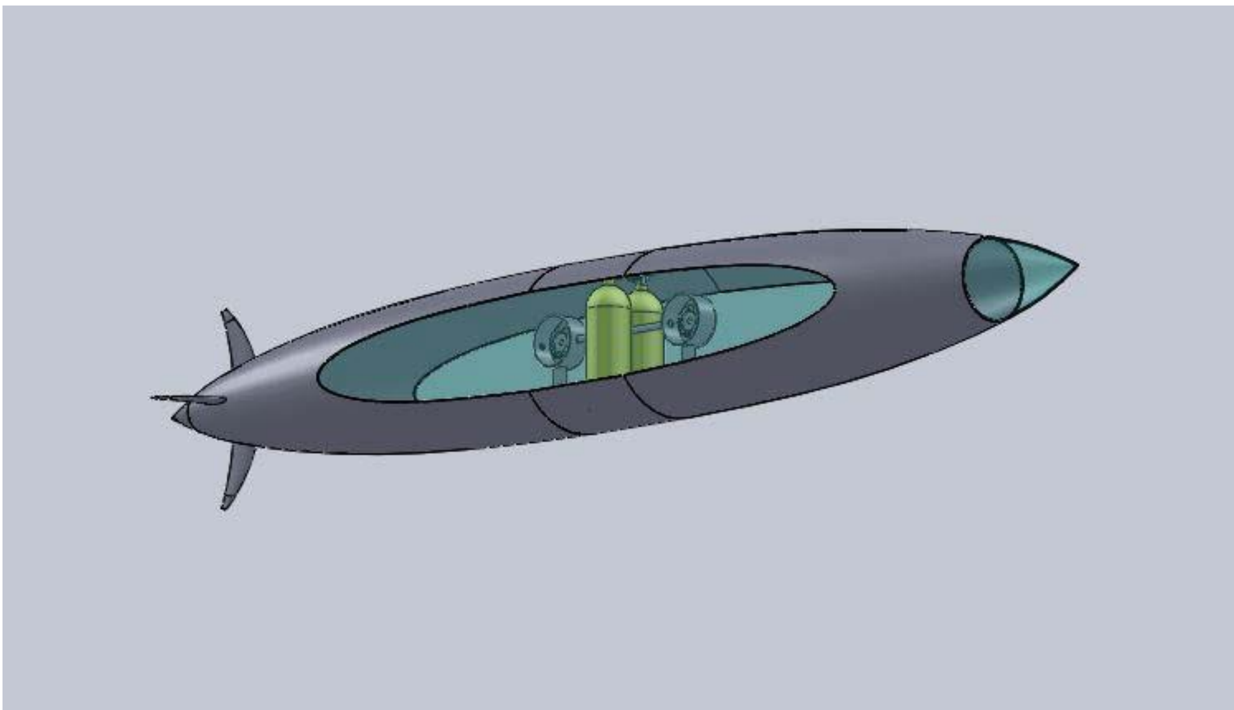
FAU-Boat II



Florida Atlantic University

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1 Introduction:

The Florida Atlantic University's Submarine Club was founded in 1989 and over the years has participated in the bi-annual International Submarine Races. From these races, the club received a modest number of awards and accolades which has helped to continue the clubs existence at Florida Atlantic University. These awards included but are not limited to Overall Performance, Speed, Cost Effectiveness, Fastest Time Trial, Best Overall and Absolute Speed Awards.

The aim of this report is describe in detail the design and construction of *FAU-Boat II*, Florida Atlantic University newest two-main human powered submarine. This includes aspects of the hull design, static trim, static trim, stability, propulsion system, control system, system aspects, ergonomics and safety. This report will cover the entire process for start to finish and provide specific details to enable the reader to potentially build their own human powered submarine.

2. Human Powered Submarine Club @ FAU

The Human Powered Submarine Club @ FAU is comprised of approximately thirty active student members. The team is registered as an academic club on campus and is strictly extracurricular. It is open to currently enrolled students at Florida Atlantic University and students across disciplines are encouraged to join. Club members learn from each other's unique set of skills, mistakes, past experiences, as well as form lifetime bonds and essentially a second family.

The team operates and build submersible with the help of a small annual club budget in addition to help from local companies and benefactors. Members actively search out local businesses for assistance whether it is monetary, materials, or services rendered. In the past year, members have been organizing fundraising events with sponsors, in particular Dairy Queen of Pompano Beach and SCUBA Network, and benefited from public awareness.

3. Submarine Hull:

3.1. Submarine Hull

The goal is 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. This submersible will provide easy entry and exiting access for the divers and for a maintenance purposes. 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 drivetrain. 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.

3.2. 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.

3.3. 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 of 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 1. 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 tht 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.

3.4. 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. The nose cone is attached to the hull by bolting it on with 10/24 screws.

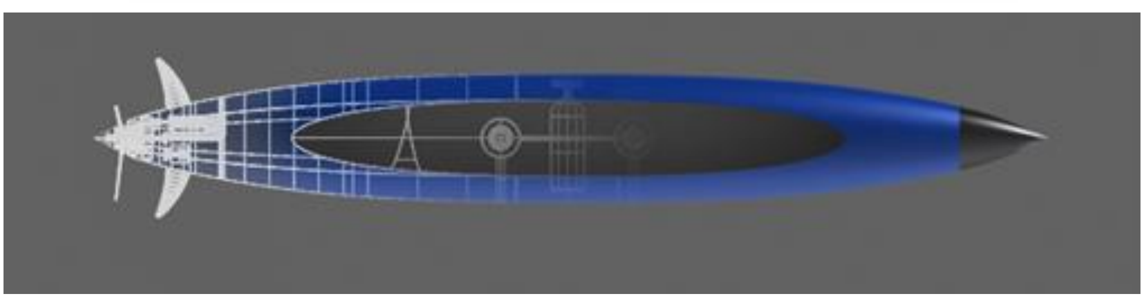
As for the windows the original shape and size did not match up to the hull. The CAD drawings were adjusted and using a water jet to precisely cut the shape of the windows from a sheet of ply wood to use for molds. The water jet was also used to cut the polycarbonate. These were used to fit the windows 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.

3.5. Material

The material used to construct the two-man submarine is a basalt composite fiberglass material. 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 is used in key high load and fatigue points, such as mounting brackets, but due to its expense the use has been minimized. Poly carbonate was used for windows and stainless steel and aluminum hardware can be found throughout.

FAU-Boat II Properties	
Max Cross-Sectional Area	2 ft
Overall Length	16 ft
Hull Weight	80 lbs



4. Electronic System

4.1. System Overview:

The intention of the electronic system in the submarine is to provide more robust control of the vessel. With a mechanical system, the pilot is not able to detect small changes in depth and the pitch of the vessel cannot accurately be determined. With the design of the two man submarine, pilot communication has become a necessity and therefore a system where the front pilot (the one who is steering the submarine) can communicate to the rear pilot how fast they need to go. Performance analysis is an attribute that is expected to provide a lot of information on how the submarines can be modified in the future. So far, the design of the submarines has been based off of what is believed to provide the most effective output with an empirical analysis. A numerical analysis allows the designers to determine what modifications to the system have the greatest impact in each specific area.

The electronic system incorporates 2 Arduino Due microcontrollers into separate housings (front console, rear console). Each microcontroller will serve as an interface for the pilots taking digital and analog input and providing visual output; however, the rear microcontroller will provide additional functions like controlling the motors and logging data. During run mode, the front console will relay the control input from the pilot to the rear console which will in turn tell the stepper motors to move to a certain position based on that input.

To relay information like pilot control input, the Arduinos communicate via an RS-485 protocol. This was chosen because it has been proven to have low noise interference over long distances because it uses a differential signal over two wires as opposed to a signal on one wire over the common ground. Conveniently, the stepper motors used to control the fins in the submarine use this communication protocol and no additional steps were needed to adapt them to the system. Two serial buses were created to streamline communication between the front and rear consoles and from the rear console to the stepper motors. Since the Arduino microcontroller can execute the command of writing to a serial buffer while the continuing with the program, the second serial bus allows the rear console to read new information from the front console without interfering with sending commands to the motors.

4.2. Display/Communication

The diver consoles are the main interface between the divers and the submarine. The visual parts of the consoles are the display and LEDs which function for diver communication and to indicate the status of the submarine. Buttons are mounted on the side console for safety and communication and the buttons on the joystick and handles navigate the interface as well as provide communication between pilots. The pilot controls the direction of the submarine and changes the pitch of the propeller using a button on a joystick in their primary hand.

One of the many advantages of using an electronic system in the submarine is that the pilots can view various bits of information collected from sensors on a visual display. For the two-man system, a liquid crystal display (LCD) module is used to display the speed, depth, pitch of the submarine, run time and the pitch number of the propeller. Pitch number is a numerical description of the position of the propeller which can be related to the gears on a bicycle, from zero to ten. The display is a 16 column by two row module that uses a parallel communication to read its information. To adapt it to minimize the number of wires required, the module uses a “backpack” that mounts on the LCD which converts the parallel communication module into a serial communication module. The LCD then only requires three pins (power, ground, serial) to operate.

One challenge faced by the pilots is controlling the power input into the drivetrain. The front pilot needs to tell the rear pilot how much power they want them to contribute to driver train. If the submarine is nearing the end of the course, the pilot will want to slow down to a stop. Conversely, the pilot may wish to tell the copilot to pedal with maximum effort during a straightaway for max speed. The solution to this is visual display that the pilot can change depending on the desired result. Two buttons on the joy stick allow for control of the visual displays. This will cause LEDs to either turn on or off indicating to pedal harder or softer. These LEDs are located just above the LCD display so the copilot doesn't have to look far to obtain all the information they need during a run.

Emergency and non-emergency communication methods were put in place for pilot-pilot communication and exterior communication. For the non-emergency communication, there is a button on the left side of each console to indicate that the pilot needs to stop pedaling for a non-emergency reason. This means that they don't need to stop the run, but they need a moment to remedy whatever issue they may be having. An example of this would be that one of the pilot's shoes came unclipped from the crank and they need time to clip in again.

4.3. Dead-man and Emergency Systems

The emergency dead-man system communicates with both the pilots and the rescue divers outside the submarine. The electronic dead-man system works similar to the mechanical dead-man; if the handle is released, the system will deploy the buoy signaling that the divers are in trouble and need to be rescued. The electronic system for the two man takes this concept a step further. If one of the divers releases the dead man, all the LEDs in the submarine will flash and a message will display on the other pilot's LCD that their teammate in trouble.

4.4. Electronic Interface

To the right of the LCD screen are the three status LEDs which indicate the status of the electronic system. During standby/low-power mode the red LED is activated and during diagnostics, the yellow and green LEDs will flash. During diver login mode the yellow LED will be active. During run-mode the green LED will be active.

Below the status LEDs are the diver login status LEDs. When the divers go through the login process in the interface, they select their name so that their names will be the name of the data file. After they select their name, they will be prompted to press and hold down the dead-man switch. This is the final indicator that the diver is ready to start the run. When the dead-man switch is activated by one diver, the corresponding LED will activate on both the front and rear console which will indicate to the other diver that they are ready. Once both dead-man switches on the front and rear have been activated, the system will start logging data before the run actually starts. This insures that all information from the start of the run until the end of the run is captured.

4.5. Linear Actuator

The linear actuator to control the pitch of the propeller comes from Firgelli Technologies Inc. It resides in a separate housing from the stepper motors and therefore requires a separate underwater connector to its housing. The controller that will be used to send the commands can receive a PWM signal or an RC signal and testing will determine which signal is the most suitable for the system's needs.

The rear console will receive a pitch number from the front console based on the pilot's desired thrust at a given position on the course and the rear console will determine what position the linear actuator needs to move to in order to provide the appropriate pitch of the propeller. The controller used to communicate with the actuator also comes from Firgelli and is a closed loop system. This means that it is able to receive a position from the microcontroller and immediately navigate the actuator to that position without additional assistance.

4.6. Inertial Measurement Unit

To measure the performance of the submarine and in turn the performance of the pilots, an inertial measurement system is to be installed on the motherboard. This sub-system will consist of an electronic gyroscope and accelerometer for the race and during testing a magnetometer will be used to insure better accuracy. This unit will keep track of the pitch and roll of the vessel. The pitch is used to modify the response of the fin motors as they will no longer be acting on the standard horizontal and vertical planes. If there is a need to modify the height or direction of the vessel, the response of the fin will change with different pitch angles. If the sub is at a 10 degree tilt the system will have to actuate moth fins to get the sub to dive or surface. The roll is used to measure the pilots power output which will be based primarily of measuring the torque roll.

The main components of the IMU are the ITG3200 gyroscope and the ADXL345 accelerometer acquired from SparkFun. The design team has chosen to use the surface mount version of these products as opposed to the pre-assembled modules as these components will be integrated into the motherboard of each console. These motherboards are significantly more compact that a series of preassembled units. Since these two components are the only components of the submarine system that communicate via I2C, they are expected to not interfere with the microcontroller network and thus provide high rates of sampling while communicating on the network.

4.7. Pressure Sensor

The depth detection is achieved using a redundant pressure sensor system that consists of two pressure sensors placed near the front console (one static and one dynamic) and one static pressure sensor near the main console. The reason for the redundant pressure system is to insure the depth readings are accurate.

4.8. Fin Control Motors

The motors used to control the fins are the Silverpak 23CE integrated stepper motors with encoders. These motors were chosen because of their ease of use, strength and precision. The integrated encoder allows for position control and correction if slip were to occur during a run. The motors can also be programmed to execute a series of functions as desired. They operate on their own closed loop system that communicate to the controller with a higher level position command, which takes the computational load off of the main processor. Also the stepper motors allow for a flexible system that would give instead of break like many geared systems would.

4.9. Fabrication

Setup and testing of RS-485 communication protocol was accomplished by acquiring a 485 transceiver chip and soldering it to a surface mount board. This setup was tested on the stepper motors by successfully sending and receiving values to and from the motor. The motor responds to an absolute position command and commands to step a specified number of steps in the forward or backward direction.

Layout of motherboard was accomplished by consulting with a member of the faculty at FAU (Ed Henderson). By acquiring surface mount replacements of the current modules a considerable amount of space is expected to be saved by mounting the components on the motherboard. Mr. Henderson has lent his time and abilities to assist in producing a printed circuit board that will mount on an Arduino Due.

Electronic wiring diagram have been produced using the software P-CAD Schematic 2006. It has provided better visualization of how the electronics will be connected. The schematic of the electronics has allowed the designers to finalize the number of pins exiting each housing as well are wire routing. This aids in producing the cables and connectors that will mate to the housings inside the submarine. Mr. Henderson is assisting with the molding of the underwater cables.

The software of the system is currently being developed and most of the planning and testing of the individual components has been completed. Assembly of the motherboards has been outsourced to faculty in the ocean engineering department (Ed Henderson).

5. Static Trim and Stability:

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

The sub is naturally stabilized against roll by flat sides and an offset buoyancy and center of gravity. The sub will be under more torque roll than experienced by the previous Talon-1 craft for two reasons. One, the gear ratio is lower (1:2) so more torque is translated to the water; two, there are two people pedaling so there will be more power for the sub to translate to the water. These factors call for drastic offsets of the subs natural buoyancy. The Hull has layers of foam in the top while it is solid on the bottom, giving the hull this offset inherently. Then to compensate for the components that we add such as the gearbox, as much foam as possible is located as high and to the starboard of the craft.

An estimated 70lbs of buoyancy should be added to offset these components, but 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.

Buoyancy Equation:

Buoyancy = density of medium * gravity * Volume

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 that 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.

The idea of having a dynamically stabilized roll system was dropped when the size of the independent steering system was considered; and the inherent drag caused by the constant correction factor of the fins was unwanted in the system. This roll will be compensated for in the steering planes, but not corrected for. However, the pitch will be dynamically stabilized to take that dimension out of the pilots concerns. 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 vehicle.

6. Propulsion:

6.1. System Overview

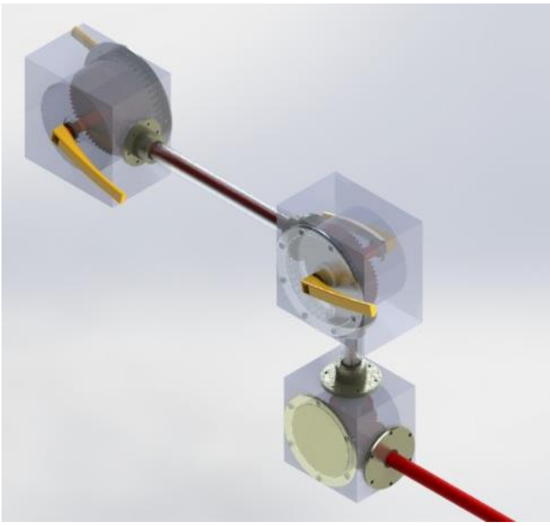
FAU-Boat II utilizes two sealed gearboxes to convert human power to forward thrust. Similar to a standard bike configures, two pedals on crank arms rotating a series bevels and pinion gears to transfer the power to the aft of the submersible. In designing the propulsion system, the amount of power that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

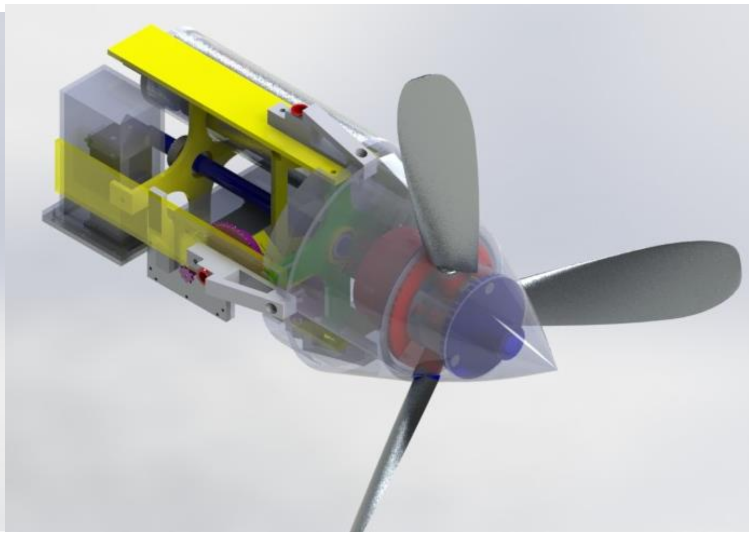
Experimental testing conducted at the school fitness center revealed that on a stationary recumbent bicycle trainer a human could output approximately 1KW of power. This peak power out was delivered at different RPM bands for different test pilots, however an ideal range of 75 to 150 rpms was selected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

6.2. Gear Box and Transfer Case

The pilots input their power into individual sealed oil gearboxes that are directly connected together with shrouded .5 inch transfer shaft. In these gearboxes, a 1:2 gear ratio is used doubling the revolutions per minute (rpm) of the system. The collective power is then sent to a transfer case with 1:1 miter gears which allows us to transfer the power aft to the submarine along the bottom of the hull. The sealed gearboxes and transfer cases are assembled to create one complete gear box. By creating separate units for each function allows for greater flexibility in the future. Individual units can be used in future submarines with minimal modification.





Power is sent via a .75 inch aluminum shaft to the aft module in the submarine. Here the .75 inch shaft attaches to a painted steel sprocket on the bottom of the hull and the power is transferred up to the mid-plane of the hull where another sprocket attached to a .75 inch aluminum shaft is present. The selected sprockets double the rpms once more to provide a final gear ration of 1:4 (one revolution at the crank : 4 revolutions of the propeller). The .75 inch aluminum shaft attached to the sprocket exist that aft of the submarine and is connected to the variable pitch hub.

6.3. Disclaimers

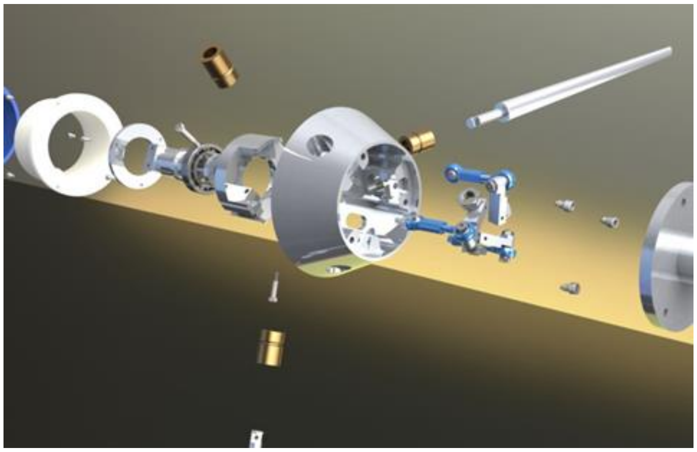
The pilots are always connected together and can never become decoupled from the propeller or each other. There are also no pressure plate clutches. Flywheels or energy storage devices are not present in the system and are not permitted per the rules. The only motors in the entire submarine operate the fins which are necessary for navigation.

6.4. Variable Pitch Assembly

In an effort to make the platform, we decided to use a variable pitch propeller system. The main advantages of running a system like this are better acceleration, better pilot flexibility, and it can be used to collect more data for a better second generation prop. This system is all part of the main tail module.

6.4.1. Design

The variable pitch hub is flexible enough to actuate the pitch of propeller blades at a 7 degree rake 45 degrees. This range of motion allows the blade to have less pitch at slow speeds allowing the pilot to get the propeller moving with a lower torque demand. The pilot can electronically shift the blades to a more aggressive angle as he speeds up just like you would shift gears on a bicycle. Having this variability in the load allows users to tailor it to their cadence of highest power output. The actual force applied to the fins is applied through a linear actuator with position feedback stationed back in the drive assembly.

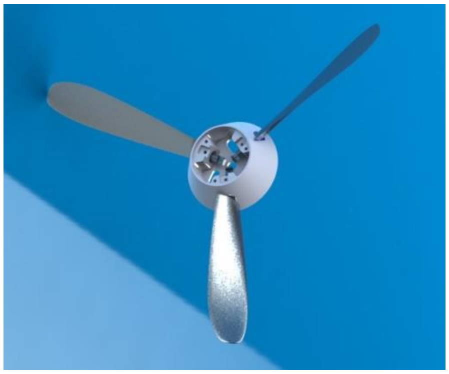


6.4.2.Fabrication

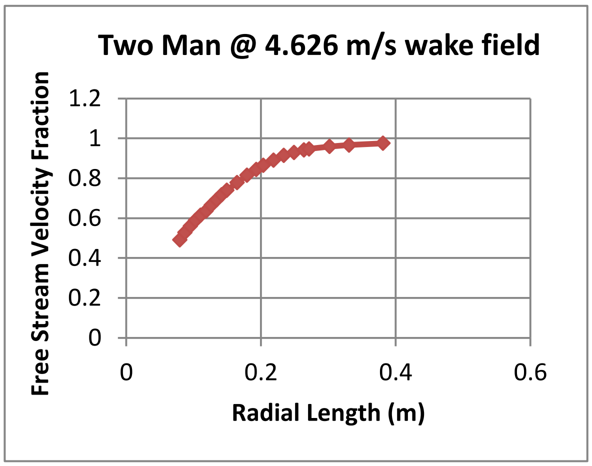
The hub and blades are all made out of computer controlled mill cut 6061 Aluminum. The blades simple mounting system is easy to replicate in order to use the same complex hub with multiple blade designs for future submersibles. It features anodized aluminum tie rod end to adjust pitch of each blade and brass sleeves to minimize wear.

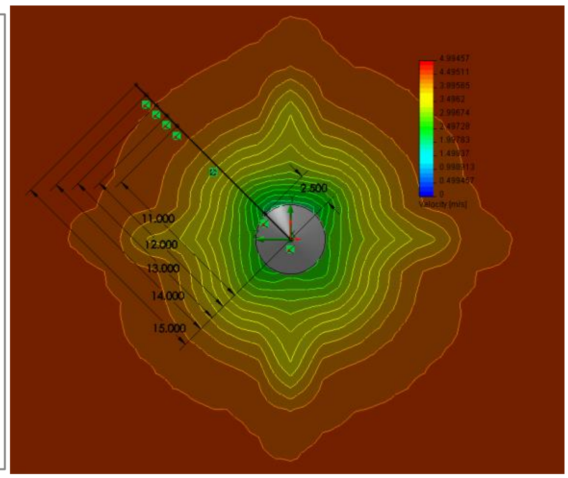
6.4.3.Blades

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 Jimmies 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 C_d= 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 effiency of 82% should allow us to achieve our goal speed. CFD modelying 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.





7. Control Systems:

7.1. System Overview

The goal is to create a reliable and flexible control system that allows us to maneuver the submarine easily. The control system will be a digital controlled fin actuation system that uses the pilot's commands and gyro sensors in order to hold a steady path. With this control system, there are two waterproof analog joysticks that control the vertical and horizontal movement. These joysticks are ergonomic and durable and are read by potentiometers. In the steering system there are control panels, that were properly designed, that are sealed with actuators and can give feedback to the surface. The steering system also holds the batteries, computer, dashboard module, and tandem communication system. The dashboard module shows the pilots the speed, communication, compass, depth and orientation. The Tandem communication system is the system that allows the two pilots to communicate with each other underwater while using the submarine. This steering system design allows the submarine to be controlled easily and effectively.

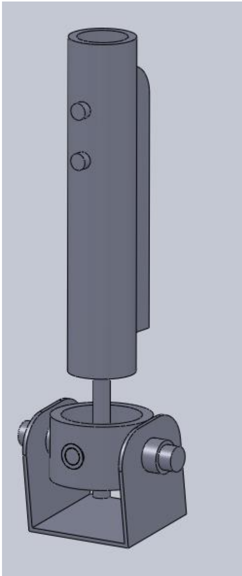
7.2. Data Logger

The goal is to have this device log information for Talon 1, which will record pilot and submarine performances for better testing feedback. Attached to Talon 1 is a small Arduino outfitted with an inertial measurement unit, tachometer, and data storage device. There is no accurate or precise means of recording the submarine's performance that has been applied to Talon 1 so in order to be more exact several factors must be recorded; some of these factors include output torque, thrust, prop rotation, and speed over-ground to improve the efficiency and performance levels. The output torque, in newton meters, is recorded by gyro sensors and characterized by torque roll. The prop rotation, in radians per second, is recorded through an integrated tachometer based on a photo-interrupt system. The tachometer is on a test stand that operates on hall-effect sensors, but the test stand operates with a single load and the power requirements are different in stationary water, which have been taken into effect by determined testing. The speed over-ground, in meters per second, is measured through either a dead reckoning, Doppler shift sensor or camera post analysis. This logging device , since no current deployment exist, allows the submarine to be used at the most accurate levels since each data set can be recorded to a user profile allowing the perfect pilot to be used for FAU-Boat II.

8. Ergonomics and Safety:

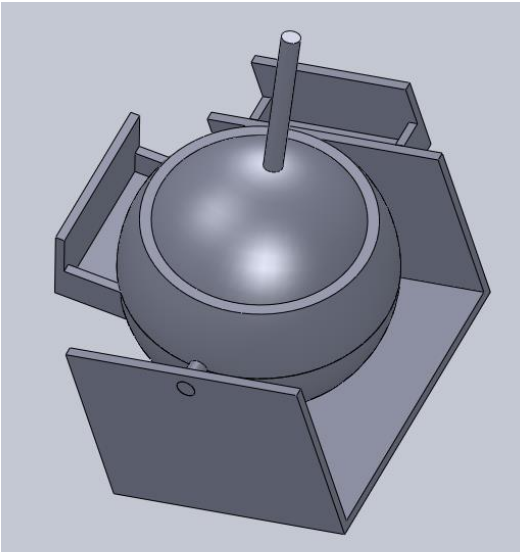
8.1. System Overview

The submersible is designed to optimize user input. A system is sub-par if it is distracting or in the way of the pilot. For this reason, the steering, communication, and dead-man systems have all been designed to require minimal pilot attention, allowing pilots to focus completely on obtaining maximum speed.



8.2. Joystick

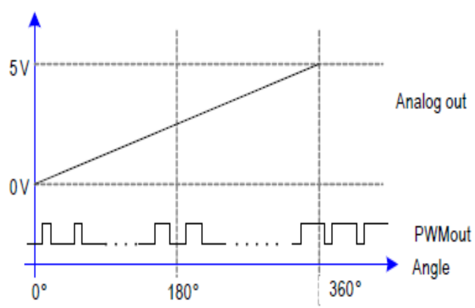
The objective of the joystick design challenge was to create a device capable of outputting an electrical signal representative of location in two axes while being submerged up to 10m deep in water. Although joysticks that output a varying electrical signal are commonplace, joysticks that can be submerged to a depth and still electrically function are not readily available. Many methods were considered to yield the desired electrical output including optical sensors, contact potentiometers, contactless potentiometers and encoders. Also considered in the design were materials that would allow the moving joints to easily move while submerge and handle repetitive use and exposure to sea water. With the consideration of all methods and materials a submersible joystick was designed.

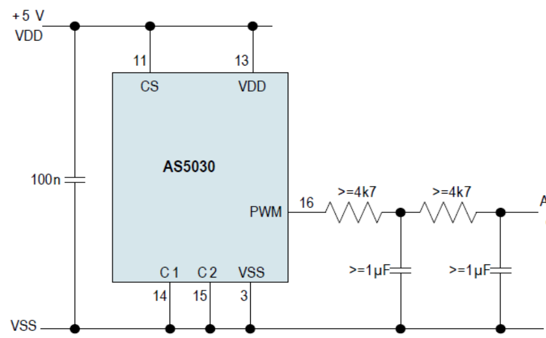


One method of determining absolute location is with an optical detection system. These systems, such as an optical mouse, detect variance in a series of photos. By identifying and comparing key pixels in subsequent photos the processor can then estimate distance and direction of movement. This data can then be added to the location of the fixed starting point and translated into absolute location. Optical detection systems can, after characterization, output absolute location, but are a more complicated than necessary in this application.

A common method of determining absolute in a rotary control system, such as a joystick, is through the use of rotary potentiometers. The potentiometer is a voltage divider that controls its output voltage by turning a physical component. If the output voltage of the potentiometer is measured it can be determined at what angle the physical component is in comparison with the body of the potentiometer. If two potentiometers are arranged in a 90° offset formation the absolute position on a plane can be determined. Potentiometers work on a simple brush contact system.

Through many design phases the final sensors and materials were selected to accomplish the goal within the design constraints. Price, size, availability, time for construction, ability to be reliably submerged in water and durability were all considered when picking materials. Aluminum was selected for the all part of the joystick except the electrical components and the bushings in the moving joints. The material for the bushings was selected to be Acetal.

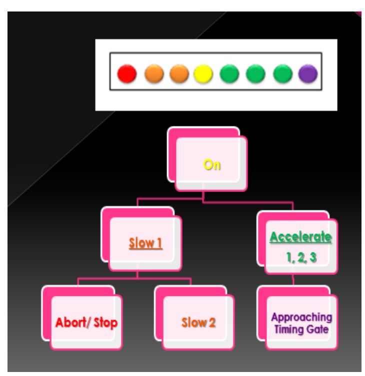




The magnetic rotary encoder underwent preliminary testing to ensure that it would work for the desired range and confirm the spec sheet. When tested, it performed as described in its published literature. All parts of the joystick have been shown to work suggesting that when all materials are present and assembled the joystick will be functional.

8.3. Pilot Communication System

FAU-Boat II's 2 Man LED Pilot Communications System will allow both pilots' to communicate and work together as a team. The problem that is being addressed is that currently there is no way of communication between the two pilots that both concurrently will be supplying power to and driving the sub. It should be noted this is a wet submarine. By using an Arduino Uno board and designing a LED Visual gauge and remote, both pilots can communicate instantaneously. This is especially important since the rear pilot cannot see out the front of the sub. The answer is this LED communications system. The visual gauge has a linear set of colored LED's which when lit signal the pilot to speed up, slow down, they are approaching a speed trap, a steady all systems go and a red emergency LED for precaution to the rear driver. The remote has two LED waterproof buttons that make them easily seen underwater so they can be pressed to indicate what action is desired.



A working electronic LED communication system has been implemented for a pilot communications system. When the unit is supplied with power, the yellow LED lights up indicating the unit has power and is in what is defined as the neutral position. As you can see in the figure to the right, the hierarchy exists below the linear visual gauge and thus is how my project operates.

The LED placement is a critical decision due to the fact that the drivers were in need of something easy to comprehend, visible underwater, small and waterproof. A linear presentation is chosen for convenience and maneuverability.

The LED colors all symbolize what is defined as a stage operation of the submarine. In a linear pattern from left to right the first LED, position one, is the only red LED and symbolizes the “Abort & Stop” command. This command is necessary since only the lead pilot is able to see out of a window and thus could communicate a potential hazard. Additionally if one of the pilots activates the Dead Man Switch, this can be communicated so that all peddling operations come to a haul.

The next LED color in the linear visualization is the color orange. There are two orange LEDs that take up positions two and three. The orange LEDs symbolize the ‘slow down’ command. Respectively Position two is slower than position three.

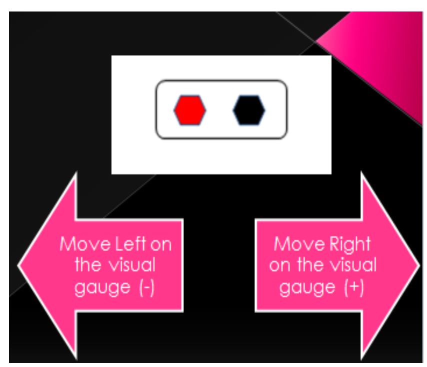
The yellow LED is the next color and occupies position four. This position had been declared as the “Neutral/On” indicator and powers on as soon and until the unit has power to show that it is ready to be used.

The green LED is the next color and occupies positions five, six and seven on the linear gauge. Like Traffic lights, green means go and each additional green light stands for the increasing of the current man power that is peddling the submarine.

The purple LED is the final color that is used and occupies position eight on this visual gauge. This color as well as position signals that the submarine is approaching a timing gate and that the submarine needs to be operating at top speed when passing this timing gate.

8.3.1.Communications Controller

The controller is operated by 2 buttons. As seen in the figure. In the left, the black button when pressed once moves the light one position to the right each time it is pressed. If the black button is held for 2 seconds or more the green LED’s as well as the purple LED lights up to signify that the submarine is approaching a timing gate and needs to be moving as quick as possible. The red button does the opposite and when it is pressed, it moves the lighting position to the left by one position to signify that the submarine needs to decrease its overall speed. When this red button is depressed for 2 seconds it will light up both orange LED’s and the final red LED to signify an Abort if needed in an emergency.



8.3.2. Materials

A grand total of sixteen 6mm LEDs will be used in in the visual communications unit. In the table below, the breakdown of each LED’s quantity, color, wavelength, and meaning is shown below in the table.

Quantity	Color	Specifications of LED	Command
1	Red	1.8-2.2 volts	Abort/ Stop
2	Orange	1.8-2.2 volts	Decrease Speed
1	Yellow	1.8-2.2 volts	On & Neutral
3	Green	3.0-3.4 volts	Increase Speed
1	Purple	3.0-3.4 volts	Approaching Timing Gate

Two different types of resistors were used in this project. The LED's indivually require a 200 ohm resistor (seen in Figure 6) while each remote requires one 10 K ohm resistor.

An Adruino Uno was used as the microcontroller in this project. This microcontroller is designed off of the ATmega328. This board has fourteen digital input and output pins 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. Table 3 gives a summary of this particular board.

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Table 3 - Arduino Specifications Chart.

The clear boxes are 7 cm by 3.5 cm by 1.5 cm and the overall thickness is 4 mm ± 0.5 mm. Originally they were going to be made out of acrylic sheet but it was both faster and 6cheaper to order six of them, then it would have been to make four of them so they were outsourced. What is nice about the boxes is there is a lip around where the lid seals that can be sealed with silicone and will showcase nice and smooth in addition to being waterproof.

Waterproof buttons are to be implemented based off the final construction of the joystick. In the figure to the right is the exact buttons that are used in the submersible instead of the previously seen red and black testing buttons.

8.4. Life Support (SCUBA System)

The life support systems for both pilots consist of two 45 ft^3 scuba tank that meet race regulations. The system is designed to provide enough air for two intense runs in addition to two more runs. This creates a 200% reserve air supply which is greater than the requirement listed in the contest manual. The tanks are placed in the center of the submersible, one on top of the gear box and one on the bottom. Both are connected to nine foot regulator hoses and run forward and aft respectively. The two tanks are mounted with tank straps to allow for quick swap outs, ensuring minimal downtime.

Two Spare Air bottles are located in the forward and aft compartments and are easily accessible to the pilots. The bottles are to be used in case of emergency egress. Some pilots opt to have the bottle strapped to their torso; a harness has been constructed to allow for that.

8.5. Restraints

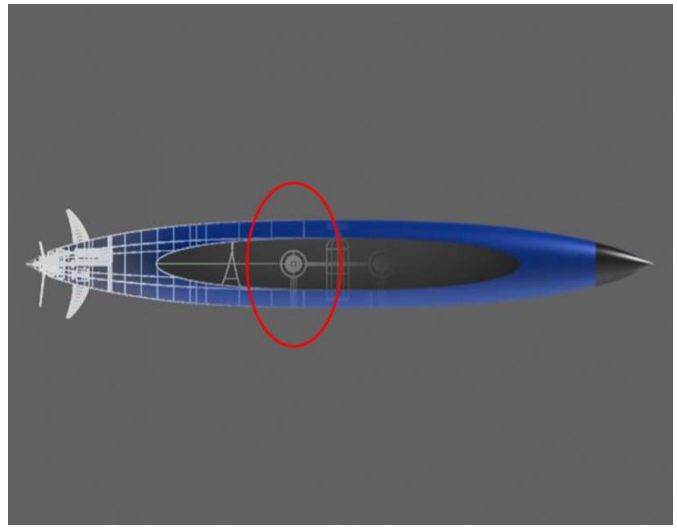
Pilots are secured into the submarine with an over the shoulder harness constructed from weight belt straps and clips. Four clips are present on each harness to ensure that the pilot and surface crew can release the restraints; two are accessible from the top for surface crew manipulation and two are accessible on the bottom to allow pilot adjustments.

The mountain biking shoe that has been selected for both craft lock into the drive train give the pilots additional opportunity to max out the submarine. The shoes are Velcro and an additional length of orange strap has been added to assist in removal. All buckles and release straps are spray-painted neon orange to make them easily recognizable.

8.6. Dead-Man System

To initiate an emergency response, a dead-man safety system has been implemented in the submarine. The dead-man safety system signals rescue divers via the release of a brightly colored buoy; the buoy is deployed in the event that either pilot is incapacitated or needs to be removed from the vessel. A 1/8" highly visible white rope 35 feet in length is connected to the foam buoy, which anchors the submarine to the surface during an emergency. The system is located on the upper mid-plane of the submarine, aft of the service hatch, in a location that minimizes pressure on the system's hatch (shown in figure below). The hatch was made as small as possible (2" x 5") to minimize the force needed to keep it flush with the hull. It covers the system and prevents the float from leaving a tube inside the vessel and is held in place by two DC solenoids which act as electromagnets (shown in the figure below). Power to the solenoids is supplied by separate battery packs in an attempt to isolate power failure. Power to the solenoids is controlled by an Arduino Nano microcontroller in conjunction with switches located on both pilots' joysticks.

The two DC solenoids used in the dead-man system's configuration.

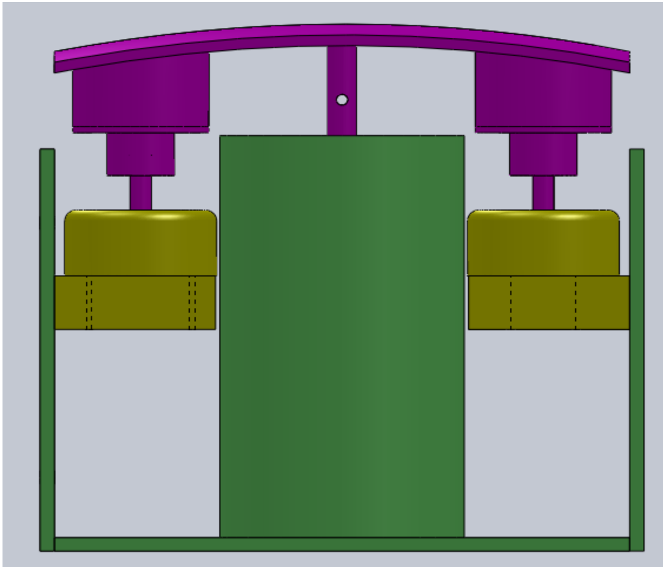


The approximate location of the dead-man system is circled in red. The hatch is located on the upper portion of the hull.

Advantages of having an electronic safety system include having a stand-by mode and a three-second delay. The system's stand-by mode allows pilot exchange to take place without buoy deployment, increasing the process' ease and speed. The three-second deployment delay provides both pilots the chance to remedy accidental switch releases. If the three-second switch release delay is exceeded, power to the solenoids is removed and the hatch is no longer held in place, as the solenoids directly connect to the hatch (shown in the SolidWorks model included below). This design was chosen because it does not include any moving parts, which limits system failure to fewer components. System status is visually communicated to both pilots through light emitting diodes, or LEDs.

8.6.1. Dead-man Interface.

Three different colored LEDs (red, yellow, and green) are located on each pilot's dashboard to indicate whether the dead-man system is operational, in stand-by, or has been deployed. Flash patterns alert pilots before system state changes; for example, the red LED flashes in warning during the three-second delay and all three LEDs pulse slowly to indicate stand-by mode. The yellow light on both dashboards communicate the status of the other pilot, which allows coordination between drivers. LEDs also serve as key components in the submarine's communication system. The electronic nature of the vessel also allows inter-pilot speed communication. Additional LEDs are utilized to convey speed synchronization between pilots not only to give the team a competitive edge, but as a measure of protection in the event that either pilot needs to cease pedaling suddenly; the connected nature of the pedaling system makes this feature especially important.



Front view of the dead-man system. Color indicates which components move as a unit. The green components are mounted to the inside of the submarine, the yellow are the adjustable solenoid bodies, and the purple are the removable hatch and solenoid pins.

8.7. Lighting and Cockpit Ergonomics

As an additional safety measure, flashing strobe lighting is located in the aft portion of the sub to aid in vessel placement. The light sources within sub also provide ambient lighting for both pilots, which aids in instrument utilization as well as pilot comfort. During emergency situations, all lights pulsate at a low frequency to alert pilot and support crews of the emergency. Finally, the forward pilot has access to a dive gauge console with compass, pressure gauge, and depth gauge. The compass is primarily used for beach dives for navigation, however it has also been used as a roll indicator as the compass dial pivots in two dimensions. The aft pilot has a pressure and depth gauge visible as well as being viewable from outside the submarine.

9. Conclusion

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 has 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. FAU-Boat II's newly designed electronic systems that control navigation, variable pitch and communications are challenges never yet faced by the team, and we are hoping for a success in the utilization of these new systems. The interchangeable mechanical systems and electronic fail safes have tested the team's resourcefulness and physical skill level. 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.