FAU BOAT II

FLORIDA ATLANTIC UNVIERSITY
HUMAN POWERED SUBMARINE CLUB

2014-2015

Bi-Annual International Submarine Races

Florida Atlantic University's redesigned two-man human powered submarine is called FAU Boat II. The new design includes redesigning of the hull, static trim, stability, propulsion system, control system, ergonomics, and safety. Over the past two years FAU's Human Powered Submarine Team has but their heads together to build the most efficient vessel they can.

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MISSION

Florida Atlantic University's Human Powered Submarine Club (HPS Club) was founded twenty six years ago in 1989. Over the years, the HPS Club has actively participated in the bi-annual International Submarine Races located on the east coast in Maryland. At these International Sub Races the club has received a modest number of awards and accolades; which include but are not limited to: Overall Performance, Speed, Cost Effectiveness, Time Trial, Absolute Speed Awards, and Best Overall.

Over the past two years, FAU's HPS Club has recreated FAU Boat II. The FAU Boat II is Florida Atlantic University's redesigned two-man human powered submarine. The new design of the two man submarine includes redesigning of the hull, static trim, stability, propulsion system, control system, ergonomics, and safety.

HISTORY OF FAU'S HUMAN POWERED SUBMARINE CLUB

The Human Powered Submarine Club located on Florida Atlantic University's main campus in Boca Raton, FL and is comprised of approximately thirty active student members of all disciplines of study. FAU's HPS team is registered on campus as an academic club. Unlike many other academic clubs on campus, the HPS team is strictly extracurricular due to the constant need to stay ahead of the competition. Students spend time day in and day out brainstorming new ideas and designs, building, testing, and analyzing. Club members engage in the invaluable experience of the sharing of unique skill sets, methods of thinking, unintentional errors, past conflicts, and teamwork; while at the same time forming bonds that will last a lifetime. The HPS Team spends such a great deal of time together that together it is essentially the same as creating a second family.

FAU's team operates and builds submersibles with a small annual club budget and sponsorship from local companies and benefactors. There is always an active search for support in all forms of assistance from aid and materials, to services and motivation, given by local businesses and other companies in the field.

Over the past year, the HPS team has been organizing fundraising events with sponsors. One fine example is in Pompano Beach, FL at Diary Queen and at SCUBA Network. At these events, Florida Atlantic University's Human Powered Submarine Club has benefited from general public awareness.

OUR TEAM

Our team is comprised of all students attending the College of Engineering and Computer Science at Florida Atlantic University. The team has all levels of students from freshman to graduation seniors. Members are enrolled in the Ocean, Mechanical and Computer Science departs at the University.

COMPETITION REQUIREMENTS

FAU Boat II is designed and manufactured to meet all ISR regulations stated in the '13th International Submarine Races Contestants' Manual Version 1.2.'

GOALS

FAU Boat II was designed to compete and excel in the overall speed category during the Bi-Annual International Submarine Races. Members of the HPS team sat down and put their heads together in order to design the fastest model that they could design and construct. During the design process, input from upperclassmen members and involved faculty was also put into considered and utilized while proceeding through the design and fabrication process.

The combination of the club's sources provided the team with the knowledge and skill set necessary to construct and fabricate a competition worthy human powered submarine. During the long course of the vigorous and extensive building process, a handful of adjustments were made in order to achieve the maximum speed possible. These adjustments were an ongoing project over the past two years of construction.

OVERALL CONCEPT

Concept of the Submarine was a team effect by each member given an area of research to put into the sub. Many of the subs that competed in years prior gave us a general direction. We as a team, decided that using the current two man submarine (FA U-Boat II) hull design would be and acceptable design primarily because it was readily available and proved to have a great flow design. Using knowledge and designs from years past allowed us to achieve our finished product.

The goal for the two-man submarine was to design and build an operational two-manned human powered submarine that can accommodate two divers, scuba tanks, propulsion system, steering system, and outfitted with a quick release dead-man system for both divers. There will be three hatches located on the top half of the hull with the front and back hatches to be able to open and close from the inside and outside whether from a rescue diver or the pilots themselves. The center hatch will be made available to access only from the outside due to that this is only to access the scuba tanks and the drive train. There are two large polycarbonate flat oval shaped windows that sit parallel with the submarine on the port and starboard sides for proper viewing of the pilots and can be removed for easy access to the internal systems when out of the water. The pilot at the controls of the submarine will have a large polycarbonate nose cone to view his heading and a square polycarbonate window looking downward to provide depth control.

HULL (DESIGN & MATERIAL)

Hull Design

The HPS team all agreed the most important features that the submarine needed was room for two divers, scuba gear and tanks for each person, an efficient propulsion system, an effective steering system, and a quick release dead man system for both divers as well as other key safety features.

FAU BOAT II PROPERTIES	
Max Cross-Sectional Width	2 ft
Overall Length	16 ft
Hull Weight	80 lbs

The design not only catered to overall speed but to safety as well. FAU Boat II is equipped with two quick release dead man system, a hatch, and a new approach to windows and the pilot's blind spots. FAU Boat II's quick release dead man system is controlled by the pilot's joystick that will release a positive buoyant hatch that will in turn, deploy the orange emergency signal buoy. Keeping safety in mind, the hatch is designed incorporating a quick release lever. The convenience of the quick release lever will also provide for easy entry and exit access for the diver as well as create an entry point to complete any necessary work and maintenance on the internal components. On both the port and starboard sides of the submarine there will be two large polycarbonate flat eclipsed shaped windows that sit parallel with the submarine for efficient viewing windows for the pilot inside. If needed, these two large polycarbonate windows are not fixed and can be removed when the vessel is out of the water to access the inside components for repairs and such. In addition to the two large main windows, there will also be viewing ports located on the underside of the nose that will allow view of the race course. Over past years, the HPS Club at FAU utilized the concept of a fully polycarbonate nose cone that lead to distortion of the illuminated light path on the course. Issues with the distortion over the past years has resulted in the decision to alter the design to simply just view ports alone.

The HPS Team believes that the new and resigned safety and viewing ports will give the FAU Boat II a better chance of finishing at the top of the record boards.

Hatches

There are three hatches located on the top half of the submarine; these hatches are designed to provide access for the divers to enter and exit the submarine. The goal is to design and construct a robust hinge and latch mechanism for the two-man submarine. The hatches that need to be attached are buoyant; therefore, they cannot be separated from the submarine or it results in the submarine becoming negatively buoyant and sinks when the diver enters or exits. Streamline hinges, an open and close operation, flush mount setback hinges. The streamline hinges will be based on the hinges on airplane wing flaps. The easy open and close operation would operate from inside and out which is the similar design of the Talon II. Hatches for forward and aft pilot must be perforated as well to allow gas bumbles from the pilots to escape to minimize the amount of added buoyancy that is achieved during a run. The hatches made during the fabrication of the hull don't fit properly due to the reshaping of the hull do to the aluminum bands stretching the original shape. Using some ingenuity and duct tape new hatches were able to be made. The process started with providing a foam mat base that was able to form the current shape of the hull and was supported underneath and pressed up flush with the gap where the hatch would rest. A sheet of duct tape was made by overlapping the edges of strips of duct tape and laid over, covering the foam mat base and sprayed with PVA. Five layers of basalt fiberglass and one sheet of foam mat were fiber glassed together. The new hatches were sanded down, fitted properly, given coats of marine grade filler, and sanded down and made a smooth curvature that relaxed to the curvature of the hull.

Nose Cone and Windows

The nose cone was originally modeled off of the CAD drawing from the hull but due to deformation of the hull new physical measurements were taken and added to the nose cone CAD drawing. Locating and contacting ADVAK a thermoforming company they were able to CNC half a male mold and thermoform 1/8" polycarbonate. Two shots were made and final cut to size and adhered together to form the cone shape. Due to human error the original nose cone was cracked, so to repair it we have used the old nose cone as a positive mold and covered it with layers of basalt and fiberglass. This process creates a shell around the cone that strengthens it as well as bonds the cracked portion of the cone together. We will remove portions of the shell to act as windows and to comply with the safety requirements. The new nose cone was attached to the submarine by drilling through the shell to original nose cone and using the old holes in the cone and submarine to bolt it down using 10/24 screws.

As for the windows the original shape and size did not match up to the hull. The CAD drawings were adjusted and using a water jet to precisely cut the shape of the windows from a sheet of ply wood to use for molds. The water jet was also used to cut the polycarbonate. These were used to fit the windows to the hull. Fitting the molds into place required some grinding, sanding, and cabosil resin filler for any voids. The windows are to be latched on using a mounted hinge system located in the interior of the sub. This system will allow for the windows to be removed and replaced if needed. In the event new windows are to be made the CAD files can be used to make exact replicas on the water jet.

Fabrication of the nose cone started with using the tip of the female mold used for making the hull. The polycarbonate was heated in an oven for several hours to dehydrate it to help prevent bubbles forming during the molding process. The polycarbonate was removed and draped over the mold which was attached to a vacuum that pulled the polycarbonate down forming the shape of the female mold. However, due to the properties of polycarbonate and the sharp curvature of the mold this method proved that vacuum forming this type of feature was not applicable and could not be done to proper standards.

Fabrication of Hull

Creating a structurally stable and streamlined hull for a tandem submarine is the first challenge to overcome. The hull started from a CAD model, there was then a male mold cut out of 8 lb fiberglass impregnated foam boards which were assembled and finished into a smooth male plug. Then two female molds were created from that plug, which is what the top and bottom half of the hull came out of. Construction started with a male quarter mold from which to female molds were constructed. The two female parts were then bolted together at the end to form the bottom/top of the hull. Layup proceeded in the following order, gel coat, chop strand, basalt with the layers of basalt varying depending on the side. The bottom received 5 layers of basalt and the top four layers with a foam core. The two halves where bonded together and reinforced with two aluminum bands. This method did not produce the exact hull from the CAD models but it was approximate even though manufacturing took place in the elements. The hull was stretched out with oversized aluminum bands that are glassed in place in attempts to recover the lost shape. Under the bands between the hull and the bands is a layer of cabosil resin filler to stabilize the glassing process. The rest of the hull was faired together using a low density resin filler, marine grade bondo, and sanded down to make a smooth transition. Strips of basalt and cabosil filler were installed to reinforce the seams of the top and bottom halves.

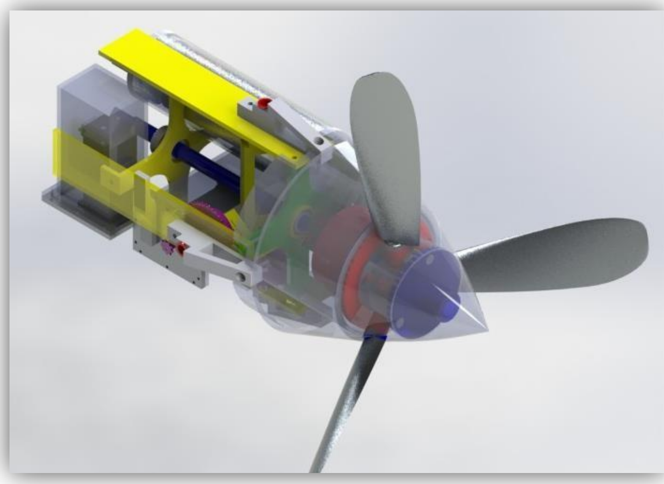
Material

A basalt composite fiberglass material was used to construct the two-man submarine. The material demonstrates a higher strength to weight ratio than fiberglass weaves of similar style however is easy to lay up and work with unlike carbon fiber or Kevlar alternatives. Polyester resin is used bond everything together primarily because of cost effectiveness. Epoxy Resin was used in key high load and fatigue points, such as mounting brackets, but due to its expense the use has been minimized. Polycarbonate was used for windows and stainless steel and aluminum hardware can be found throughout.

PROPULSION

System Overview

The overall goal of the propulsion system is to provide efficient power to the submarine that will maximize velocity while minimizing weight and drag. The FAU Boat II system consists of a series of gears and shafts connected to a fixed-pitch propeller (FPP) customized through FAU's CNC machine to create an optimal output efficiency at a medium to high intensity from the pilot. Due to the HPS team having varying drivers we are forced to accommodate for different physical capabilities versus fixed operating components.

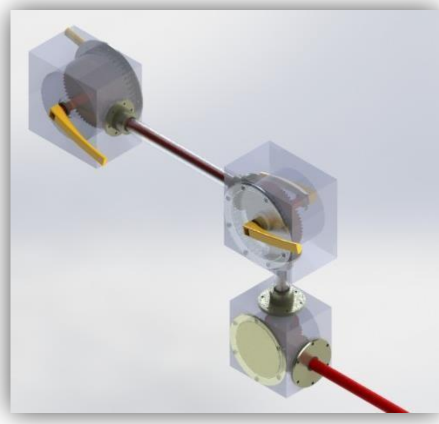


FAU-Boat II utilizes two sealed gearboxes to convert human power to forward thrust. Similar to a standard bike configures, two pedals on crank arms rotating a series bevels and pinion gears to transfer the power to the aft of the submersible. In designing the propulsion system, the amount of power that a human could input into a drive mechanism must be considered as well as the maximum revolutions per minute that they are capable of.

Experimental testing conducted at the school fitness center revealed that on a stationary recumbent bicycle trainer a human could output approximately 1KW of power. This peak power out was delivered at different RPM bands for different test pilots, however an ideal range of 75 to 150 rpm was selected which determined the final gear ratio.

Research and past data from the one man submersible 'Talon 1' allowed for a final drive ratio of 1:2. A larger cross-sectional propeller was selected to match the gear ratio, final RPM, and total power output of two humans. Ideally for two pilots, an average of 2 kW of power will be delivered, however final testing has yet to be conducted leaving the overall output number inconclusive.

Gearbox and Transfer Case



The divers wear bike shoes clipped into an egg-beater style pedal and 127 mm aluminum bike crank. Egg-beater style pedals and shoes are preferred as it allows the pilot to push and pull on the pedal ensuring the maximum power delivered. The 127 mm aluminum cranks have been modified from a standard 170 mm bike crank. The shorter crank decreases the amount of leverage available to the pilot and increases the effort required, but the final rotations per minute of the propulsion system is increased. This ensures that the divers can input the maximum amount of energy into the system and avoids free spinning. The pedals and cranks are set to a square ended axel protruding from the sealed gearbox.

The gearbox, as mentioned before, is recycled from the original FAU-Boat. A complete service was performed replacing all seals and bearings before it was mated to Talon 1 or the training stand. This service was completed in house by the Department of Ocean Engineering machinist Frederick Knapp. The gearbox was constructed from an aluminum block, it measuring 5.856 x 6.000 x 2.950 inches. Inside, a 1:3 steel ground spiral bevel and pinion gear system transfers the power to a stainless steel output shaft to the stern. To protect and lubricate the gears and bearings it is filled with 0W motor oil. The gearbox is mounted on an extension and mount that is fabricated to fit our modified hull. They were designed using Pro Engineer and a CNC to mill the parts. The mount was modeled to fit the curvature of the hull exactly. The mount is 14" long and the gearbox can be moved accommodating pilots from 5'6"to 6'3". There are a total of 13 different adjustments allowing placement of the pilot in the optimal position.

Blades

To properly design blades for our application we had to first accurately predict the power input of the system. To do this we did some stationary bike testing, and a joint inverse parametric study of the Talon 1 submarine. Between our propulsion team and Greg Platzer at Frank and Jimmy's prop shop we determined the prop to have an available 1.66 Hp (1237 Watts) at about 1.6 Hz. We used tools such as the MIT-PSF2 program, which uses lifting line theory to determine the propeller's characteristics; a similar program was attempted by several members of the club but its shortcomings consisted of lack of verification and it was based off of the obsolete wing sections theory which does not account for finite wing analysis. Due to these shortcomings, we decided to seek a better source of design.

The other half of our prop design consisted of the hull characteristics. After running CFD and mathematical model simulation, a drag coefficient of Cd= 0.002616. At our target speed of 9 knots, the sub's drag is about 219N (49.2lbs). The power equivalent of that is 1013w. Hypothetically, a propeller and drive system with an efficiency of 82% should allow us to achieve our goal speed. CFD modeling also allowed us to include our nominal wake field into our design. Seen below is the velocity cut away (left) and the plot of the free stream velocity constants for the radial section of the prop. This analysis helps us tailor the blades to work more efficiently behind our hull than in open water. The product of all of this is a left handed 30" diameter 3 bladed prop that is powered by a 1:2 gear ratio. The prop has a proposed 89.6% efficiency and harmless strength and cavitation concerns.

CONTROLS

System Overview

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Manual Pitch and Roll Controls

Modified to fit the existing mechanics of the electronic system in place, a cable system is attached for manual operation of the pitch and yaw controls. The cables are attached in a manner that allows the driver to control the submarine with a bi-directional joystick. The back and forward motions of the joystick will control the pitch while the left and right movement of the joystick will steer the submarine. Diagonal movement of the joystick will control the yaw and pitch of the submarine. The joystick is connected to the rudders via a set of steering cables, these cables are attached to the rudder posts which pass through thru-holes.

Static Trim and Stability

The submarine has two major combatants when it comes it comes to trim and stability. The first being torque roll from the propeller, and the second being the pitch and yaw reactions of the sub.

FAU Boat II is naturally stabilized against roll by flat sides, an offset buoyancy, and center of gravity. A combination of the vertical sides, offset buoyancy and center of gravity allow for a reactive counter-force produced from the torque of the driver. This compensation is what will allow the submarine to remain stable throughout the water. The hull has layers of foam in the top while being solid on the bottom, therefore this inherently provides an offset buoyancy. In addition, we have compensated for the added component weight, such as the gearbox, by placing foam in dead space in order to achieve the required natural buoyancy.

An estimated 80lbs of weight has been added to offset these components. The more buoyancy to offset with ballasts, the more stable the hull will be since its righting moment is a function of the coupled buoyancy and weight force along with the roll angle. The buoyancy of the submarine is mainly created using pourable closed cell polyurethane foam.

According to Archimede's Principle, the buoyant force on an object is the weight of the fluid that it displaces.

Buoyancy Equation:

Buoyancy (B) = Density of Medium (ρ) * Gravity (g) * Displaced Volume (V)
Weight (W) = Density of Medium (ρ) * Gravity (g) * Displaced Volume (V)

Since the sub's internal volume moves with the hull, any weight added to the sub in lead does not add to the accelerated inertia of the system due to the weight being offset by foam to keep the sub neutral. While this may seem to suggest that weight is not a concern for speed, it is a concern for space. The heavier the sub, the more interior space we lose to foam and the less efficient our pilots can be while racing.

Therefore, in order to make the submarine buoyant, foam inserts must displace at least 80 lbs. plus their own weight in water.

In the past the volume was displaced by 2lb/ft poured into different molds and shapes to make foam inserts. Now the pourable polyurethane foam has been switched to 1.75lb/ft3 foam. This was in need of replacement because the foam shrunk causing the gel coating to crack and deteriorate. The extruded polystyrene foam was chosen as a replacement because it is easier to shape than the pourable polyurethane as well as weighing less. The extruded polystyrene foam retains its shape better than the pourable polyurethane which eliminates the problem that the pourable polyurethane foam demonstrated. The pieces of the extruded polystyrene foam must be large enough for buoyancy purposes but strategically placed to give the pilot ample room to operate the submarine and aid in egress situations if necessary. The blocks interlock in the sub for support during runs and transport.

When it comes to dynamic stabilization we are able to make use of a combination of foam and weight to prevent roll created by the propeller. Since the propeller caused the submarine to experience a right hand rule we placed extra foam on the starboard side in conjunction with equal weight on the port side. Also, the pitch will be dynamically stabilized to minimize any forces the driver has to deal with. The pitch and depth are not a constant adjustment so the drag caused by these corrections is necessary. Overall the sub is a combination of static and dynamic methods for a stable underwater vessel.

ERGONOMICS

System Overview

FAU Boat II was designed to be easily manufactured, assembled, transported and repaired. Manufacturing of the submarine was completed on FAU's main campus in Boca Raton, FL, due to time and financial constraints. One major fabrication inhibitor was that systems were designed so that the submarine could be built using on-campus resources. For more complex or specialized tasks such as the polycarbonate nosecone and the vinyl exterior wrap, local sponsors were sourced for assistance.

Joystick

The Joystick in the submarine is a totally manual system that has been placed in a location so that the driver is oriented in a head first position with his back against the top of the submarine. The joystick is placed far enough forward to allow for drivers varying in height to be able to fit and have their knees amidships in the sub to allow for the greatest range of motion. The other consideration concerning the joystick is placing it an area where it still has a full range of motion and doesn't contact the hull as it is used.

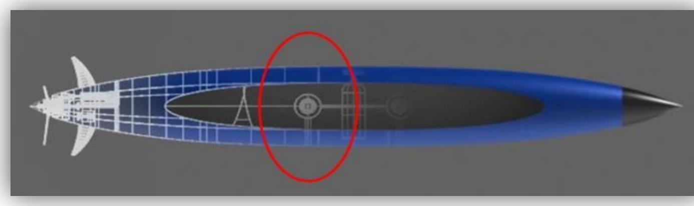
SAFETY DEVICES

Life Support

Onboard FAU Boat II the life support system is designed to meet the regulation of the 13th ISR Manual. Each of the aluminum air supply tanks are up to date on both hydro and visual checks indicated by the latest date on the tank. Each pilot and support diver on the FAU HPS team is PADI open water diver certified or higher. During the operation of the submarine one forty-five cubic foot tank will be filled to meet race regulations which will be used for the pilot's air supply. This supply will provide enough air to run for more than two complete runs. This provides a 200% air reserve supply which meets the required 150% indicated in the Bi-Annual International Submarine Race Manual. If needed, the submarine will also have a spare emergency air bottle located next to the pilot for any sort of issues that may occur. Before each run the safety chair will be checking the air pressure in both the pilot's primary and spare tank to ensure the 200% reserve supply is kept and that the tank does not fall below the indicted five-hundred pounds per square inch.

The main air supply will be secured to the hull by dive straps for easy removal of the tank when it is empty. The spare emergency air supply tank will be secured in a different location for ease of access for the pilot. The regulators and pressure gauges will be connected to the tank when the pilot enters the sub. The support diver will be equipped with an octopus regulator to give needed air to the pilot or whoever is in need of oxygen.

Dead Man Switch



ABOVE SHOWS THE APPROXIMATE LOCATION OF THE DEAD-MAN SYSTEM WHICH IS CIRCLED IN RED. THE HATCH IS LOCATED ON THE UPPER PORTION OF THE HULL AND IS A INDICATED WITH ORANGE SAFETY TAPE.

In case of any emergency that the pilot may have, there is a dead man switch located on the joystick. The component is a re-engineered bicycle break handle that be used to deploy a pop-up buoy that has a high-visual orange coloration with thirty two feet of cord that will be attached to the sub. The buoy is be deployed from a 3 inch tube from inside the hull. The buoy hatch is locked by the engaged lever. Both the switch and the engaged lever will be attached by a throttle cable which will open and close the switch. When the lever is engaged the switch will be closed and open when the lever is released. To ensure the full release of the buoy the switch will be spring loaded. Once the lever is released in an emergency the hatch will unlock, open, and the buoy will deploy.

Pilot Restraints

The diver restraints inside FAU Boat II are similar to those inside the sister one-man submarine Talon II. The driver are secured by harness which is constructed from diving weight straps and clips. The pilot has their own length of the straps that adjust to his or her personal desire.

Road bike clip in shoes will be used to get the maximum force on the crank. These shoes all have Velcro straps. These clip-in shoes have been modified with a high-visual reflective orange strap for emergency removal. All buckles and straps have be modified as well to ensure all restraints can easily be identified for removal by safety officials in case of any sort of emergency.

CRADLE

Two different cradles were used during the manufacture and test processes in making FAU Boat II. One cradle made from wood 2x4, rubber, and wood screws was used during the building and fabrication process. The other cradle is made from aluminum and has four wheels that can is made so that the sub can be easily transported over rough terrain. The aluminum cradle also has four clips so that the sub can be moved in to the testing pool via a crank pulley system behind the workshop. This way the sub is not damaged during the testing process.

FINANCES/SOURCE OF FUNDS

All funds that were given the Human Powered Submarine Club was provided by the universities' COSO account. COSO is the Council of Student Organization and provided finances to clubs that meet the requirement throughout the year. Requirements included participation in school events and logging a minimum amount of hours during those events.

TRAINING

Each member of the club that is going into the sub is encouraged to exercise extensively before the competition. Cardiovascular exercises like cycling, swimming, and jogging is a great way to get into shape before the competition. Members also joined spinning classes located on campus to help prepare before the race. These exercise will best prepare the pilot to cope with the pressure on the leg muscles underwater. The biggest factor in conduction underwater movements is the resistance of motion underwater will waste most of the power delivered. Studies conducted at FAU states that 0.33 HP can be produced by a fit adult and when underwater about half is lost to resistance [1]. The best way to deliver the most power to the propulsion is by extensive cardiovascular and weight training.

CONCLUSION

The purpose of this Human Powered Submarine project was to bring together a team of multi-disciplinary students with a wide range of skill sets to develop a functional, racing submarine through teamwork and cooperation. For many of the club members it was their first serious engineering venture. Due to the amount of inexperienced engineers, there was a rollercoaster of ups and downs, giant steps forward and overwhelming steps backwards. Overall it has been an amazing hands-on learning experience for all members and in the future we are guaranteed to see vast improvements in capabilities, design and manufacturing. The continual advancement of computer technology and 3D modeling allows for more precise and accurate manufacturing of parts and designs. The use of computer programs allows creative and innovative ideas to be manufactured and tested. Between the design, craftsmanship, management, and constructive testing of the sub it's an invaluable opportunity to learn and apply new skill sets. From these acquired skill sets the completion of new designs will be used to optimize the efficiency and performance of future submarines.

FAU-Boat II has proven to be an excellent new addition to the HPS @ FAU family of vehicles. The design, craftsmanship, fabrication, management, and intensive testing have taught the team invaluable skills over the past two years. This report detailed the steps and new information pertaining to human powered submarines as well as other engineering and creative projects. Innovative, new designs and systems have expanded the teams knowledge and creativity in ways never hoped before. Between the design, craftsmanship, management, and constructive testing of the sub, the experience gained has proved to be an invaluable opportunity to learn and apply valuable skill sets. From these learned skill sets, the completion of new designs to optimize the efficiency and performance of the sub will continue to exceed new limits and set new expectations, not to mention having fun.

REFERENCES

1. Lockert, Charles R. "Basics of Design and Construction of A Human Powered Submarine" , FIT Sea Panther, 1989