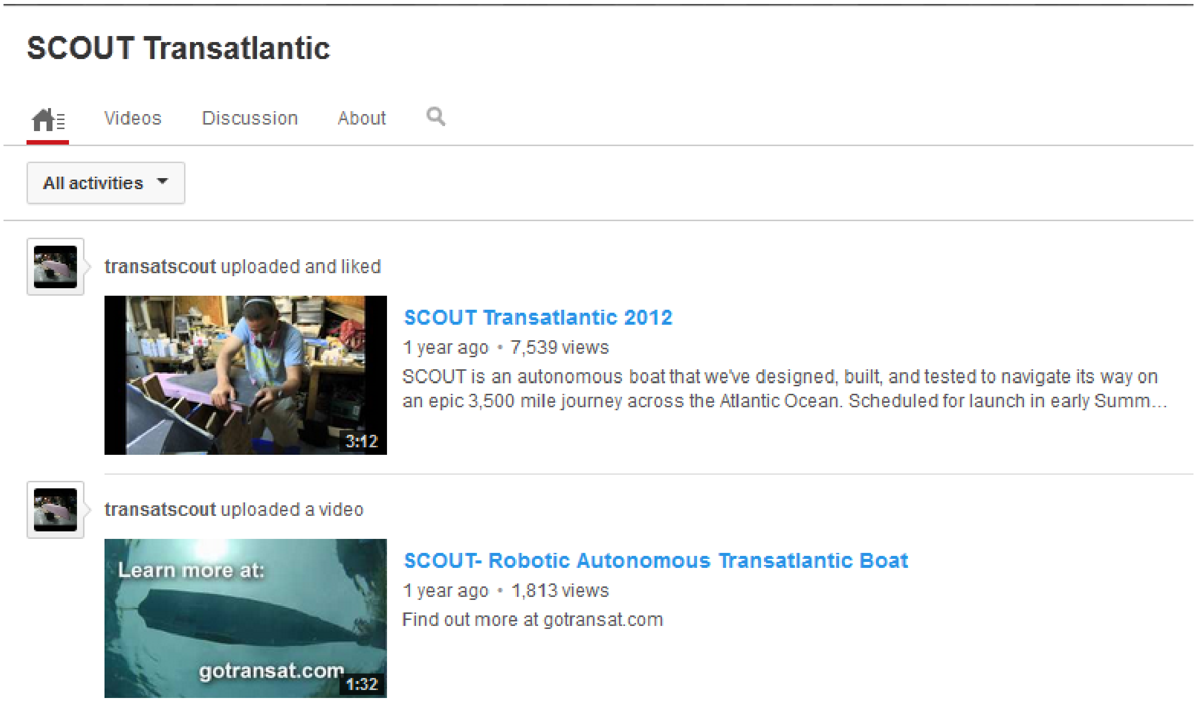
TWEETS 340
FOLLOWING 29
FOLLOWERS 305

Retweeted by Scout Transatlantic
Andrew Terranova @ignoblegnome · Jan 28
Failure IS an option, and it worked out pretty well for the crew of @ScoutTRANSAT. makezine.com/2014/01/28/sco… pic.twitter.com/RL4Kr0LQHJ

Retweeted by Scout Transatlantic
SolarRacing.org @SolarRacing_org · Dec 5
It's been some time, but @ScoutTRANSAT has not made it across the North

Scout Transatlantic YouTube page (YouTube.com/user/transatscout)

The Scout YouTube page had the least activity compared to the project's other social media outlets, but provided a good space to post videos related to the project.



SCOUT Transatlantic

transatscout uploaded and liked

SCOUT Transatlantic 2012

1 year ago • 7,539 views

SCOUT is an autonomous boat that we've designed, built, and tested to navigate its way on an epic 3,500 mile journey across the Atlantic Ocean. Scheduled for launch in early Summ...

transatscout uploaded a video

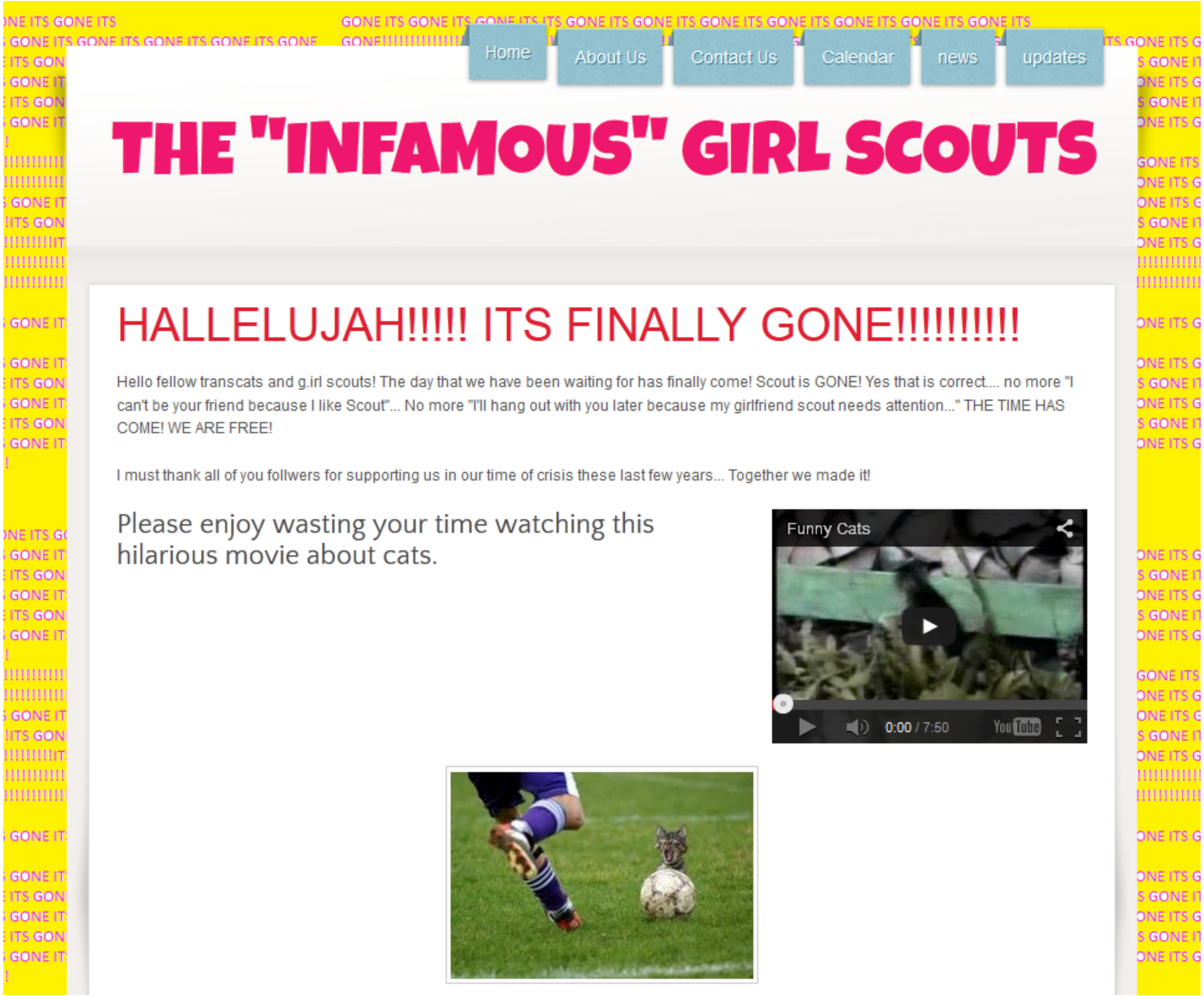
SCOUT- Robotic Autonomous Transatlantic Boat

1 year ago • 1,813 views

Find out more at gotransat.com

The GirlScouts (http://gotranscat.webs.com/)

The GirlScouts was an anti-Scout group consisting of sisters, girlfriends, and neighborhood friends. The group maintained a website documenting why they disliked the project and often frequented events attended by the media in order to spread their anti-Scout views. After the failure of Scout's secondary tracking system, the GirlScouts issued a press release stating in part "we wish we could take credit for Scout's disappearance, but we didn't even bother sabotaging the boat because we knew that since Dylan and his friends built it, it wouldn't last long anyways."



THE "INFAMOUS" GIRL SCOUTS

HALLELUJAH!!!!! ITS FINALLY GONE!!!!!!!!!!

Hello fellow transcats and g.irl scouts! The day that we have been waiting for has finally come! Scout is GONE! Yes that is correct.... no more "I can't be your friend because I like Scout"... No more "I'll hang out with you later because my girlfriend scout needs attention..." THE TIME HAS COME! WE ARE FREE!

I must thank all of you follwers for supporting us in our time of crisis these last few years... Together we made it!

Please enjoy wasting your time watching this hilarious movie about cats.

Bibliography

Anderson, D. M., Glibert, P. M., & Burkholder, J. M. (2002). Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition, and Consequences. *Estuaries, 25*(4), 704-726. doi: 10.2307/1353028

This journal article studies the causes, impacts, and nature of harmful algal blooms. Algal blooms are often predictable events that can be stimulated by artificial means, so the focus of science concerning these events is on detecting conditions that may trigger harmful algal blooms, predicting the expansion and travel of these events, and preparing coastal resource authorities with information as soon as possible. The enablers of harmful algal blooms are quantifiable by in situ sensors.

CNN. (2012, 2012, October 28). CNN.com - Transcripts. Retrieved September 28, 2013, 2013, from http://edition.cnn.com/TRANSCRIPTS/1210/28/cnr.07.html

This transcript of a CNN television broadcast aired while Hurricane Sandy was building off the coast of the Eastern United States. Chad Myers, CNN's senior meteorologist, voiced some of the issues with the data collection systems that were being used to gather the data that was being supplied to the weather models used to project the future attributes of the hurricane. Myers also discusses the formation and some of the valuable data metrics that can be collected from storms. This transcript is useful in identifying the issues that some weather scientists believe can compromise the efficacy of today's weather models.

Crunchbase: Liquid Robotics. (2013). Retrieved 10/29/2013, 2013, from http://www.crunchbase.com/company/liquid-robotics

Derived Motion Winds. (2013). Retrieved October 7, 2013, from http://www.star.nesdis.noaa.gov/goesr/product_winds_dmw.php

The Derived Motion Winds page of the National Oceanic and Atmospheric Administration explains how cloud features and water vapor gradients can be tracked to approximate speed and direction of atmospheric winds. This page identifies the usefulness of derived wind data for locations, especially for areas without in situ wind observation systems.

Fahimi, F. (2009). Autonomous Surface Vessels *Autonomous Robots* (pp. 221-262): Springer US.

"Autonomous Robots" was written by Farbod Fahimi of the Mechanical Engineering Department of University of Alberta, Canada. The book is designed to inform the reader of progress in the field of autonomous robots, as many books focus on conventional

robots that are controlled by a human. The chapters on autonomous surface vessels reviewed the nature of ASV control surfaces, specific challenges and obstacles to successful navigation, and extensive analysis of the dynamics of surface vessels.

Grasshoff, K., Kremling, K., & Ehrhardt, M. (2009). *Methods of seawater analysis*: John Wiley & Sons.

"Methods of Seawater Analysis" is a consistantly updated resource designed to maintain relevance to current methods and practices of scientific seawater sample collection and analysis. This book reviews the current landscape of seawater sample collection and reviews a number of sample collection and analysis methods and outcomes. Although the book covers common sensor configurations, it is the information about existing practices that make it a valuable resource in consideration of how autonomous vehicles will interact with the existing data collection environment.

Grosky, W. I., Kansal, A., Nath, S., Jie, L., & Feng, Z. (2007). SenseWeb: An Infrastructure for Shared Sensing. *MultiMedia, IEEE, 14*(4), 8-13. doi: 10.1109/MMUL.2007.82

This document, published in IEEE MultiMedia Magazine, was written by four Microsoft researchers to introduce a developing sensor data sharing system to the magazine's audience. This system, called SenseWeb, is designed to facilitate the sharing of sensor data from multiple nodes owned by different organizations through a common network that would allow all contributors to access the full datasets. The paper reviews the SenseWeb data sharing system, identifies advantages to the system, and covers application-specific capabilities and constraints.

Kampel, M., Gaeta, S. A., Lorenzzetti, J. A., & Pompeu, M. (2007). *Satellite estimates of chlorophyll-a concentration in the Brazilian Southeastern continental shelf and slope waters, southwestern Atlantic*.

This work reviewed and compared measurements gathered by in situ sensors and satellite payloads designed to quantify the same indexes. The value of maintaining in situ sensors was suggested, as the tendancy for bias in readings taken from the satellite platform was not statistically insignificant. This report is relevant to the field of ASV development because many thousands of square miles of ocean have no in situ measurement devices capable of validating and calibrating the data returned by the satellite, allowing inquantifiable bias into the measurements returned by those units.

Kampel, M., Lorenzzetti, J. A., Bentz, C. M., Nunes, R. A., Paranhos, R., Rudorff, F. M., & Politano, A. T. (2009). Simultaneous measurements of chlorophyll concentration by Lidar, fluorometry, above-water radiometry, and ocean color MODIS images in the Southwestern Atlantic. *Sensors, 9*(1), 528-541.

Le Traon, P. Y. B., M.; Dombrowsky, A.; Schiller, A.; Wilmer-Becker, K.;. (2011). Observing and forecasting the ocean: 10 years of achievements.

This report, written by five research scientists from several international research organizations, reviews the performance of the last ten years of the Global Ocean Data Assimilation Experiment- a project designed to facilitate the sharing of ocean measurement data between the scientific bodies of a number of nations participating in the program. The system's goal is to "sustain a reliable, global operational system that provides regular, timely, and accurate forecasts and analyses for many different scientific, industrial, and governmental applications."

Liquid Robotics: About Us. (2013). Retrieved 11/20/2013, 2013, from http://liquidr.com/company/strategic-advisory-board.html

Lu, Z., Ramsey, E., III, Rangoonwala, A., Suzuoki, Y., & Werle, D. (2012). Limitations and potential of satellite imagery to monitor environmental response to coastal flooding. *Journal of Coastal Research, 28*, 457+.

Manley, J., & Willcox, S. (2010, 24-27 May 2010). *The Wave Glider: A persistent platform for ocean science.* Paper presented at the OCEANS 2010 IEEE - Sydney.

This paper was written by Justin Manley and Scott Willcox, two employees of Liquid Robotics, the company that designs, manufactures, and sells the Wave Glider. As both authors were employed by Liquid Robotics at the time of authorship, there is potential for bias in this report. The document identifies benefits of autonomous platforms, especially in regards to their potential for data collection. It also proposes a number of potential uses for ASVs and identifies cases in which Liquid Robotics products were used.

Marzuola, C. (2002). Ocean View. *Science News, 162*(23), 362-364. doi: 10.2307/4013883

"Ocean View" is an article published in Science News designed to inform the reader of the development of buoy networks that have been developed and deployed to report data from locations that have previously been isolated from continued assessment. This article focuses largely on sub-seafloor activity and details the establishment of static sensor modules, often thousands of meters below the surface of the water. The article serves the purpose of making clear the importance of physical sensor deployment, even in the presence of satellite coverage of the same areas studied.

NDBC- Moored Buoy Program. (2013). Retrieved 10/4/2013, from http://www.ndbc.noaa.gov/mooredbuoy.shtml

Pawlak, G., McManus, M., Tuthill, L., Sevadjian, J., Ericksen, M., & Rocheleau, A. (2011, 19-22 Sept. 2011). *Real-time ocean water quality monitoring for the south shore of Oahu.* Paper presented at the OCEANS 2011.

This document was written by three environmental scientists to identify the feasability and need for real time ocean data collection systems off the coast of Hawaii. Written to summarize existing particle flow mapping systems and identify weaknesses of these offshore systems, the document reviews the environmental impact of offshore flow, the necessity to map particles, and the system which was used off the shore of Honolulu to do so.

Roboat: Home. (2013). Retrieved October 29, 2013, 2013, from http://www.roboat.at/en/

Robotics, L. Wave Glider Schematic. In Schematic500.jpg (Ed.). Rasqua.co.uk.

This image shows a simulated side view of a Liquid Robotics Wave Glider as it ascends a wave.

Saildrone. (2013). Retrieved 11/10/2013, 2013, from http://saildrone.com/

Staff, M.-H. (2007a). Cyanobacteria (pp. 163-166): McGraw-Hill.

This study of cyanobacteria defines cyanobacteria and outlines the measurement techniques and impacts of cyanobacteria, especially in regards to the toxic algal blooms that have adverse impacts on marine and human life. As cyanobacteria feeds from nutrients in seawater, monitoring excesses of these nutrients can assist in predictions of the location and severity of potential algal blooms.

Staff, M.-H. (2007b). Instrumented buoys (pp. 270-274): McGraw-Hill.

"Instrumented Buoys" reviews the types of instrumented buoys and their areas of impact in environmental science. This work serves as a reference of the strengths and weaknesses of moored, drifting, and variable drift buoys, and covers an array of typical uses of each.

Toggle Overlays Explained. (2013). Retrieved October 7, 2013, from http://www.srh.noaa.gov/tropical/satpix/toggles.php

"Toggle Overlays Displayed" is a webpage maintained by the National Weather Service that covers important metrics used by the NWS for their online satellite data viewing platforms. This page defines the altitude ranges of different selectors of wind speeds and directions on the NWS imagery.

Venkatesan, R., Shamji, V. R., Latha, G., & Mathew, S. (2013). In situ ocean subsurface time-series measurements from OMNI buoy network in the Bay of Bengal. *Current science (Bangalore), 104*(9), 1166-1177.

This journal article reviews a data collection operation that involved both in situ sensors and satellite imagery, and compares and contrasts these data types. In this instance, it was found that "the increased use of satellite data did not diminish the need" for in situ measurements, which exhibits the need for this type of measurement even though satellite based measurement systems can cover thousands of square miles of subject area in a single pass. Highlighted as being particularly irreplacable are sensors that take measurements below the surface of the ocean, which is an area completely inaccessible to satellite based sensors. The article summarizes that use of a number of sensor systems is the best way to collect and cross reference data critical to an operation.

Watkins, J. Picasa Web.