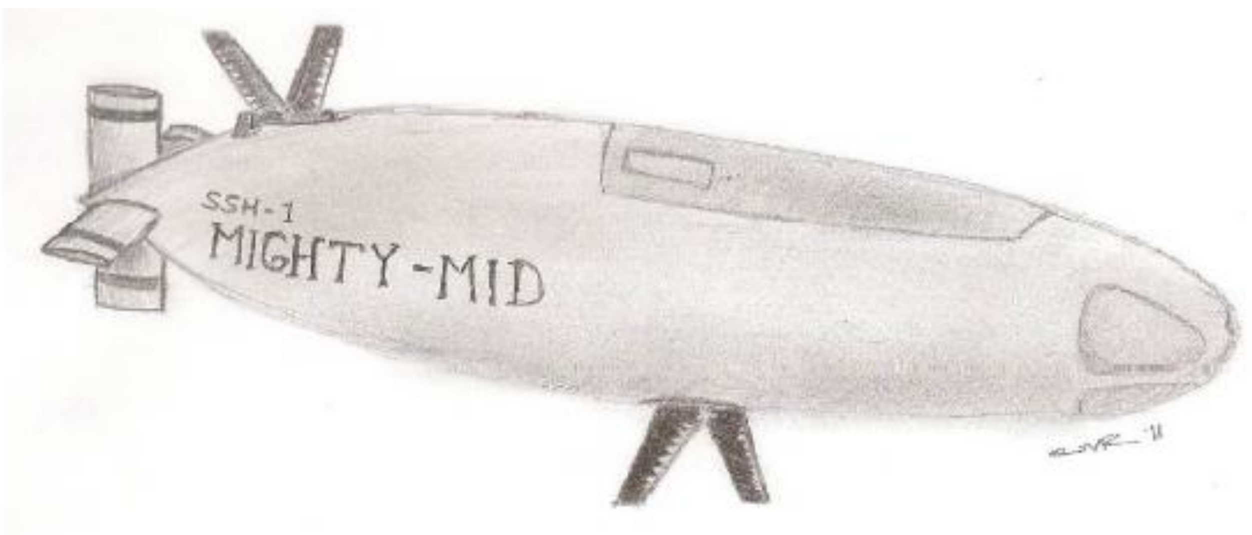
# USNA HUMAN POWERED SUBMARINE DESIGN REPORT




# SSH-11 MIGHTY MID

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**ABSTRACT**

The International Submarine Races propose the opportunity for students at various levels of academia to design and develop a human powered submarine, thus challenging each team with the chance to "achieve excellence in areas of maritime technology and ocean engineering." The United States Naval Academy is one of the leading colleges in the development of undersea research and technology at the undergraduate level, therefore making an ideal entrant for the 11th International Submarine Race to be held in June of 2011. This report will outline the design and development of the United States Naval Academy *TEAM SEVERN GLORY'S* submarine entrant, the *SSH-11 MIGHTY MID.*

**INTRODUCTION**

The United States Naval Academy is a four-year service academy located in the historic town of Annapolis, Maryland. Being one of the five service academies in the United States, most graduates of the Naval Academy enter directly into military service upon completion of a rigorous four years of military training, academics, and leadership development. While the mission has always been first and foremost to train and prepare individuals to become competent officers in the Navy or Marine Corps, academics have always been a crucial part of every Midshipman's development.

As many already know, the very first International Submarine Race (ISR) was held at Singer Island near Riveria Beach, Florida in 1989. Entered in the competition were two Midshipmen from the Naval Academy who aimed to prove just how effective their education could be. In true Navy fashion, the Mids came away with the "Best Overall Performance," and a desire to do even better at the next competition. Two years later, at the 2nd ISR, the Midshipman entered two submarines (*SQUID* and *Subdue*) and would have competed very well except they were disqualified for a faulty emergency buoy. After that, the United States Naval Academy and the short legacy they established at the first two International Submarine Races disappeared for nearly two decades.

Almost 22 years from the *SQUID*'s first rendezvous with victory, the United States Naval Academy is once again submitting an entrant to the International Submarine Races. This entrant marks the beginning of a renewed commitment to human powered submarine design, research and development at the nation's premier maritime-focused undergraduate institution. The Naval Academy intends to make a respectable showing with their 2 person non-propeller contestant for the 11th ISR: *THE SSH-11 MIGHTY MID.*

**CONCEPT**

For this year's competition the Naval Academy team considered a variety of designs. These designs were categorized into two main categories; Propeller and non-propeller. Figures 1-1 through 1-4 show a few of the many different ideas considered during the preliminary design stages of the submarine.

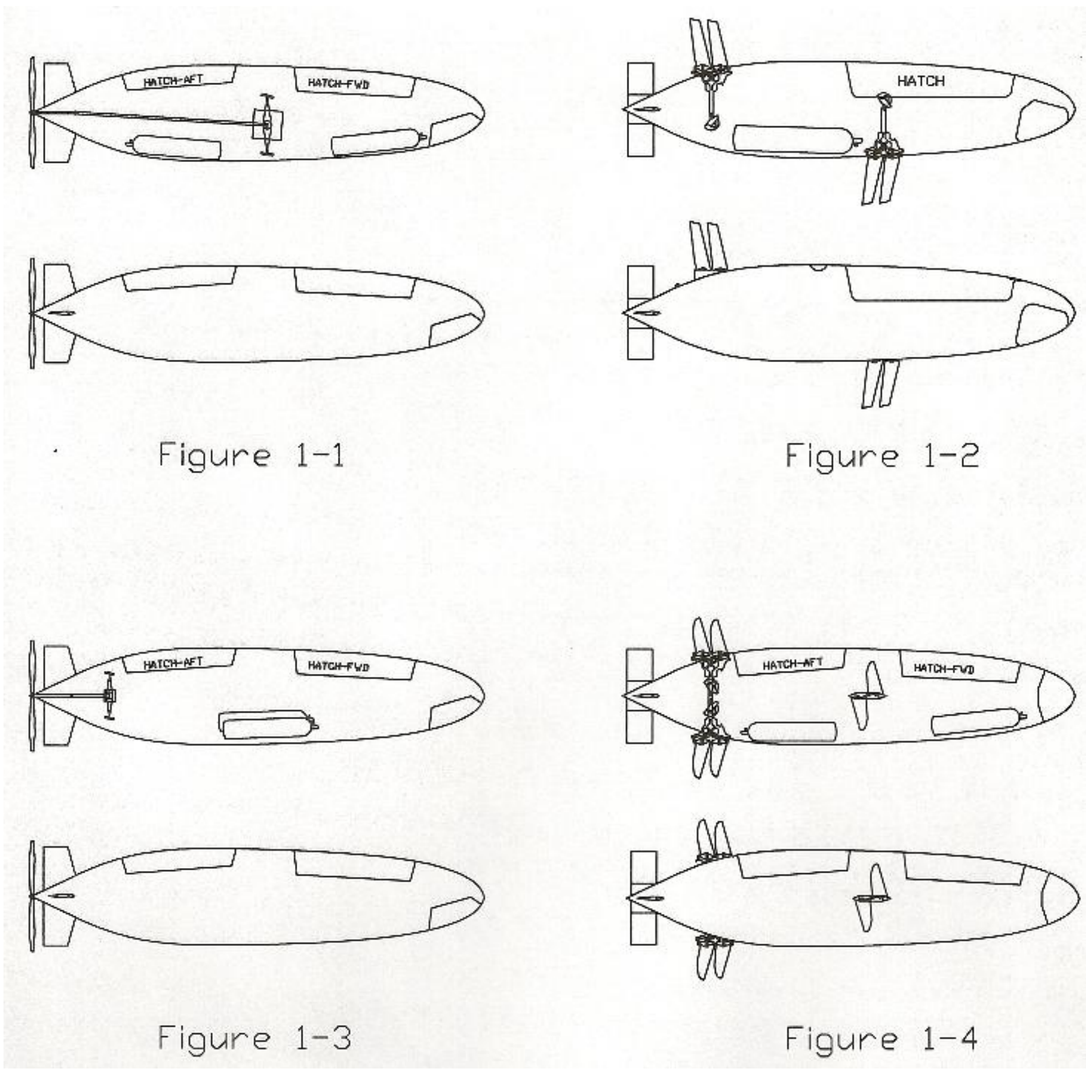



**FIGURE 1**

Each of the preliminary designs was considered for a variety of different reasons. However, each design still fit in what *Team Severn*

*Glory* considered to be our four guiding design constraints, which soon molded into our central design concept:

1. Design a platform that is above all simple, basic and effective in order to produce a timely and race-worthy product not inhibited by complex variables.
2. Design a platform that complies with all of the regulations and rules set by the 11th ISR Year 2011 Contestants' Manual, in its entirety.
3. Produce a product that allows for additional improvements based on further research and future developments, thus aiming to create the best possible platform.
4. Adhere to the true spirit and meaning of the ISR by seeking and pursuing new and creative ways to both advance the races as well as achieving excellence in the areas of marine technology and ocean engineering.

Referring to the sketches in Figure 1, one can see that for each design the hull shape remains the same. Only one hull form was considered due to time constraints. Our team only had one year to research, design, test, and fabricate the submarine as well as train the operators.

When Hurricane Isabel ravaged the East Coast in 2003, most of work done by the Naval Academy for the first two International Submarine Races were lost. Fortunately, a half-scale model built for the purpose of testing and developing a submarine for the 3rd ISR was spared by the hurricane. Thus, in order to save time in terms of having to create a brand new hull design, the United States Naval Academy team instead chose to develop a submarine based off of the half-scale model. It was for this reason that numerous hull designs were not considered when developing the *SSH-11 Mighty Mid.* A more in-depth discussion of the hull development will be explored in the FINAL DESIGN / FABRICATION section.

A primary difference between the preliminary design options shown by the sketches in Figure 1 is the propulsion system. We originally were set on developing a conventional propeller, two person human powered submarine. It seemed to be the most basic and simplest category to enter, using both occupants to produce a force to conventionally propel the submarine through the water. A final preliminary AutoCad layout of the first proposed submarine design is shown below in Figure 2.

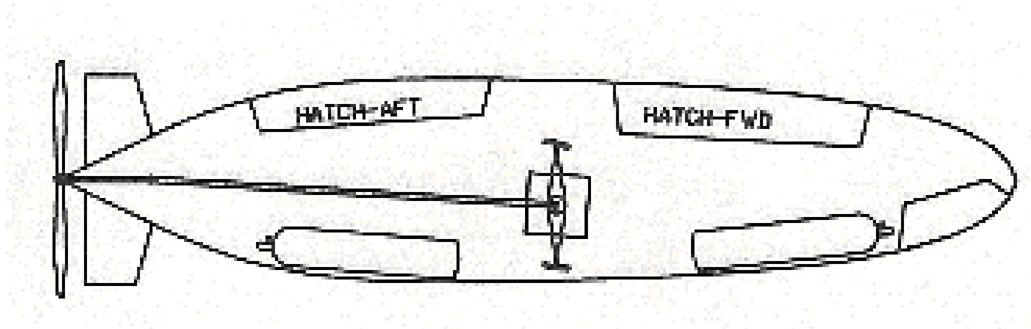



**FIGURE 2**

It is important to note that the hull design above was completed during spring of 2010 well before the full United States Naval Academy team was formed. Up until September of 2010 most of the conceptual and basic design work was done by individuals and it was not until afterwards that the team was organized. Looking back at first drawings (Figure 1), all of the sketches involving the unconventional propulsion systems were not even considered, nonetheless drawn, until the second week of January 2011. Simply put, once September of 2010 hit the trade-offs in design and development began and by January the modified and improved design were conceived and put into action. The following sections will describe the trade-offs as well as go into detail about how the hull redesigned and developed into our team’s final product.

**TRADE OFFS**

The first design (Figure 2) proposed only a few basic trade-offs for us to initially consider. The first item looked at was the position and orientation of the personnel inside the submarine. The team's faculty advisor and head mentor, Commander David Robillard, USN, is currently certified as a Navy Diver. Therefore, he had a lot of valuable input to what would be best in terms of our life support system. In terms of orientation of the pilot and navigator, it would be easier for each occupant to breathe if they were in a prone position rather than reclined. This philosophy again regulated the positioning of the occupants with the final deciding factor being to put both occupants on the same set of pedals. The final position of each occupant is shown below in Figure 3 for the initial iteration.

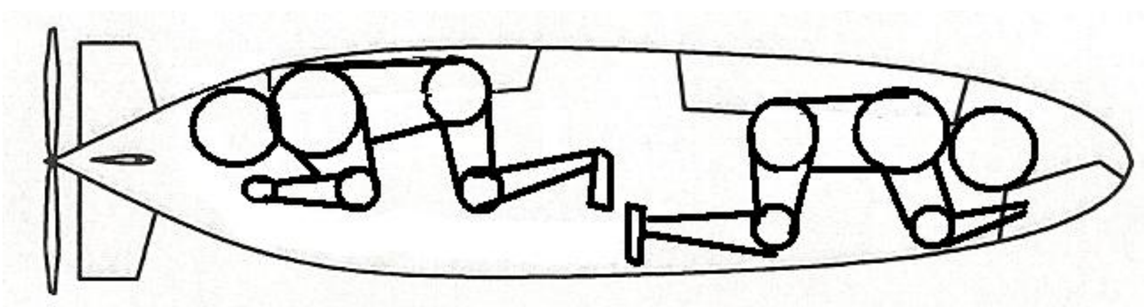


**FIGURE 3**

One will notice that the positioning of the occupants also finalized many other components of the submarine. For one, it was now quite obvious that our hatches would either have to be above the occupants or on either of the bulkheads (sides) if the SCUBA tanks were placed on the deck of the sub. While putting the hatches on either the port or starboard bulkhead may have been easier in terms of fabrication (the bulkheads are reasonably flat compared to the more complex curvature of overhead hatches), in the end it would have made an emergency egress more difficult for the occupants. Furthermore, having hatches in the bulkheads would cause the hull to be unsymmetrical because we would either have two hatches on the starboard or port bulkhead (with one being forward and the other being aft) or a hatch on the port bulkhead and a hatch on the starboard bulkhead (again, one being forward and the other being aft). This would make the balancing of the submarine a little more difficult so it was thus decided to put the hatches in the overheads.

The hatches, occupant positioning and tank location also finalized the position of main shaft of the propeller (not shown in Figure 2). Since both occupants would be on the same set of pedals, the main shaft would have to be connected to the small horizontal shaft that connected to the propeller by a universal joint in order to ensure that the aft occupant could fit in the submarine. This is better explained by Figure 3 below:

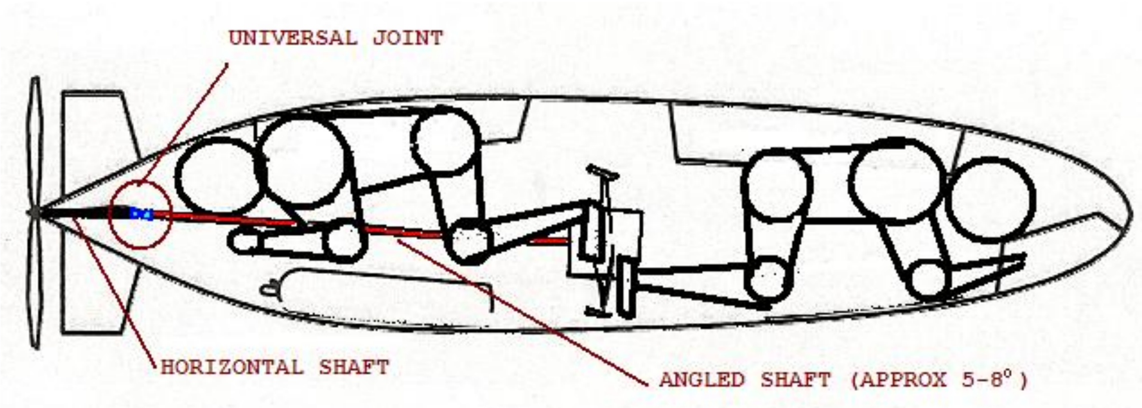



**FIGURE 3**

A single, horizontal shaft located aft of midship would severely cut down the space available for the aft occupant. Therefore, to ensure that the individual could safely fit it was decided to slightly angle the shaft. While we realized there would be minor losses in efficiency due to the use of the universal joint, we decided it was a choice we had to make in order to make certain that both occupants could fit in the submarine.

Despite these decisions, the design described above did not end up being the final product. Instead, we decided to completely switch the propulsion system to a non-conventional propulsion system during the second week of January 2011 after much debating and numerous runs in the tow tank. The decision was made based on the following 4 reasons:

1. The original design (described above – Figure 3) called for a gearbox and gear ratio specific to the requirements of both the requisite propeller output (Thrust Horse Power-THP) and the calculated power output of the two occupants (based of Shaft Horse Power-SHP and Delivered Horse Power-DHP). Since the gear box was custom to the design, it could not be purchase off-the shelf and would therefore take an exceptional amount of time to construct and fine-tune.
2. *Team Severn Glory* was not officially formed until around the end of September 2010, which only left about seven months to complete the entire project (again, starting from basically ground zero). Thus, having to build specific parts (specifically the gear box) would take time away from the overall completion of the project (it was estimated that the fabrication of the gear box would take almost two months and was thus the critical path in our GANTT chart, leaving no time to fine tune and practice with the submarine).
3. The team understood that most of the participants in the 11th ISR have been improving and/or fine-tuning propeller based submarines for over two years, most for over four years now. Therefore, it was felt that entering the non-conventional category would present out team with a better chance of success overall
4. Finally, to try something that outside the box matched our team's core concept of "creating something that advanced the races," as well as producing "a product that allows for additional improvements based on further research and future developments."

As a result, a new design was developed based off of the commercially available Hobie Mirage Drive. A more detailed explanation of this system and how it works will be described in the FINAL DESIGN/FABRICATION section. A sketch of the Hobie Drive is provided in Figure 4:

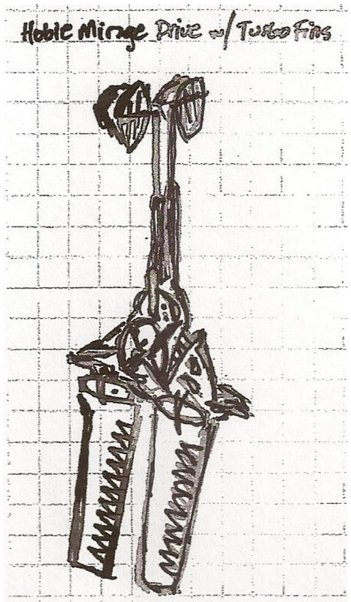



**FIGURE 4**

Furthermore, the new and final design layout of *Team Severn Glory's* submarine, the *SSH-11 Mighty Mid*, is shown in Figure 5.

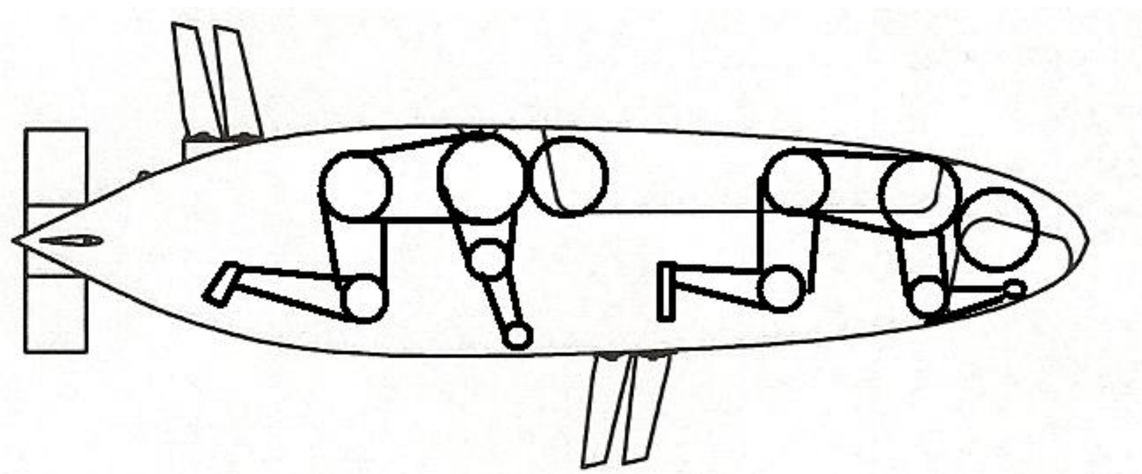


**FIGURE 5**

As one can see from Figure 5, the design matched that of Figure 1-2 on page 5 (CONCEPT section). Of course, due to the new form of propulsion there were a few more decisions that had to be made in order to properly accommodate the occupants. Looking again at Figure 1-2 and

Figure 5, one can see that while the tank location remained the same, a single customized tank would be used rather than two separate tanks. While this would require two regulators to be fed off of a single tank, it simplified the design and made use of the fact that our hull girth increase significantly in the aft section. Secondly, there is only one large hatch instead of having two smaller hatches. This was done in order to accommodate the rear propulsion system and decrease the amount of cuts we made into the hull. Lastly, the rear occupant direction was reversed in order to effectively put both individuals on their own separate drive system.

In short, a lot of changes were made in a little amount of time but the overall benefits from our trade-offs were extremely useful in terms of meeting time lines and being able to finish the project in well under one year. The next sections will further explain our final design and explain the fabrication and design techniques used to make the final product.

**FINAL DESIGN / FABRICATION**

**HULL**

As mentioned earlier in the report, the hull of the *SSH-11 Mighty Mid* was set from the beginning of the project. To reiterate, the reason was simply because the team had a half scale model available which would give us the opportunity to model test. However, the half scale model was the only physical starting point we had. Thus, the first task was to recreate the model in order to produce the full scale submarine from this half scale model.

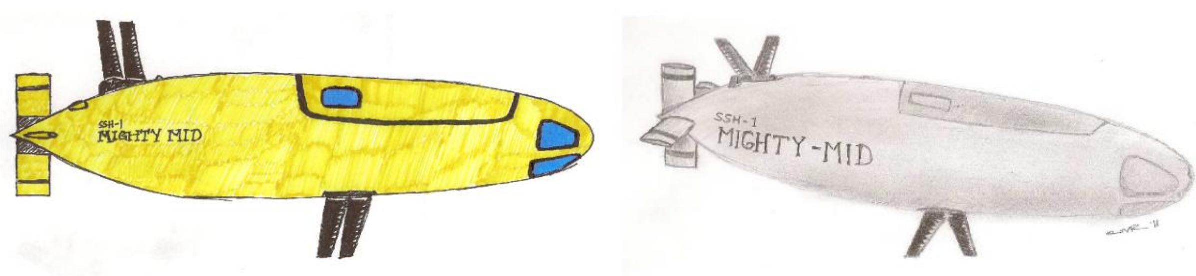
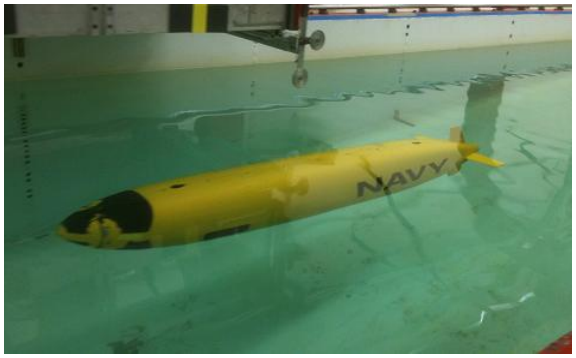



**FIGURE 6**

*(Various renderings of the final product)*

This was done using hand measurements and a hull design program called MaxSurf. While this method would not produce a 3D hull that perfectly matched the model, we needed the rendering as a design starting point. It was intended to make some major modifications to the hull, some of which included decreasing the beam and increasing the length. Thus, the hand measurements were more of a guideline to get the hull on the right track. Figure 7 shows a picture of the half scale model in the Naval Academy's 120' tow tank as well as on a stand.



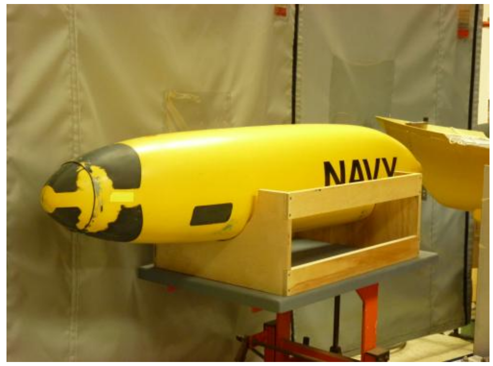




**FIGURE 7**

After the general hull design was generated in MaxSurf, we took about almost three weeks for conceptualizing where everything needed to be (in general) and adjusted the hull accordingly. During this time we also discussed the materials to use when constructing the hull, and the best fabrication method. It was decided that the best course of action would be to make a full-scale foam mold and then set the fiberglass to the mold. Thus, at the end of the three weeks, a final hull design was given to the Naval Academy's Technical Support Department-Model Shop Division so that a foam mold could be constructed. Figure 8 shows the machine cutting segments of the foam. Figure 9 shows the process taken in order to fabricate the mold. The process for making the mold will be described below.

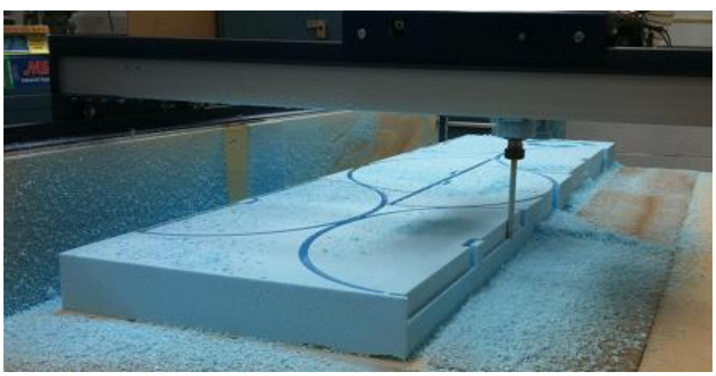


**FIGURE 8**

FIGURE 9

Th was to cut out all of the foam se can be seen in Figure 8 on the p ke a port side mold and a starboard s gments are in the shape of half c tions. In total, there were 72 foam segments made, 36 for each half of the submarine. A few of the foam segments are shown in the upper left picture of Figure 9, where one can see that the general shape of the submarine hull is starting to emerge.

Next, all of the segments are aligned and glued together to form one half of the submarine, as shown in the upper right picture in Figure 9. Once the glue dries the entire half must be sanded smooth and faired, shown in the lower left corner of Figure 9. This is about a 3 hour process and is extremely important because it governs the shape of the submarine. Lastly, once the fairing is complete the hull is covered in tape as shown in the lower right picture in Figure 9. The tape is then covered in a special wax that makes it easier to separate the mold from the fiberglass once all of the glass has set and is ready to be released from the mold. For this project we put about six layers of wax on to ensure that the mold would release the fiberglass properly, in turn leaving an intact mold that could be used by future Naval Academy Teams.

Once the two halves of the mold were complete, the process of laying the fiberglass came next in the fabrication process. We decided to use a mix of both fiberglass and carbon fiber, effectively using the carbon fiber as a central layer in order to add hoop strength to the hull. Multiple fiberglass layers were used for the rest of the hull. Figure 10 shows layering at different locations on the hull. One can see that the center is reinforced and that numerous layers of fiberglass and carbon fiber were used to complete the hull. Lastly, a layer of peel ply was applied in order to leave a generally smooth and lightly textured finish.

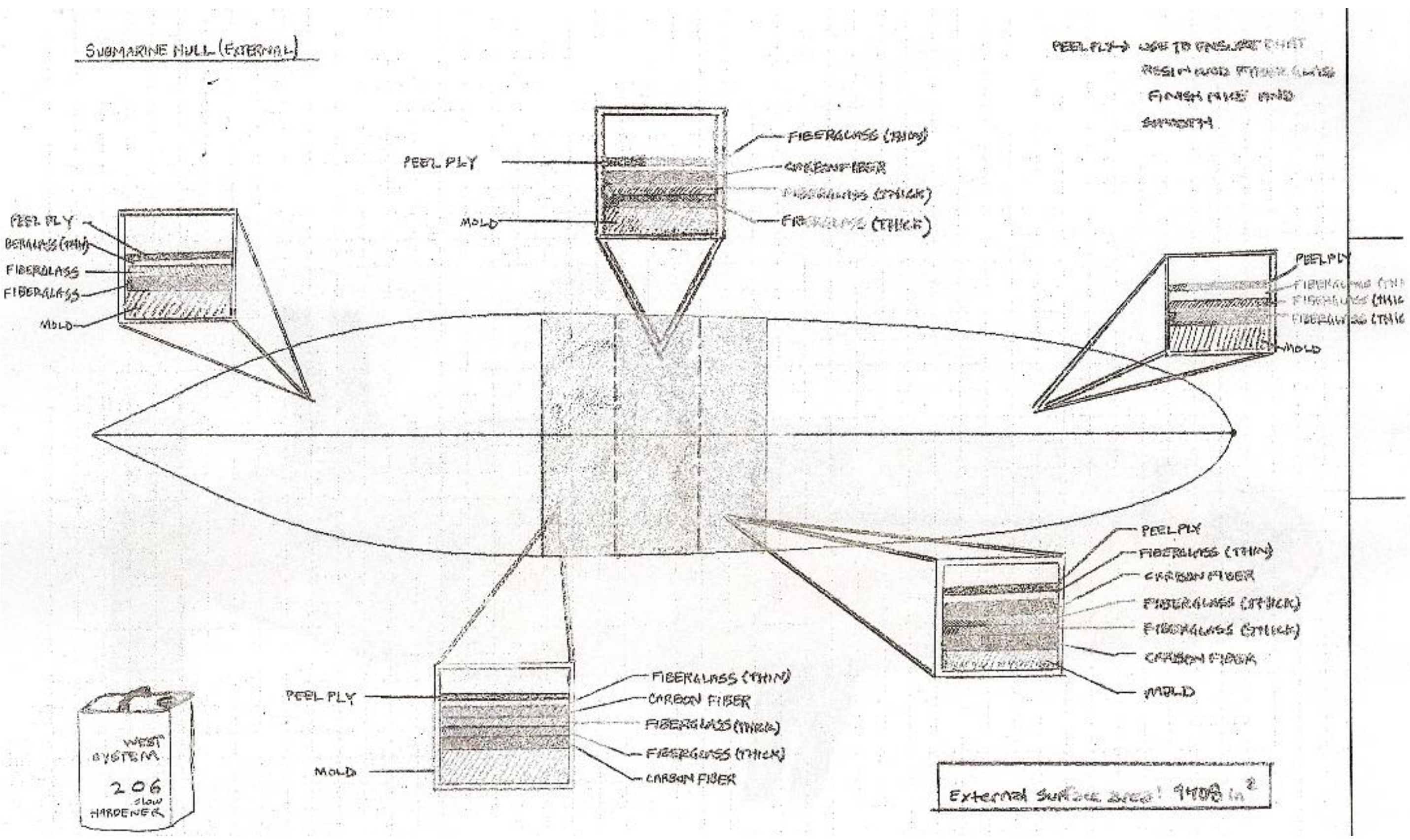



**FIGURE 10**

Once the two halves were completed (meaning that the resin and hardener mixture was finished and had cured) the two halves were sanded around the edges so that everything would line up correctly. The two pieces (port and starboard) were then combined by a strong fiber band that was placed on centerline. This band was placed both in the overhead of the two sides and the deck. Once aligned, the two pieces were then molded to the band as well as secured with screws for extra strength. This permanently joined the two sides and made one complete hull. The finished product is shown in Figure 11 along with the mold (still covered in yellow tape and wax). The hull is shown again in Figure 12 on a stand.

**FIGURE 11**

**FIGURE 12**

**PROPULSION**

As noted earlier, the *SSH-11 Mighty Mid* will have a non-conventional propulsion system. This will be accomplished through the use of the Hobie Mirage Drive, a system normally used to power fishing kayaks. A rough sketch is shown in Figure 4 on page 11. There were many reasons that the group chose the Hobie Mirage Drive over a conventional propulsion system. A main factor in this decision, as explained in the TRACE-OFF section, was due to the time needed to fabricate a functional gear box. Unlike the conventional propulsion system, the Hobie Mirage Drive was available to us off-the shelf. Furthermore, it put us into the non-conventional (non-propeller) category for the race, a category that we believed we could compete more effectively given the amount of time we as a team had to work with. Lastly, in terms of overall functionality, the Hobie Mirage Drive does not require a circular pedal motion to operate. Instead, it uses a linear pedaling motion to produce the required thrust to move (this will be explained in greater detail below). This was beneficial because it created more room in the submarines interior while also making it easier for the occupants to power since the linear pedaling motion is subjected to less resistance when fully submerged than the circular pedaling motion.

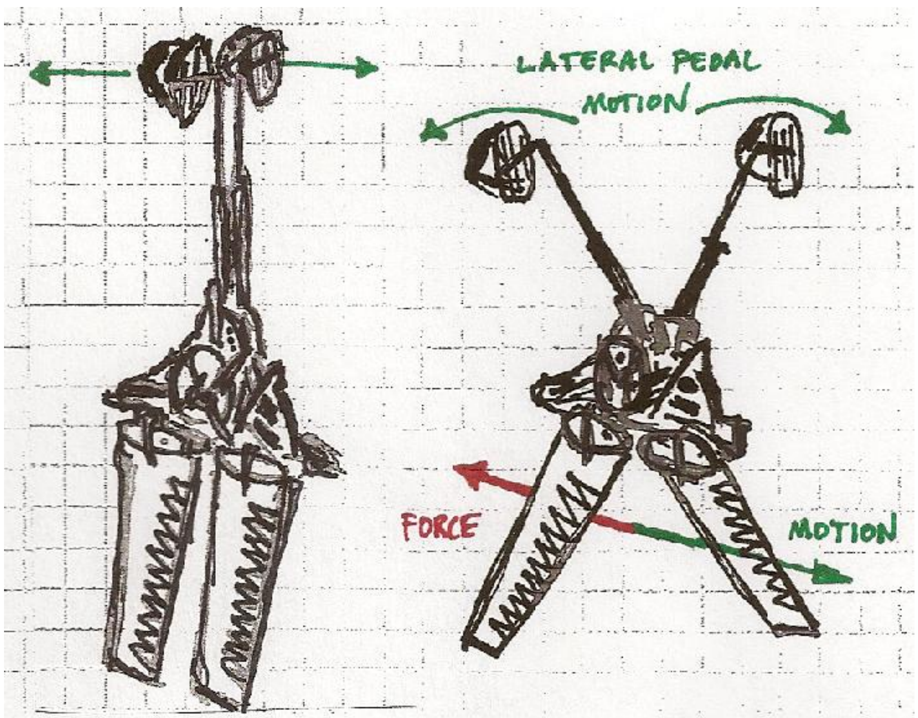



**FIGURE 13**

Figure 13 shows a sketch of the Hobie Mirage Drive and how it works. In short, by manipulating the two pedals back in forth (as if they were levers), the two fins at the bottom flap back and forth like the wings of a penguin. A picture describing this motion is depicted in Figure 14. As one can see (still looking at Figure 14), by moving the pedals back and forth the fins respond by reciprocating the back and forth motion, except that the fins are rotated 90 degrees. This produces a thrust which is perpendicular to the motion of the fins and parallel to the motion of the pedals, as shown in Figure 13.

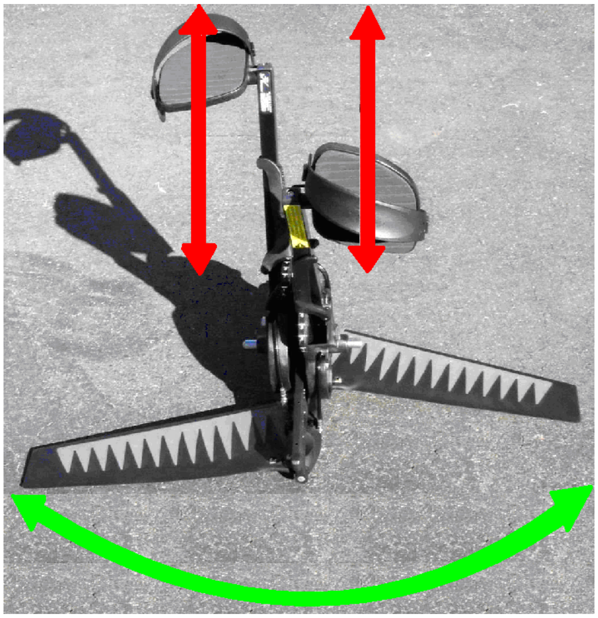


**FIGURE 14**

However, it must be noted that the decision to use the Hobie Mirage Drive as our main propulsion system was not made without some research and testing. The test results will be described in the TESTING section of the report.

**CONTROL SURFACES and CONTROLS**

While a significant amount of time and a full semester's research project was devoted to understanding and optimizing the control surfaces for the *SSH-11 Mighty Mid,* the final design aligned more with the team's core concept of simplicity rather than complexity through extensive research. Two systems that were highly considered for the control surfaces have been included in the final section of the report. The design chosen for the 11$^{th}$ ISR was simple in every regard. A conventional propeller normally induces a moment along whichever axis is rotating, unless there are two counter-rotating propellers being used. This makes the submarine less stable, and therefore it must have a more robust control system in order to counteract the produced moment. However, with the drive system used on the *SSH-11 Mighty Mid*, there is no induced moment. Thus, the need for a complex control surface design was not required.

Therefore, it was decided that a standard cross patterned design would be used, with each of the four control surfaces measuring 8” x 10”. The team also decided to base the shape of the control surfaces off of the NACA 0013 section, opting for a shape a little slenderer than the NACA 0015 section which is generally accepted to be the most efficient. This also made fabrication easy. Two long foam surfaces in the shape of the NACA 0013 section were cut (using the same machine that cut the hull mold) and then shaped into four control surfaces. These were then mounted on a shaft and covered in fiberglass. Their interior consisted of the shaft and an aluminum plate for added strength. The figure below (Figure 15) shows the basic control surface design.

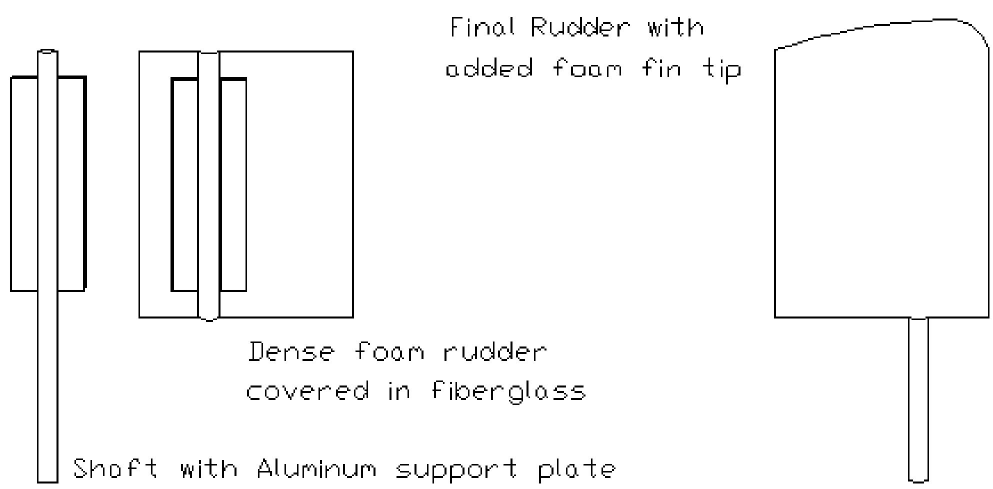



Figure 15

The control surface interface will be done mechanically rather than electronically. Using a custom build joystick attached to a modified Teleflex Marine Steering Kit (basically just the cables), the forward occupant will easily and effectively be able to manipulate the submarine with a single control system. Figure 16 shows the design of the joystick.

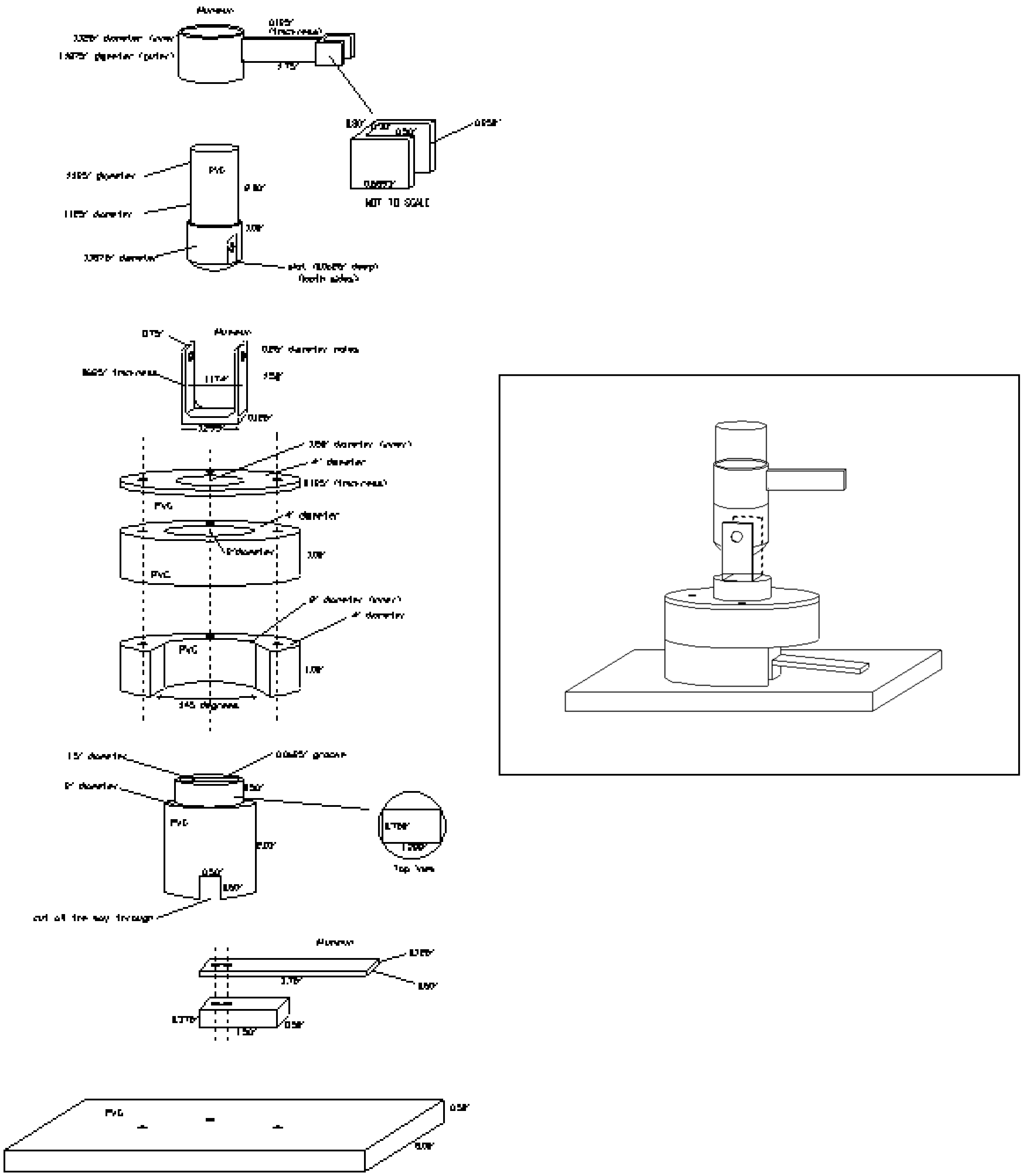



**FIGURE 16**

**HATCHES AND VIEWPORTS**

The hatches and viewports were one of the very first items to be fabricated once the hull was finished. This was done for two reasons. One, we needed access to the interior of the submarine (since the two halves were now sealed together) and it would also help us to finalize the exact positions of the occupants. As one can see from Figure 6 on page 13, it was decided that there would only be one hatch. This helped us retain the structural rigidity of the hull since we did not have to cut two holes into the submarine. The hatch was then fitted with a lip on the aft edge which would slip under the hull edge, coming to rest on the recessed edges of the hull once it was set flush. The hatch was made from the cutout section of the hull so it lined up neatly with the hull. It is locked into place by a custom build latch that is accessible from both inside and outside of the submarine. Figure 17 shows a sketch of the hatch design while Figure 18 shows the lip being fastened to the hull.

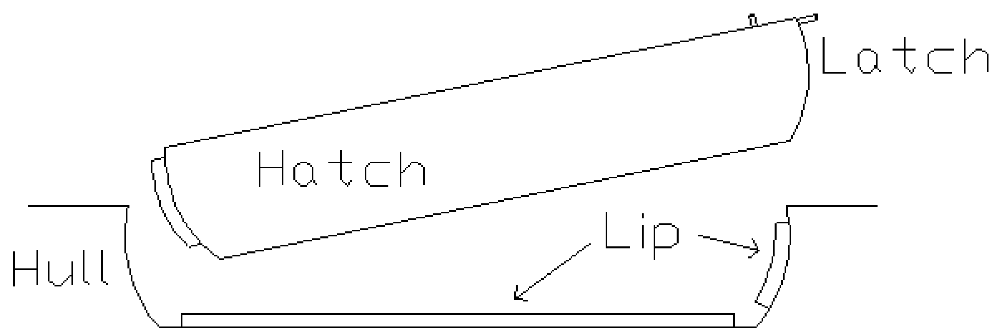



**FIGURE 17**

**FIGURE 18**

The viewports were not as simple to make as the hatch. Constructed from sheets of heat molded Plexiglas, we quickly learned just how difficult it was to make complex curves with glass. Figure 19 shows the three iterations of viewports we considered, with the final decision being the smallest of the three. Four of these smaller viewports were than arranged in the nose of the submarine, as shown in Figure 20. Two viewports were also put in the forward section of the hatch for the rear occupant in order to comply with the rule that required a viewport in the vicinity of each occupants face in order to tell their state of consciousness.

**FIGURE 19**

**FIGURE 20**

**EMERGENCY SYSTEMS**

The emergency buoy design for our submarine was regulated by the ISR rules for the competition. We determined it would be most feasible as well as easiest to place the emergency buoy in the aft most point of the submarine, thus allowing for easy release and no chance of a tangle up. The buoy is secured to the hull by a small magnet that is in turn linked to an electronic system that can activate or deactivate the magnet. The waterproofed system is then linked to water proof switches that, when released, deactivate the magnet. All together, we created a very effective dead man switch that will comply with the ISR Rules and Regulations. A basic layout of the system is shown below in Figure 21.

Note how the buoy is shape like a half cone in order to fit the full form of the submarine, thus reducing any drag.

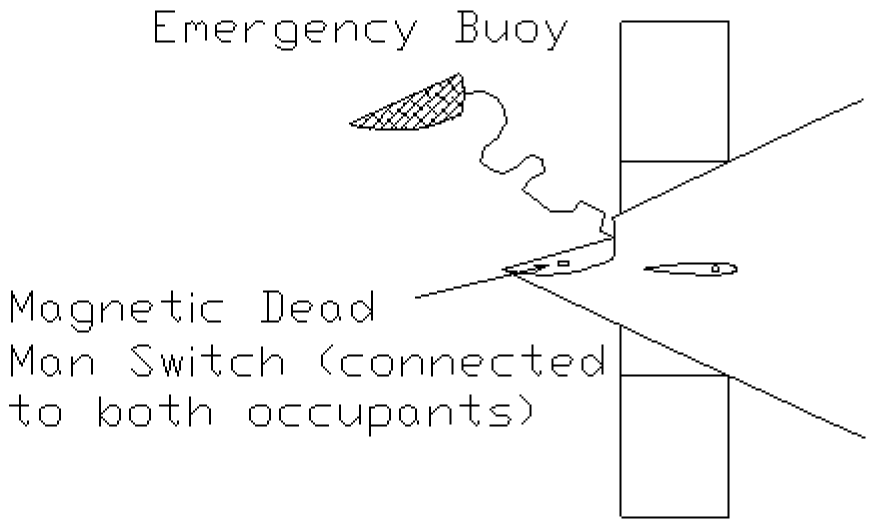



**Figure 21**

**LIFE SUPPORT SYSTEMS**

A basic layout of our life support system is shown below in Figure 22. It allows both occupants to breath easily from the same air source, which carries 150% of the required air needed for racing.

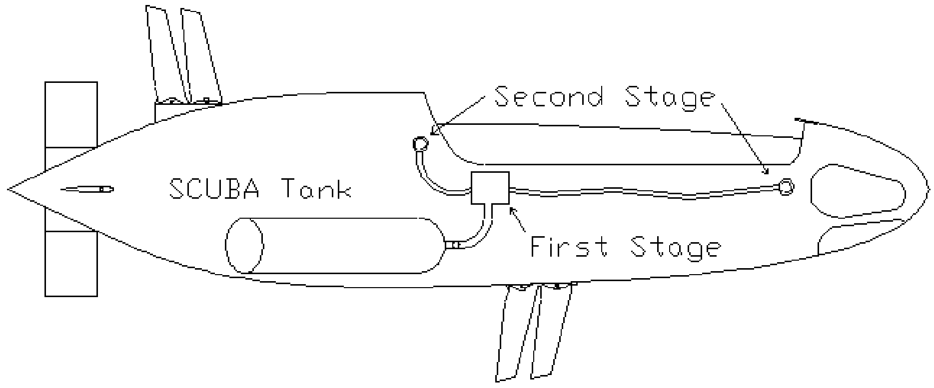



**Figure 22**

**TESTING**

Unfortunately, most of our major testing has not been done yet. We are currently in the process of completing the submarine so that we can begin finalizing and streamlining our design in order to be completely prepared come race day. That being said, we still ran numerous tests in order to ensure that our design would function properly in the first place.

**Basic Hull Test**

The first test we ran was to see how the submarine hull functioned in the water. This was done using the Naval Academy’s 120’ tow tank. Since the tank apparatus was unable to properly tow our model at the time, we had to run a simpler test which involved pulling the model by a tow string. The test allowed us to pull simple resistance data from the test; however, the overall goal was to see how the hull responded at different speeds.

To prepare the sub we simply made it slightly negatively buoyant with weights, flooded it and then attached to the towing apparatus with a medium weight string. The string was attached to the force block in order to determine the approximate resistance of the hull as it moved from the water. The submarine was then towed at various speeds and accelerations in order to observe the general character of the submarine.

From this test we learned three main things. For one, unless the model was accelerated slowly (about 0.5 ft/s$^2$ model speed), the model would rapidly stray out of control until it rammed the side of the tank. Thus, it required slow acceleration speeds to keep the model in control for the entire 120’ tank run. Secondly, we would need some sort of control surfaces in order to keep the submarine correctly oriented (we ran the test without control surfaces and with control surfaces to see the differences since we were considering retractable control surfaces at one

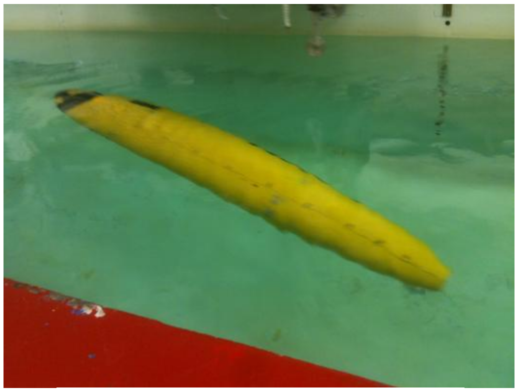


**FIGURE 23**

point). Without control surfaces, the submarine was helpless. Figure 23 shows the half-scale model belly-up as it moves down the tank on an out-of-control course. Lastly, it was found that the hull experienced very little resistance if kept at a constant speed. In other words, if we could design control surfaces that were effective at low angles of attack (and thus they would produce a smaller resistance), the speed of the hull would not vary as much every time we needed to make direction adjustment.

**Control Surface Test**

The next test we ran was to get a general estimate of how the submarine model would respond with control surfaces of varying surface area. We first ran the model (again, pulled by a string and slightly negatively buoyant) without control surfaces at a number of different speeds, noting when it first broke off course and lost control. We then ran the same exact test (same speeds), only this time with an oversized controlled surface (about 33% of the submarines surface area). These two data sets gave us the limits of the submarine; with on being complete control and the other being complete lack of control.

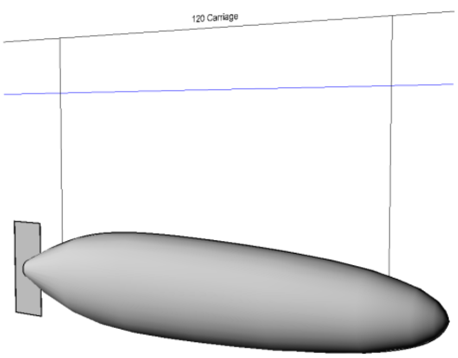


**Figure 24**

Next, since we knew how the submarine would perform when in total control (again, due to oversized control surfaces), we slowly trimmed down the control surface until we reached a combination that was borderline unstable. The results were qualitative in nature but provided a general idea of size and shape of control surfaces and thus the test generally served its purpose.

**Hobie Mirage Drive Test**

For this test we were given the use of a Hobie Kayak installed with the Hobie Mirage Drive, thanks to a local boating shop. We took the kayak to the Naval Academy's 380' tow tank and decided the first test to run would be to see how fast we could get the kayak to go.

After a few runs the kayak leveled out at a speed of about 5 knots. The same kayak only went about 4 knots with a person paddling with a conventional paddle. Next, it was necessary for us to run a bollard pull test in order to get a rough estimate of force generated by the Hobie Mirage Drive System. Last, the kayak was pulled by the tank's towing apparatus at the same speeds achieved by human power. This way, we could compare the power of the kayak to the amount of resistance that it experienced at certain speeds and thus assess if the Hobie Drive would be powerful enough to propel the *SSH-11 Mighty Mid*. The bollard pull yielded a force of about 25 pounds simply using one Hobie Mirage Drive, and since it was estimate that the full scale hull would only experience about 30 pounds of resistance we as a team concluded that the dual Hobie Drive Systems would suffice in terms of our propulsion system. A summary of the results is shown below.

USNA Hydro Lab test of Hobie Revolution Kayak 21JAN201

Pilot: Calum Ramm (160 lbs), Marathon Runner

Boat and Paddle: 78 lbs

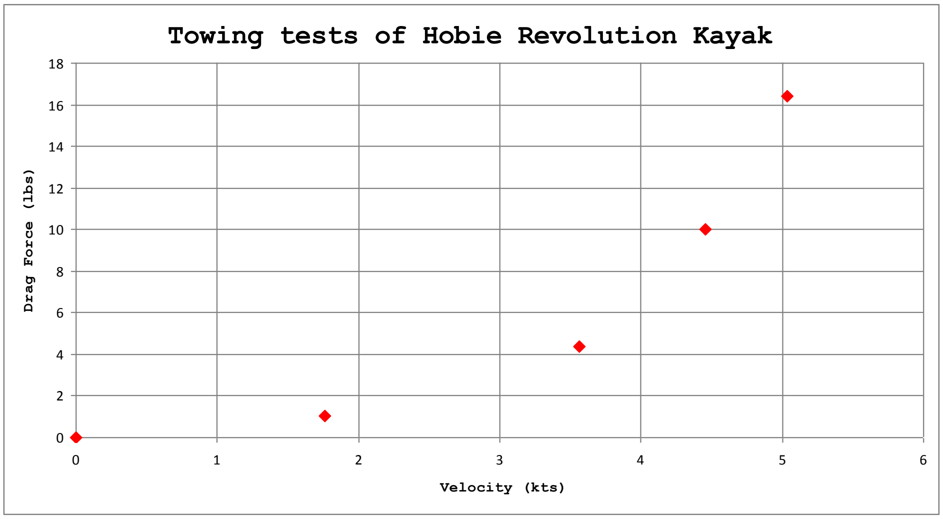
Hobie Drive System: 8 lbs (outfitted with Turbo Fins)

Total Configuration Displacement: 85 lbs

Course: 50 ft starting run to achieve max speed, 100 ft speed gate

| Run | Time (sec) | Velo (ft/sec) | Velo (kts) | Comments |
|---|---|---|---|---|
| 1 | 15.00 | 6.667 | 3.949 | first run; getting hang of peddling |
| 2 | 12.66 | 7.899 | 4.679 | |
| 3 | 11.84 | 8.446 | 5.004 | longer foot strokes |
| 4 | 11.82 | 8.460 | 5.012 | cadence ~1/sec |
| 5 | 15.09 | 6.627 | 3.926 | double paddle propulsion; best shot |

Towing Test Data



**TRAINING**

The team is holding tryouts during early March to determine the best possible candidates for Navigating and Piloting the submarine. Two or three pairs will be selected by mid-March. These teams will all train to get comfortable with powering and operating the submarine.

In terms of finding a place to train, or even launch the submarine, we as a team are still overcoming some of the many obstacles associated with operating the Human Powered Submarine, most of them involving safety. Until a training plan can be approved by our Chain of Command here at the Naval Academy, we are unable to test or even put the submarine into the water. Thus, we are working on establishing a safe and flexible training plan with the officer staff and faculty here at the Naval Academy.

We are fortunate to have one of the United States premier towing facilities here at the Naval Academy, which will be a great avenue for testing the submarine once the proper requirements are met. The 380 ft tow tank is ideal for testing, training, and optimizing the *SSH-11 Mighty Mid's* capabilities and will thus be the ideal training facility for USNA *Team Severn Glory*.

**TEAM ORGANIZATION**

| Faculty Advisor<br>Mentor | Lab Support<br>Construction |
|---|---|
| CDR David Robillard<br>USN | Tom Price |

| Student Project Lead<br>CO | XO |
|---|---|
| Calum Ramm | Chris Price |

| Hull | Propulsion | Control Surfaces | Hatches/Viewports |
|---|---|---|---|
| Ramm | Ramm<br>Tan<br>Mariscal | Ramm<br>Maliniak | Tan<br>Mendez |

| Life Support | Emergency Systems | Occupant Support | Control Interface |
|---|---|---|---|
| Price<br>Wegele | Tan<br>Mendez<br>Maliniak | Wegele<br>Mendez | Price<br>Ramm<br>Mariscal |

**CONCLUDING THOUGHTS / FUTURE DEVELOPMENTS**

The United States Naval Academy has always been proud of its long standing commitment to the pursuit of undersea development and breakthrough technological advancements. The International Submarine Races present a perfect avenue for allowing colleges around the world with like-minded goals to achieve these developments and advancements at an academic level, fueled by competition and the desire to excel. Since this is the Naval Academies first entrant in over twenty years, there are still numerous concepts and capabilities that we would have liked to outfit our submarine with. However, time and testing have prevented these ideas from being incorporated in this iteration of our submarine. Nevertheless, by the 12$^{th}$ ISR the following additions will hopefully be added to the Naval Academy's entrant:

**Retractable Control Surfaces**

This concept was briefly looked into and designed to the point where it could be fabricated. However, with little knowledge of the practicality and success rate of such a system, the team decided to wait for the next iteration to add retractable control surfaces. The thought was to employ two separate vertical rudders, each angled at the optimal angle of attack for the submarines max speed. One rudder would be utilized for maneuvering to port and the other to maneuver to starboard. They would be spring-loaded and be employed similarly to bicycle breaks. Thus, when not in use they would be inside of the submarine and therefore not creating additional drag.

**Motorized Control Surface Controls**

Another possibility considered for our 11$^{th}$ ISR entrant was motorized control surfaces. Instead of trying to ling the control actuator to the physical control surface mechanically, we would instead do so electronically with motors controlling the angle of attack of each individual control surface. This would allow for a much simpler user-interface system, while also allowing for much more advanced maneuvering possibilities. However, the electronic system always poses a slight threat being underwater in terms of waterproofing the system so that it does not short out and result in complete loss of the submarine's controls.

**Modified Fins**

The Hobie Mirage Drive fins are the biggest fins available for the Hobie Drive System. However, research done here at the Naval Academy has presented the opportunity to expand on the design of the hard-rubber fins. For the next ISR there are plans to create bigger and more flexible fins, thus creating more thrust and a more efficient system.

In all, the design that the United States Naval Academy will be entering in the 11th ISR is a complete and race worthy Human Powered Submarine. Hundreds of man hours have gone into creating a platform that not only complies with USNA *Team Severn Glory's* mission statement, but with the mission of the ISR. We as a team look forward to competing in June as well as getting the chance to meet and converse with teams around the world who share the same desire and drive to succeed as we do here at the United States Naval Academy.

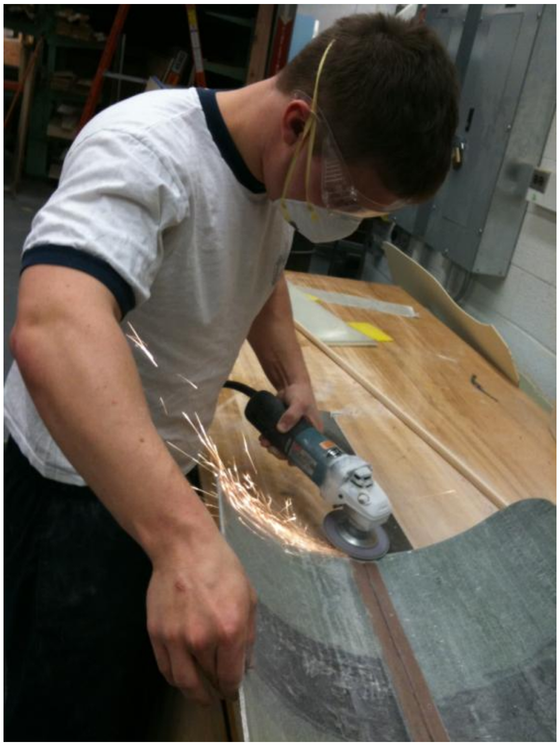
**ADDITIONAL PICTURES**

**HULL FABRICATION**

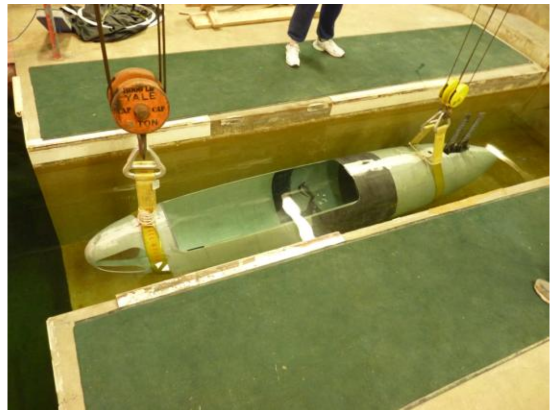





**GENERAL CONSTRUCTION**



**PRELIMINARY TESTING**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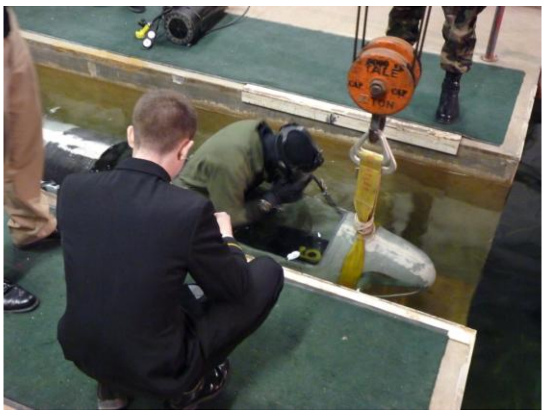
YALE