U.S. Navy Engineering Internship
Summer 2007

Final Report – by Daniel Bodenstein

Acknowledgements

This internship has been one of the most unique experiences of my life and has given me an incite into the field of engineering not possible anywhere else in the world. I would like to thank all those involved in making this possible in particular George Wozencraft, Jim Corry, Martha Sanders, Roberta Flanders and the rest of the Our World Underwater Scholarship Society (OWUSS) crew. I am deeply indebted to Jeff Krueger of Mercury Marine for funding my endeavors this summer. I also owe a debt of gratitude to NSWCCD for hosting me, its staff of truly world-class engineers for lending me a small part of their knowledge, and especially Dan Dozier for coordinating my time there.

1.0 Introduction

As a Scuba Diver since my twelfth birthday, The University of Colorado at Boulder seemed like an odd place for me to end up for my undergraduate career in Mechanical Engineering as it is about as far and removed from diving as geographically possible. Over my past four years there my contact with the diving industry and the underwater world became more and more infrequent however my desire to design tools and resources related to the underwater world never subsided- if anything it was growing. It was April, 2007, I had just returned from a dentist appointment and was nursing my sore jaw by watching a show on the history channel about exploring a deep cold water wreck – such shows are not uncommon in my infrequent spare time- when I noticed the use of a rebreather I hadn't heard of before. I checked their website during one of the commercials and after a while I noticed the OWUSS emblem in the corner of the page. After frantically filling out an application and getting a hold of my references that day I found myself running to Fedex to get it postmarked that very day out of excitement more then need. Next thing I knew I received a call from George Wozencraft and was on my way to the Naval Surface Warfare Center Carderock Division (NSWCCD) in late May- just in time to arrive for DC and West Bethesda, Maryland's humid summer.

Upon arrival, Dan Dozier, the Corporate Office Director, and I sat down and set to work determining how and where to spend my time in Carderock and 'do good work' as Dan so fondly puts it. Much like Bridget Benson, the my predecessor, I had previously decided that I thought to get as broad a picture of Carderock as possible- Carderock however is a incredibly diverse research center and would take many summers if not a life time to experience all of its facets. Instead I decided to try to learn about Carderock by following the various stages of experimental testing from beginning proposal to full scale testing and get a feel for how the business of engineering and design works in a non-university environment in the process. Dan plugged me into several projects and connected me with engineers within Carderock's numerous CODES (departments) to make my goals not only possible but inevitable as well as extremely satisfying and fun.

2.0 The Projects I Worked On

This report outlines the projects I was privileged to work on in my time here at Carderock. I have compiled them to follow the experimental design process not the order I worked on them in, with the hope that doing so will help give you a understanding of how an experiment evolves from start to finish. These descriptions also include a bit of what I learned and accomplished in my time with each of them. Hopefully you will find them as interesting and educational as I did.

2.1 ENTANGLEMENT

Project Advisor: David Coakley

This project was my 'big secret' while working at Carderock, and as such I must leave you with your imagination to fill in many of the blanks. I met with Dave Coakley upon my return from Bayview, ID to discuss a project proposal that was recently submitted requesting funding approval for the 2008 Fiscal Year. The proposal is to better understand and develop the science of entangling propellers on higher speedboats. In other words: what does it take to jam and stop a prop and why don't current techniques always work? This proposal comes in the form of a Statement of Work (SOW) which is a outline of an idea for performing research and development in a particular topic, the expected benefits and goals, a time table for work and a overview of prior supporting research. It has very little engineering in it- this is where I came in. My job was to start to lay the engineering groundwork and give Dave and his team a jumpstart into 2008. To do this, I had to take the proposal's goal and work backwards to develop the test conditions and parameters. This test is going to be conducted in the model basin on the high-speed carriage. I had to research all of the various types of speed boats, commonly called 'go fast' or cigarette boats and develop a generic hull that is basically an industry average. This required a lot of Google searching, and even some phone calls to manufacturers. There are a lot of different types of planing hull boats on the water today made and sold around the world. These boats come in several variations- vee shaped, deep vee, catamaran; semi- planing and flat-bottomed versions were of primary concern to me. From here, I had to study the market and determine the most common type- and then justify my results, which I will talk about in a few moments- but to do this I had to set my own parameters including geographic location, length, weight, capacity, maximum speed, and several others that must remain unnamed.

Once I had completed the parameters for my generic hull, I had to do the same with engines. There are several elements which make up the propulsion of a speedboat and any could be the critical component in this test and therefore I decided these components needed to be broken down individually so they could be isolated and tested individually for the best results. I decided on the following categories: engine/power plant, drive (stearndrive, outboard, or inboard), and propeller. These divisions allowed me to study the industry and decide on the most common, the maximum, and note any unique conditions, which should be considered in the test. These variables included multi-engine boat designs, dual counter rotating propellers, gear ratios, gasoline and diesel engines. Again after collecting data on each of these categories I had to develop and recommend the parameters of what to model in this test.

Research is easy. Averaging is easy. Explaining why you chose something over another seemingly as good alternative succinctly is difficult. This is a critical part in engineering however. This project challenged me not only to define the parameters, assumptions, and variables for a major experiment but it forced me to continually support my decisions with more then a excel sheet and a few paragraphs here and there- I had to learn to sell my ideas to other engineers and convince them my approach is valid. In my update meetings with Dave, he often said what I had was great but he usually wanted more data, just to confirm the data was correct. Developing a model based on 20 boats and 12 manufacturers is good but coming to the same model based on 48 boats and 26 manufacturers is much better.

Armed with my generic hull and several select propulsion system parameters, Dave asked me to start to figure out how to apply this information into a scale model test for the basin. To do this Dave gave me a paper by Daniel Savitsky on how planing hulls work and fundamental governing equations for them. This paper (Hydrodynamic Design of Planing Hulls, *Marine Technology V1 1964*) is a fascinating read for those interested in how trim and hull geometry effects how a boat operates, and for those interested in making their own boats a little bit faster and more efficient. Dave also introduced my to Froude Scaling, a method capable of deriving scaling factors for every aspect of an object. I found this fascinating to see how by making something half its original size (a scale factor, called λ, of 2) events would happen √2 times quicker. It also means the power requirements for the models engine are substantially less then for full scale. For example, a boat with a 500 HP motor full scale and a operating maximum speed of 75 miles per hour only needs about 10.7 HP to reach its scaled speed of 43 MPH for a model that is 1/3, or λ = 3, of the full size version. This example illustrates why model testing is so important because a 10 HP motor is certainly cheaper then a 500 HP motor. When scale is reduced further- λ is increased- extreme testing becomes plausible. Take for example a 900 foot long destroyer, when made to a scale factor of say λ=36, becomes 25 feet long and testing of 20 foot seas becomes waves of just inches. This is certainly more economical and much safer to test then building a full size boat.

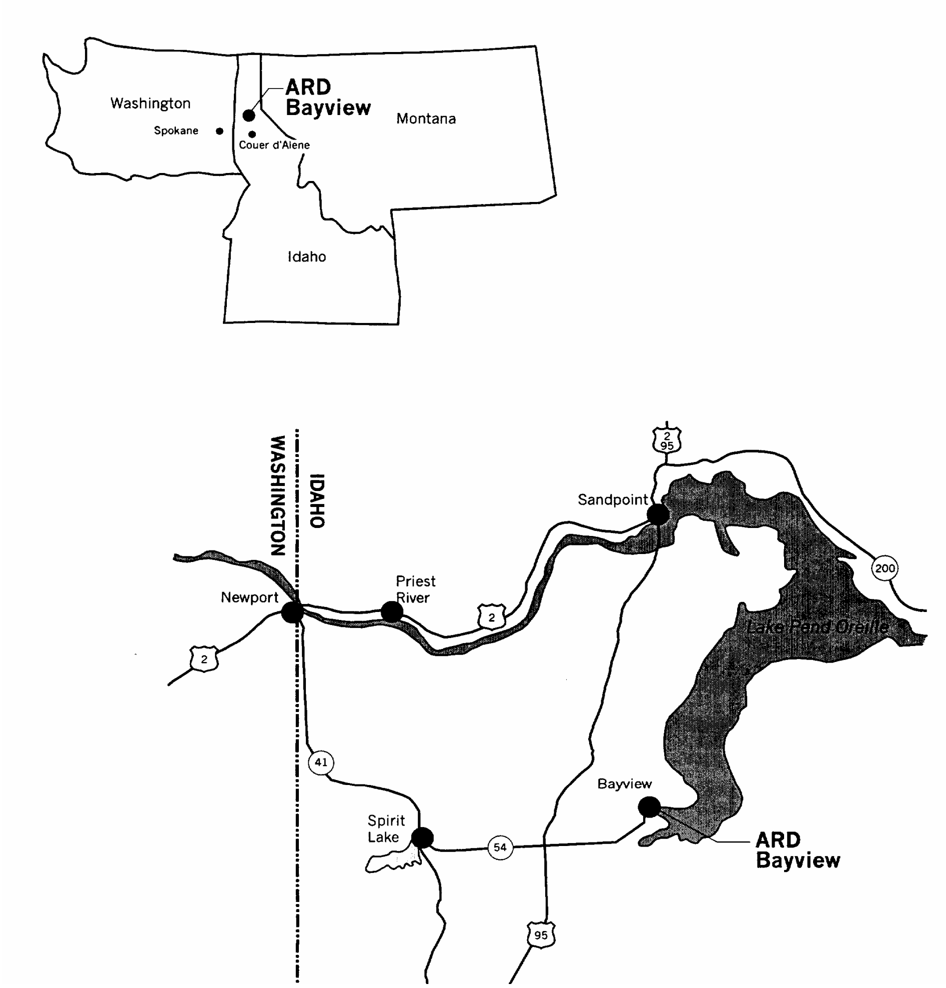
This project took me through the very beginning of an experiment from design to deciding on the parameters and assumptions stage of testing. My time at in Idaho provided me with the next stepping-stone in an experiments journey.

2.2 BAYVIEW: The Acoustic Research Detachment

Project Advisors: John Suiter and Jerry Stevenson

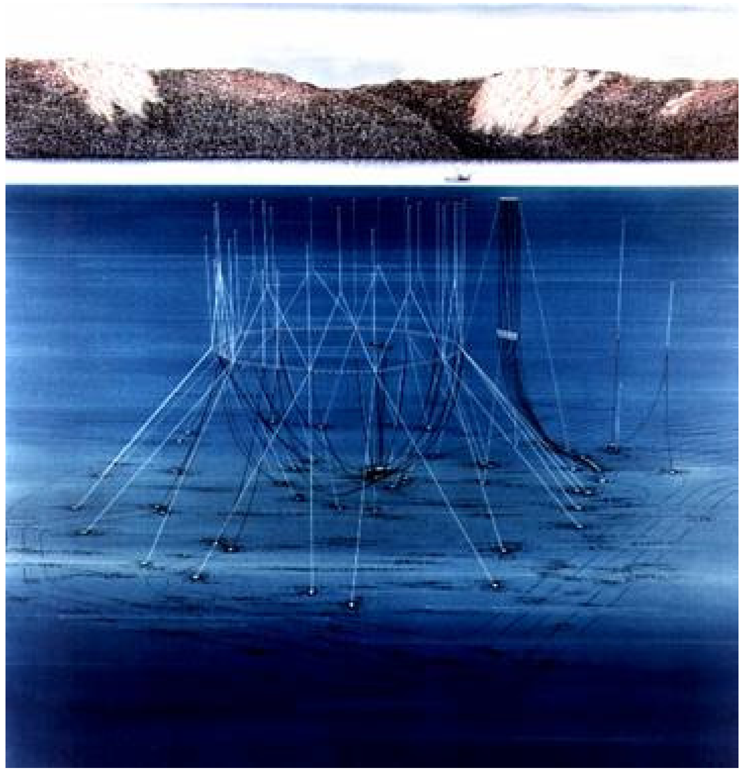
Due to some family obligations in Spokane, Washington I had to spend two weekends in June there. Dan helped me avoid two cross-country red-eye flights by setting me up at Carderock's Acoustic Research Detachment (ARD) in Bayview, Idaho. Bayview is on Lake Pend Oreille which provides a unique location for taking acoustic measurements for several reasons: the lake is cold (around 44 degrees), has an average depth of over 1000 feet, and because of the way the river feeds into and out of the northern section, the majority of the lake has very few currents. These measurements are taken in one of five test platforms in the lake. I spent several days on the water on the Buoyant Vehicle Test Range (BVR) and the Intermediate Measurement System Range

(ISMS). These platforms each have very unique functions.



Bayview, ID, Image courtesy of Henry Netzer, Director ARD

The ISMS range is the furthest north of all the ranges, located in excess of 1000 feet of water. Imagine a giant basketball net of hydrophones, speakers, and other sensors tethered underwater and I give you the ISMS range. Models are towed down in the middle of this net with their own compliment of sensors. This configuration allows for extremely accurate measurements of vessel acoustic signatures and other important information.



ISMS Range, image courtesy of Carderock

The BVR is for testing of buoyant vessels, commonly referred to as 'pop-up' models because they are dragged down by a platform cabled to the bottom of the lake and then released to shoot to the surface under nothing more then buoyant propulsion. I worked in two of the pop-up models, Dolly Varden (DV) and PIKE. These models are approximately quarter scale in size and shape of current submarines and a loaded to the brim with hundreds of different sensors ranging from gyroscopes to sonar systems. While floating to the surface they are completely independent and capture all data themselves that is then downloaded fiber optically back to Bayview once back on the surface.

ISMS is supported by the OUTPOST facility and the BVR by the WIGWAM facility on the nearby shore. They are the connecting hub for the mostly underwater ranges, providing all of the power, fiber-optic communication lines, and adjusting cables for the range via massive wenches and pulleys on the bottom. When I first arrived at Bayview, the OUTPOST and WIGWAM shore stations were both running on generator power providing the ranges with only minimal power. It took the power company several days to find the cut in the power cable running from Bayview to the shore stations before normal work could resume. John Suiter speculated a raccoon had eaten out the line, as apparently had happened in the late 90's.

When not on the water I helped Jerry Stevenson prepare equipment for a test called the DV Duct. This was a test thought of by scientists back at Carderock Headquarters in Bethesda. It entailed putting PIKE on the ISMS range with this giant fiberglass duct floating above it. PIKE is there to act as the data acquisition device, and was to be mounted statically, not to pop up in this case. This duct was to be several hundred feet above PIKE in the measuring sweet spot, between 400 and 600 feet below the surface. The Duct was shipped in naked with no sensors on it, Jerry and my job, along with another intern from the Maritime Academy was to outfit this 1 ton tube with approximately 100 dynameters and 48 tennis ball sized hydrophones in the exact locations specified by the engineers at Carderock. This provided a challenge in several ways. The shear number of wires, which had to be fed down and connected to PIKE made the duct into a veritable spider web. Additionally, the locations of the hydrophones required them to be floating at various locations from the inner surface. These hydrophones had to be completely isolated, meaning no vibrations (sound waves) could be transmitted from the surface of the duct through a mount. This required us to mount them with bungee cord connected by stick on tabs and zip ties. Despite being a seemingly simple task, it required a lot of thinking and ingenuity on our part because the engineers in Bethesda did not provide any more then where they wanted the sensors. In all it took almost 150 man hours of work to get the Duct fully outfitted to their liking.

This project provided me with a great appreciation for the technicians who have to take engineers ideas and build them into reality. It also gave me an incite into making sure designs are practical to build, anything can look great on paper but in the case of the duct, it may be nearly impossible to implement. This is a notion that many designers and engineers, myself included, are naive to in today's industry. All of the time that was put into the model, the duct and preparing the ISMS range totaled about 400 man hours in all. Performing the experiment will probably take under 200 all for probably not more then 10 minutes of data.

2.3 Laser Doppler Velocity:

Project Advisor: Chris Chesnakas

Back at Carderock, Chris Chesnakas needed a hand for a few days preparing his equipment for a test in the basin. I spent several long days helping him prepare his Laser Doppler Velocity (LDV) measurement platform in his lab and then mounting it onto Carriage One in the Basin. Laser Doppler Velocity is a method for measuring the velocity, vorticitiy, and other motion related data of a fluid flow. It does this with the use of two multi spectrum argon lasers, which intersect at the point of interest. Water flow however is optically neutral. In order to obtain a measurement of flow (velocity) silica slurry is injected into the water stream. This creates an interference pattern, which can be measured and interpolated to produce the velocity of the silica, and presumably the stream. This experiment called to measure an area of water about the diameter of a CD where the propeller would be under a model of a prototype trimaran cruiser and later in the same week measure the flow under a heavy sealift model. Normally, the lasers are mounted on a pole from the side of the model however due to the size of the sealift model, this was not feasible. Chris designed a new frame for the laser to mount on made out of 10/80 aluminum components (think erector set for big kids) and several other custom machined and anodized aluminum stabilizing bars. I helped him assemble these into one working unit and transport it to the basin and mount it onto the carriage. This provided a unique challenge and multiple day delays resulted for two reasons. Firstly this new frame was much larger then the old one and didn't fit through the lab doorway. Secondly, construction at the end of the basin had taken the main crane off line so an alternative had to be found to get into the water and the center of the carriage. The solution was to lower it down from a hoist further up the basin into a punt (flat bottomed row boat) and have me row it into place where the carriages onboard hoist could take over while in dry dock. This took many hours to get right because the carriage and the dry dock both had to be reconfigured to allow this to happen. Eventually we got the model mounted, the laser and computers onboard the carriage and started testing. In order to get the required data for this disk of area many runs had to be performed. The lasers had to measure 287 different points and yet could only record about 10 per run. Testing for each model took several 12-hour days of back and forth runs. All said and done, a nice pretty chart was produced just like what would be used in a homework problem from a Fluid Mechanics textbook, except this one took hundreds of man hours to create.

This project showed the final stages of calibration and setup and the start of an experiment. It also demonstrated the attention to detail and precision required for accurate data. This is the very boring work of an experiment however it is quite probably the most critical part. Scott Gowing and Young Shen's Porous Hull test started where Chris's project left off as the next stage of experimental testing.

2.4 POROUS HULL: THE SECOND STAGE

Project Advisor: Scott Gowing and Young Shen

Many of you may remember hearing about this concept in Bridget Benson's report from 2006. I was fortunate enough to work on the second stage of this experiment- model testing. For those of you unfamiliar, I will provide a brief background: Small combatant craft used by marines and other elite services for rapid deployment are notoriously uncomfortable and dangerous to ride in during rough seas. This is generally a mission requirement and the results have ranged from sprains, to compression fractures as a result of slamming forces caused by these boats running through or over large waves. Scott Gowing and Young Shen came up with the idea of placing air bladders in the bow of the boat with holes allowing this bladder to contact the water and act as a shock absorber to help reduce the force of these slams. To prove their concept, they built a box with a bladder and various hole shapes and sizes and dropped it into the water, measuring the resultant forces and their reduction over a solid box. After the promising results of the data Bridget helped analyze in the box experiment, Scott and Young were granted funding to continue their research by putting bladders into a planing hull model and test at various speeds and waves on Carriage Three. To do this a model of Vietnam era patrol boat was taken out of storage and fitted with four front bladders, two on each side. Two sets of plates were then made to cover these bladders, one smooth and the other with holes throughout most of it surface. This model was of the NASTY class patrol boat and prior to paint, the name seemed quite fitting.

With the model mounted, balanced and the smooth plates installed we set off, to determine the thrust unloading in calm seas. Running the model in four different weight/ballast configurations: light ballast with CG forward and aft and heavy ballast with CG forward and aft, determined the correct thrust unloading. The model was then run at five different speeds in calm water. The test was then repeated in waves with the porous plates installed at three different speeds. My job during the tests was to setup and run the camera capturing the slamming and insure that all other variables on the model remained constant during the runs. This gave us the condition to run the model in waves and begin actual baseline data collection

Initial tests showed an extreme amount of drag with the porous panels in place. Scott theorized correctly that some of the holes were not being sealed by the smaller bladder and were creating a lot of drag from flow through the holes. To remedy this, he and I placed military grade duct tape over the holes we felt were causing problems and then re-calibrated the system for the fourth time now. While the drag numbers were still higher then hoped for, the tape did the trick and we set to work running the model in waves measuring the slamming forces and drag at two different bladder pressures and three different speeds. All said and done, nine runs were performed beyond the smooth hull baseline and calibration runs. This experiment was scheduled to last 4 days, however if you factor in the construction delays it ended up taking over two weeks to complete. My time at Carderock ended before Scott and Young could analyze much of the data thoroughly, however initial inspection looked promising and hopefully this work will continue development and produce more model tests over the next year with an improved design.

This was a great experience for me because it allowed me to see how experiments must adapt on the fly and be dynamic with schedule changes, and other delays. I also gained a good bit of experience collecting data with Lab View, its respective equipment and how to troubleshoot a test when the preliminary data looks just plain off.

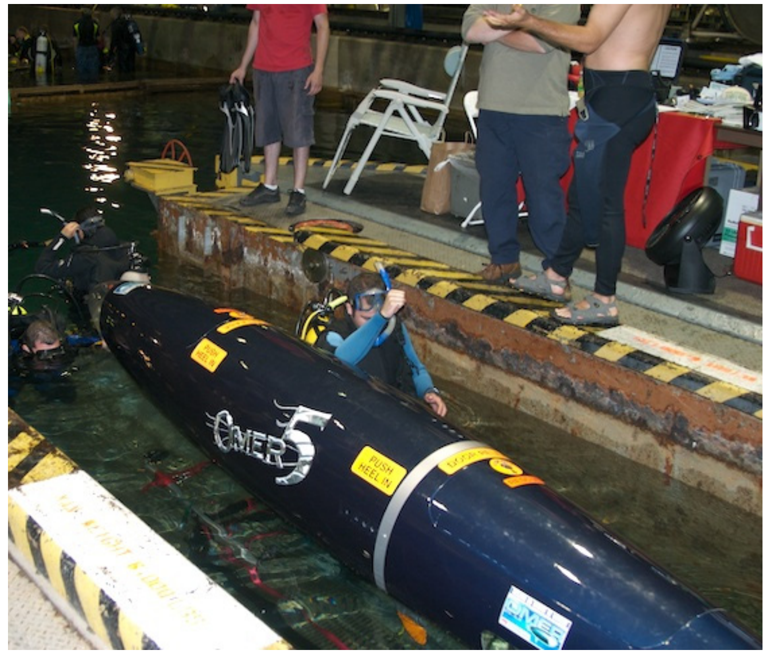
3.0 MEMORABLE EXPERIENCES

3.1 INTERNATIONAL HUMAN POWERED SUBMARINE RACES:

I arrived back from Bayview, ID in the middle of the 2007 ISR competition in the model basin. I grabbed my dive gear and set to work as a support diver in the basin. This seemingly simple set of dives quickly turned brutal for most of my dive gear. I am known in Colorado as a professional gear junkie and am generally considered uptight about its maintenance; my dive gear is certainly no exception. However, things happen. Five minutes into my first dive my trusty computer gave up the ghost and died. I had been half expecting this and was planning on replacing it this summer, however a few minutes later my backup watch decided to go into low battery mode and thus refused to work in dive mode as a safety feature. Borrowing a gauge, I continued the day without any additional glitches. I thought I was past the problems, I was wrong. On the second day, suiting up I snapped the plastic rear zipper on my 7mm wetsuit. This made for a very cold day. On the third and final day, with a repaired suit I figured I was out of things to break. Again, I was wrong. On a turtle step off the dock, I looked down to check my decent only to see a fluttering neon yellow blob fluttering down below me. Initially confused because none of me gear is yellow I realized the clasp on my tiny dive knife sheath was yellow. Sure enough, the solid plastic sheath had cracked in half and was now on the bottom of the basin. This whole experience made me feel completely sheepish. I have hardly ever broken any of my gear and in three days I managed to go through most it, all while diving with some of the best divers from OW USS, Igor the European Rolex Scholar and the Navy's premier diving salvage and recovery unit, MUDSU II. I am very grateful however that my gear broke in such a controlled environment rather then in the field.

The races themselves were quite an experience separate from the diving. I was able to watch the Canadian team OMER set a new world record, aid the short handed

University of Maryland team both underwater and in the garage, and provide technical advice and assistance to the struggling University of British Columbia team. I also borrowed a video camera housing and was able to film some of the races underwater. I could rant on about how unique some of these submarines were, however it would fail to do many justice so attached bellow are several of my pictures from the event.



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

3.2 LOST IN DC: A County Kid on Independence Ave.

I drove from Boulder, CO to Maryland in a little under 36 hours including a brief sleep somewhere in Iowa. This was the easy part. I spent that Sunday with some friends in Fredrick, MD and then in the evening I made the seemingly short trek to Arlington to stay at another friends house for the night so I could move into my new room in the morning. This 50-mile trip is supposed to be easy. Well, being a county kid, I'm not used to turnpikes, expressways, and parkways- especially all at the same time. One thing led to another and next thing I knew I was at 800 Independence Ave. thoroughly lost in the heart of the Nation's Capital. Despite being miserably tired, it was a really cool experience to see the sights at night. In all it was a great way to welcome myself to the area because I had unintentionally ended up following almost the exact same route as I had nine years earlier on my 8th grade tour bus. I manage to see the Washington Monument, Iwo Jima, The Lincoln Memorial, and the Kennedy Center all in the same lost wandering. Eventually through a lot of phone calls to my friend and her use of Google Maps, I eventually found my way to her apartment, two hours late. Later in the summer, I went back- this time on foot and during the day for an afternoon of sightseeing and photos. It was an enjoyable excursion despite the humidity, which I seem to now be able to tolerate- barely.

3.3 THE FIRST WEEK:

I spent the first four days of the internship in Carderock, getting a feel for the area, being knocked around by traffic and the mess of tangled roads they call DC, getting all set up logistically with access to the navy computer stuff, email, a basic security clearance, parking and ID badge. My first day there I was fortunate enough to attend Carderock's Magnificent Seven awards ceremony which recognized the best people in their respective fields, and was able to see first hand the high caliber of intellectuals and industry leading projects that Carderock does. I then spent the rest of my time shadowing Dan Dozier, seeing how the business end of Carderock functions- budgets, fund allocation, project assignments, and marketing/selling of Carderock as a product. Of course this and a good amount of my time was consumed by the bureaucracy of the system, but that, while frustrating at times, was also a good learning experience. Dan was also kind enough to take me on a tour of the model making shop, which I found nothing short of amazing. By my estimates, none of the tools were newer then the 70's and all in beautiful shape. Growing up as a woodshop rat I recognize quality and also that I am not capable of producing such art. The craftsmanship of the models produced at Carderock is exemplary and is part of what makes Carderock so successful in it's testing. It is also a component, which so infrequently receives recognition.

4.0 Conclusion:

I hope you have gained a glimpse into my experiences however I know that words can fail to do justice to how much I have gained from my time with Carderock. Carderock has provided me with an incite into the experimental process, and even into the process of developing science. I sincerely hope that Mercury Marine, OW USS and Carderock can continue this partnership in the future and allow others to be as fortunate as I have been and enjoy this experience and provide them with as many tools for the future as I have been granted.