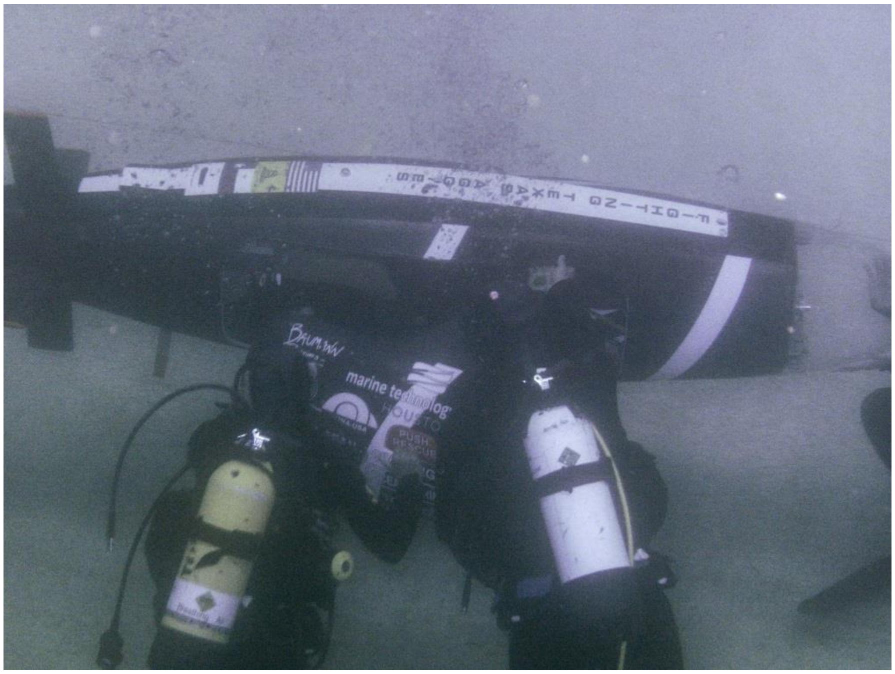
Texas A&M University
Human Powered Submarine Team
"SS Rowdy Howdy" Design Report
ISR 2013



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Introduction

Students in the Ocean Engineering Program at Texas A&M University in College Station, Texas designed and constructed a submarine hull during the 2006-2007 school year. The submarine was raced in the 9th International Submarine Races (ISR) in 2007, the 10th ISR in 2009 and the 11th ISR in 2011 at the David Taylor Model Basin in Bethesda, Maryland as well the European International Submarine Races in Gosport, England in 2012. While the hull has remained basically unchanged since 2007, there have been many modifications made to the rest of the operating systems.

The hull design is based on the dimensions from the earlier one-person propeller submarine, “Ol’ Sarge III”, but was scaled up to allow for a pilot up to 5 feet 10 inches tall to pilot the submarine. The new control system is comprised of a throttle cable system that allows for roll adjustment in addition to pitch and yaw corrections. A new propeller has been added, and the drive shaft, gear box, and emergency buoy have been redesigned. All designs for submarine controls and propulsion are in accordance with the specifications of the 12th International Submarine Race rules and regulations.

A new two-person submarine has been designed and was scheduled to be competed for this summer’s races, but delays prevented the sub to be ready for the 12th ISR. The team looks forward to racing the new sub at the next ISR.

Hull Design

The hull is a one-person propeller driven design. In the initial design of the hull, a pilot height limit was determined. With these limits known, a study on hull shape design was completed to determine the proper length to diameter ratio to produce a hull with the lowest possible drag coefficient. The Reynolds number was calculated for a 7.0-knot velocity to give an idea for the drag coefficient. Figure 1 shows the drag coefficient curves for various hull shapes.

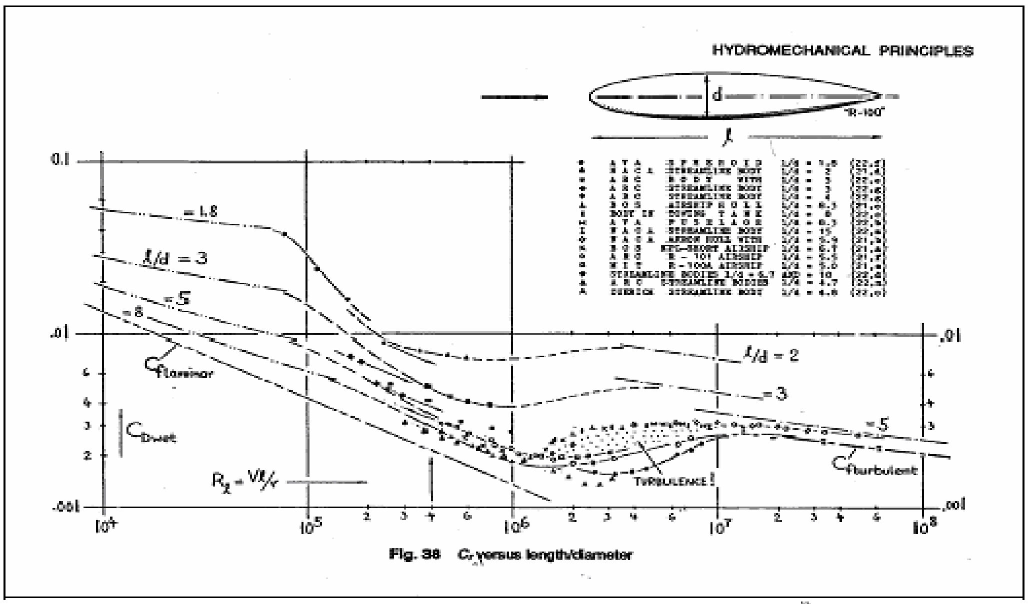

Figure 1: Drag Coefficients for Various Hull Shapes (Allmendinger, 1990)

The resulting length-to-diameter ratio of 5, correlates to a drag coefficient of 0.003. This ratio resulted in the shape shown in Figure 2 below. The shape in Figure 2 does not include the nose cone.

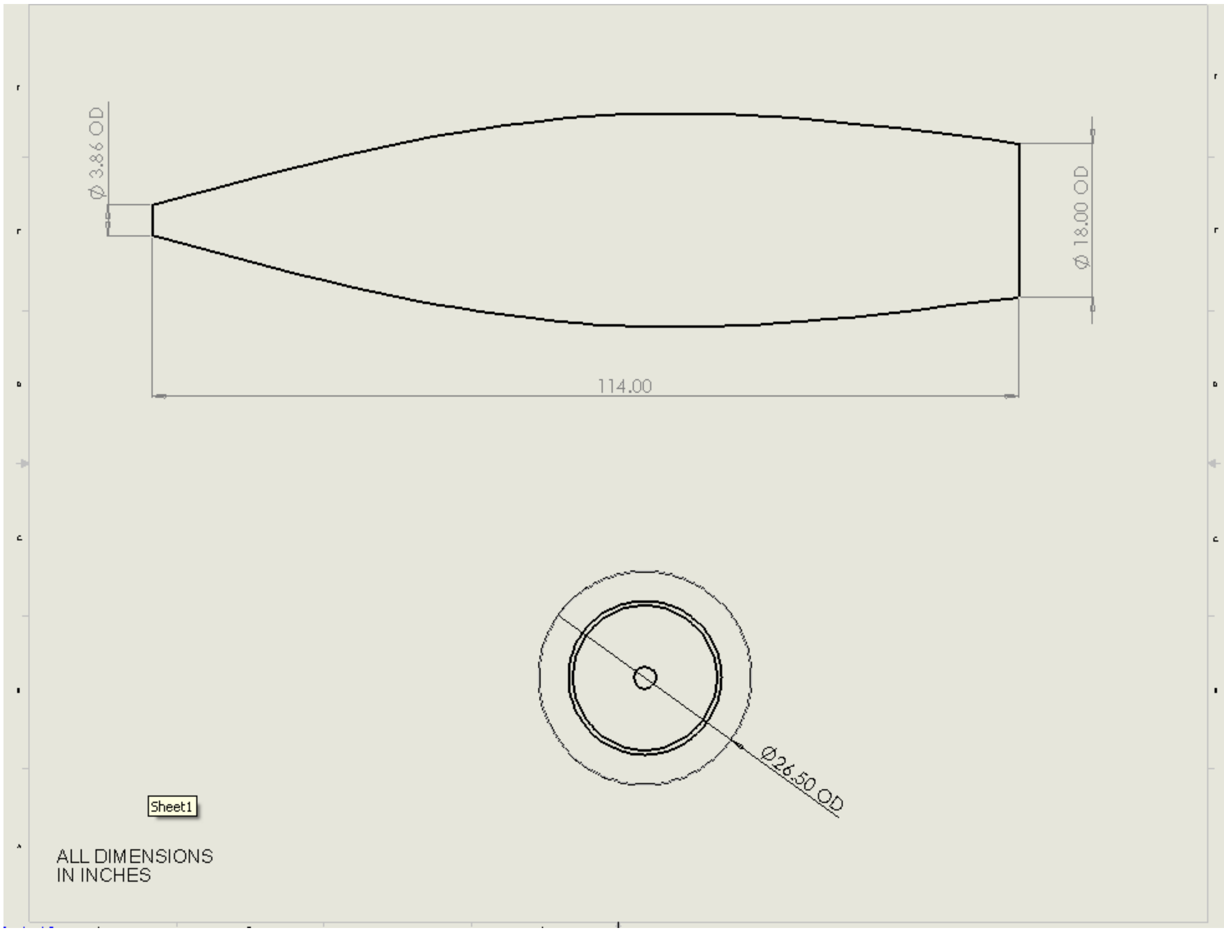

Figure 2: General Hull Design Dimensions

The pilot's position is shown in Figure 3. The pilot is lying in the prone position with stomach downward and the head toward the bow of the submarine. An air tank is mounted to a solid harness underneath the pilot's torso. In order to insure an optimum position for leverage on the drive system, a top-mounted shoulder harness was designed for the pilot. The harness includes a waist belt to secure the driver's torso, and bicycle toe clips are used to ensure that the pilot's feet do not slip and push and pull while pedaling.

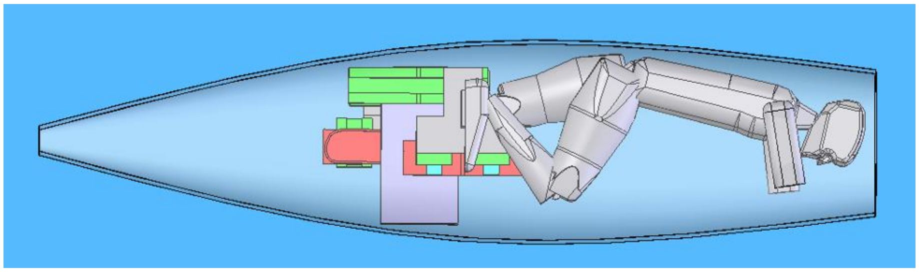

Figure 3: Pilot/Driver Position

Materials

The hull was fabricated using a fiberglass sandwich technique with Kevlar material and flexible syntactic foam. Various other materials, such as carbon fiber, E-glass, and S-glass were considered while brainstorming the design of the hull. Carbon fiber would have been a great option due to its strength and flexibility; however, it is a very expensive material in comparison to the team’s budget. E-glass and its stronger counterpart, S-glass, were also both discarded. E-glass is not as strong as Kevlar and S-glass is also too expensive. Kevlar has the added advantage of superior impact energy absorption. After some consideration, Kevlar was chosen as the best material. Kevlar is a polymer made of aramid fibers. Hexcell Schwebel donated a sixty-yard roll of Kevlar material for the team to use. First, two layers of Kevlar were applied with resin onto the foam hull mold. Next, flexible syntactic foam was placed on top, followed by three more layers of Kevlar. The flexible syntactic foam was donated by the DIAB Group in 3ft x 4ft sheets at a quarter inch thickness. Figure 4 shows the composite layer cross-section. The details of the hull construction are discussed in depth in the next section.

Figure 4: Hull Layers and Thicknesses

Construction

Before submarine construction began, it was necessary to build a ventilation room in order to contain the fumes produced during the composite lay-up and priming stages. The room was built using 2x4 in lumber and 6 mm plastic and ventilated using a large fan that discharged the fumes and dust to the outside of the building. The wooden-framed lathe, shown in Figure 5, was custom designed by the team to fit the 120 inch foam block. A plywood template was used as a guide to shape the hull.

DUNA USA, Inc. donated a 30x50x114 inch, 4-lb/ft^3 density block of foam, which was used for hull construction. The block was cut in half in order to insert a 120 in long by 1.5 in diameter steel pipe through the center. The pipe, with a sidewall thickness of 0.5 in, was supported by two bearings on either side of the lathe. This setup easily supported the nearly 100 lb block that became the hull mold. A sharpened heavy-duty tile scraper was used as a chisel to shape the submarine mold until only 0.125 in of material remained and was removed by sanding. Figure 6 shows the mold after chiseling and sanding. The mold was then wrapped with cellophane, which was used as a release film.

Figure 5: Foam Block Lathing

Figure 6: Hull Foam Lathing

The five layers of Kevlar were cut using cardboard templates. The alternating layers of Kevlar were cut at 0° and 45° angles in order to maintain rigidity and reduce stress. The order of hull material application was two layers of Kevlar first, followed by the syntactic foam, and then finally the last three outside layers of Kevlar. After the syntactic foam layer was applied, the hull was covered with the release fabric (cellophane). Subsequently, the hull was sealed with a vacuum bag, which was connected to a vacuum pump in order to remove the air within the layers, ensure hull smoothness, and to allow the resin to cure. A vacuum bag was used again after the fifth and final layer of Kevlar was applied. After ensuring that the resin cured sufficiently, the vacuum bag was removed and rough spots were smoothed out using lightweight Bondo and paint primer.

The original foam male mold was then carved out of the Kevlar, fiberglass, and syntactic foam sandwich hull. Hatches and holes were cut for control surfaces, propellers, and the acrylic nose cone. The main hatch measures 3.5 ft long and serves as the primary entrance and exit for the submarine pilot. The hatch, which is capable of being released from the inside or outside, is fastened with a spring mechanism and capable of completely detaching and reattaching. A secondary hatch, located on the rear starboard side, is used for maintenance access to the submarine; it remains closed during operation, and is not used for entry or exit. Finally, the hull was primed and sent to a body shop to be painted.

The first testing of this submarine hull took place on May 9 and 10, 2007, in the Offshore Technology Research Center at Texas A&M. Table 1 summarizes features of the SS Rowdy Howdy human powered submarine.

Table 1: Rowdy Howdy Basic Specifications

Lightship Weight in Air	Dry, Equipped Weight in Air	Hull Thickness	Overall Length	Max. Diameter	Volume	Category
72.5 lb	233 lb	0.375 in	10.3 ft	2.2 ft	25 ft^3	One-person, Propeller driven

Nose cone

The nose cone used for the SS Rowdy Howdy, shown in Figure 7, is molded of clear acrylic, made by Texstars, and cut to the proper length by the sub team. The use of clear acrylic enables the pilot to have visibility from the front of the hull. The nose cone is attached to the hull at a flared edge with a diameter of 18 inches. A one inch lip was added to the inside of the hull, and weather-stripping was laid around the lip in order to form a tight seal (Figure 8). Three rubber-tension latches (Figure 9) were spaced inside the nose cone and connect the nose cone to three small plastic notches on the inside of the hull to secure it to the submarine (Figure 10). This system is considerably safer for the pilot than previous designs because there are no sharp metal or plastic attachments near the pilot's head.

Figure 7: Nose cone

Figure 8: Weather-Stripping on Nose Cone Rim

Figure 9: Rubber-Tension Latches

Figure 10: Rubber-Tension Latch Connected to Plastic Notch

Drive Train

Gearbox

The gear box is designed for a pilot input of approximately 50 rpm and has a gear ratio of 4:1. The resulting propeller speed is 200 rpm. The gearbox is positioned in the stern of the submarine and is mounted in the hull using adjustable threaded rods (Figure 11). The threaded rods are expanded to provide compression that keeps the gearbox in place. The use of threaded rods allows for adjustability in gearbox height in order to better align the drive shaft. The gear box is restrained between an aluminum plate and to form-fit aluminum shims with receptacles for the threaded rods. The gearbox frame has been designed so that after the gearbox is disconnected from the output shaft and unscrewed from the frame, the gearbox can then slide out the front of the aluminum frame for easy access and quick repairs. This is different from previous designs where the gear box housing had to be removed from the sub before the gearbox could be removed. The output shaft of the gearbox is attached to the propeller shaft using a stainless steel rigid shaft coupling.

Figure 11: Gearbox Mounting Plates

Drive Shaft

The team designed a drive shaft, which was constructed and donated by Oceaneering International, Inc. in Houston, Texas. The driveshaft in Figure 12 is made from MIL-A-8625 anodized aluminum with a rigid shaft coupling and misalignment joint. The driveshaft is 22 inches long with a maximum outer diameter of 0.97 inches, tapering to 0.623 inches at the gearbox. It is flanged at the hub end to mate with the propeller hub. The driveshaft passes through a bearing to outside the submarine where it is attached to the propeller hub.

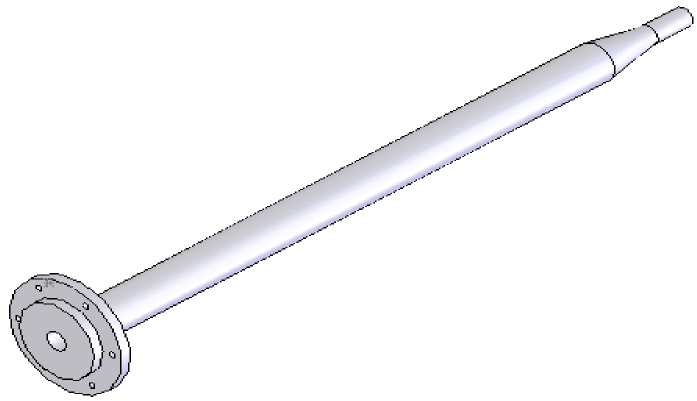

Figure 12: Driveshaft

Shaft Bearing and Completed Assembly

A bearing attachment fits inside of the tapered stern of the submarine (Figure 13). The bearing attachment holds two glass bead bearings securely in the stern through-hull, by clamping against the tapered hull. The attachment is made from nylon and clamped together using four Allen head cap screws. The completed assembly is shown below in Figure 14, which demonstrates how the final assembly fits together.

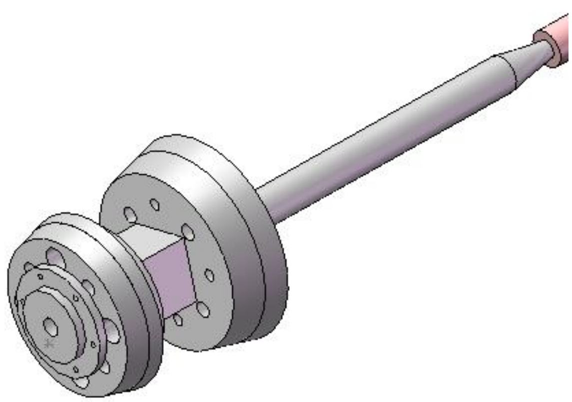

Figure 13: Bearing Schematic

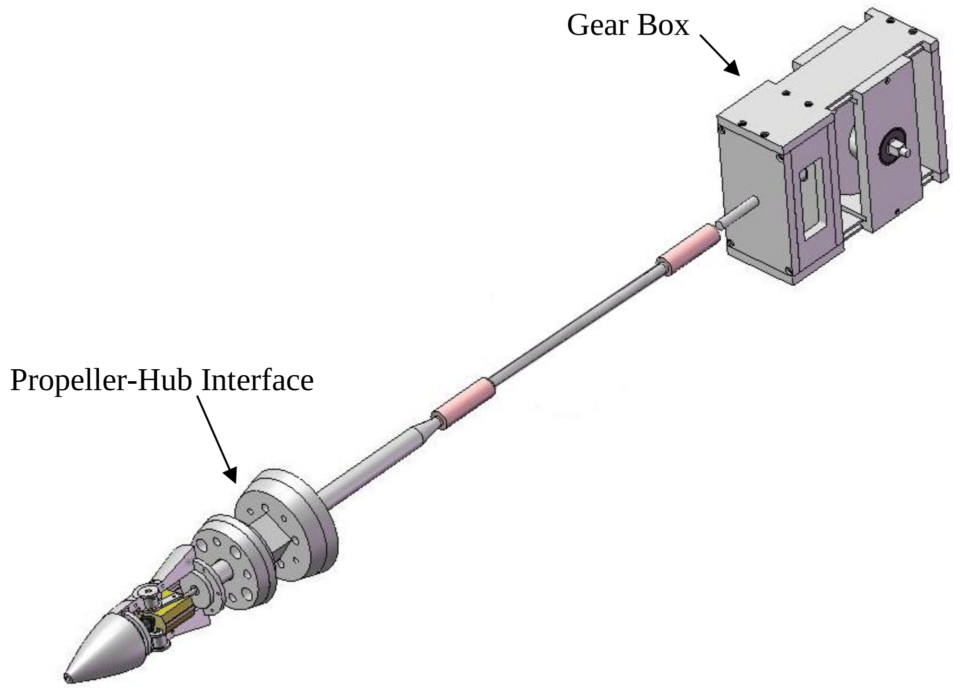

Figure 14: Complete Cyclical Drive System

Propulsion

Propellers

The team has three, two bladed propellers to attach to the variable pitch propeller hub (discussed later) that was designed by Texas A&M Submarine team members with the help of Oceaneering International Inc. The pitch of the blades can be altered before a race, but not while underway. The propeller blades were designed and fabricated according to the specifications of TAMU students by Baumann Marine in Houston, TX. The blades are optimized for an expected operator power output of 0.4 bhp and a design speed of 6 plus knots. The propeller in Figure 15 was designed and used in previous races on the "Ol' Sarge" series of hulls and was used to help design the other propellers. Various propeller shapes have been tested in order to find the most effective design and best pitch setting. Figure 17 shows the two bladed propeller used at previous ISR races, and will be used as the team's secondary set of propellers. A new two bladed propeller was built by Baumann Propellers, Inc., which is the team's primary set of propellers for the 12th ISR, Figure 16.

Figure 15: Propeller and Hub

Figure 16: Primary Propeller


Figure 17: Secondary Propeller

Propeller Hub

The propeller hub, shown in Figure 18, was designed by previous Texas A&M Submarine team members, and then built and donated by Oceaneering International, Inc. The propeller hub allows for in situ adjustment of propeller pitch angle prior to each race, which previously required removing the drive shaft.

Inside the hub is a worm gear, which is turned by a nylon knob on the outside of the hub. This worm gear drives two cams that travel through downward angling grooves, forward or backward, which turns the blade attachments. The mechanism is shown in Figure 19 and Figure 20.

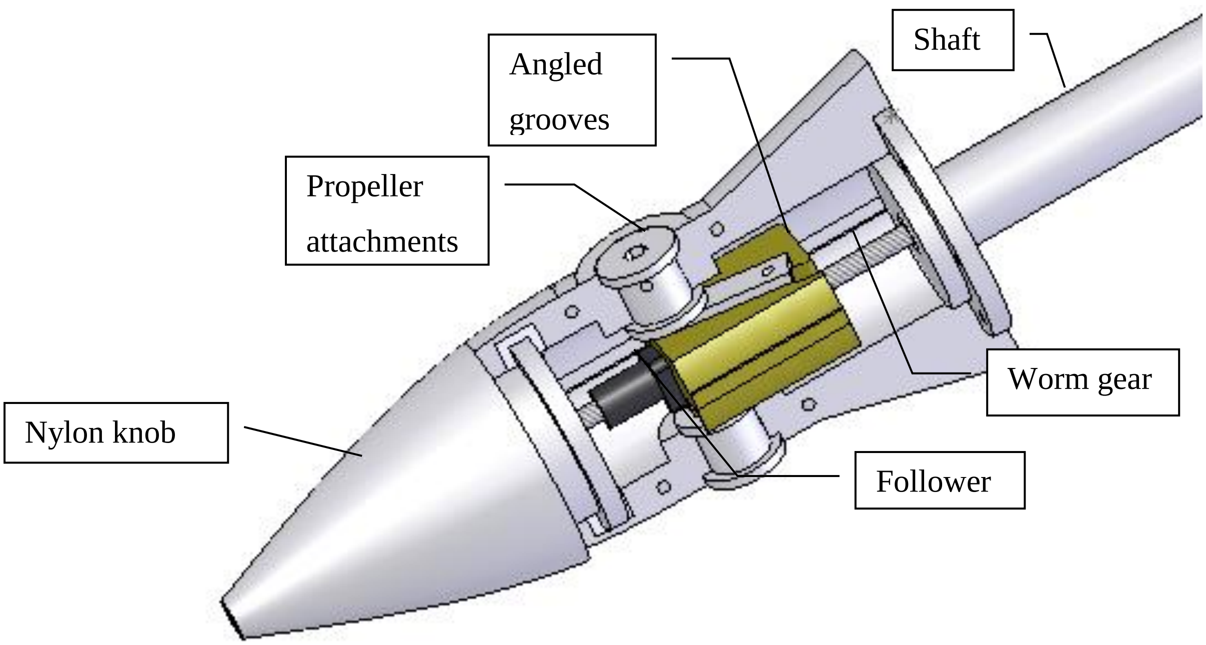

Figure 18: Propeller Hub

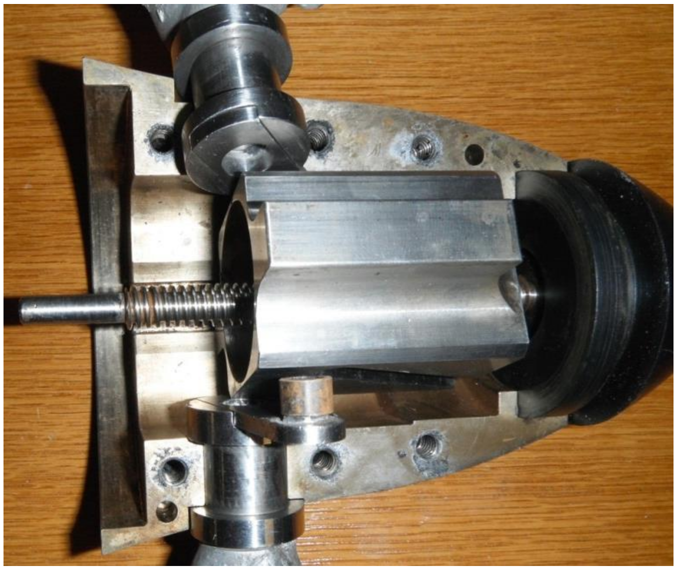

Figure 19: Hub - Top View

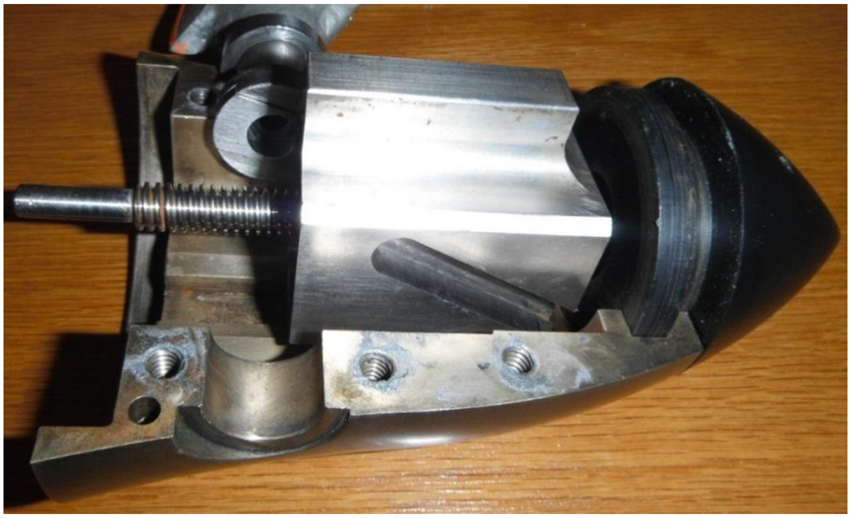

Figure 20: Hub - Side View

The blades are attached to the hub using tapered inserts, which fit into the hub mechanism and are secured by a ¼-20 hex cap screw. The taper works like a Jacob's Taper on a lathe or mill, and prevents the blades from spinning out of their attachments. Figure 21 and Figure 22 show the propeller-hub interface.

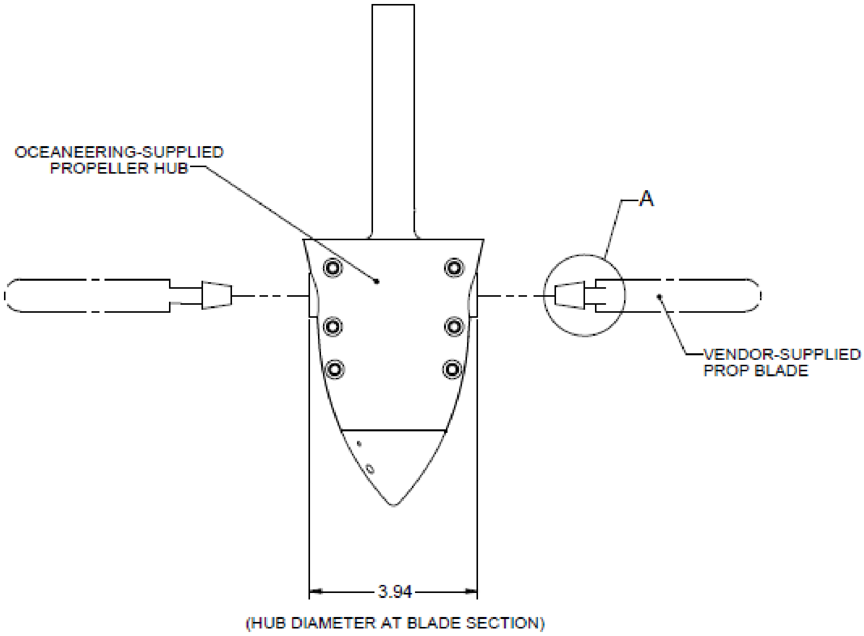

Figure 21: Propeller Hub Interface (Dimension is inches)

Figure 22: Propeller Interface

The initial pitch angle of the blade is set while the blade is unattached to the hub. Once installed, the hub allows for 15 degrees of rotation in both directions for easy adjustments. Pitch angle is determined from a line drawn on each blade and measured with an angle locator. The propeller blades are initially set to an angle of 35 degrees in the hub, which allows for a pitch angle adjustment of 20-50 degrees.

Control System

Control System

Control and stability is achieved through the use of four control planes mounted at 90-degree increments near the stern of the submarine. The two horizontally mounted planes induce pitch, and the two vertically mounted control planes induce yaw. A new feature to SS Rowdy Howdy includes the ability to counteract roll with all 4 control planes. This is achieved by the device, seen in Figure 24, which combines all three-motion inputs into outputs for all 4 control planes. Movement of this device is governed by a system of throttle cables, shown in Figure 25, which have the ability to transmit an input in tension or compression. These throttle cables run from the steering mechanism, shown in Figure 23, to the combination device, and then run from the combination device back to the control planes.

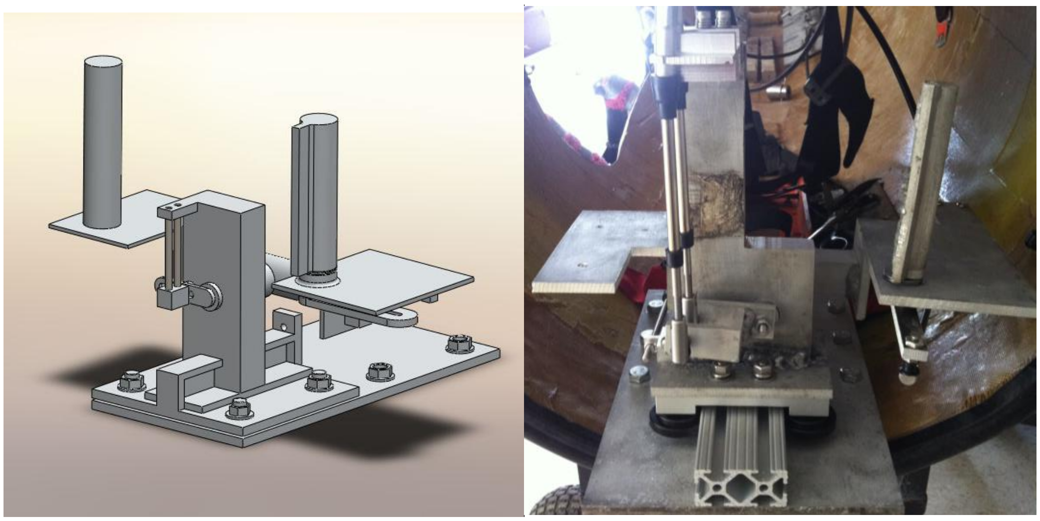

Figure 23: Steering Controls

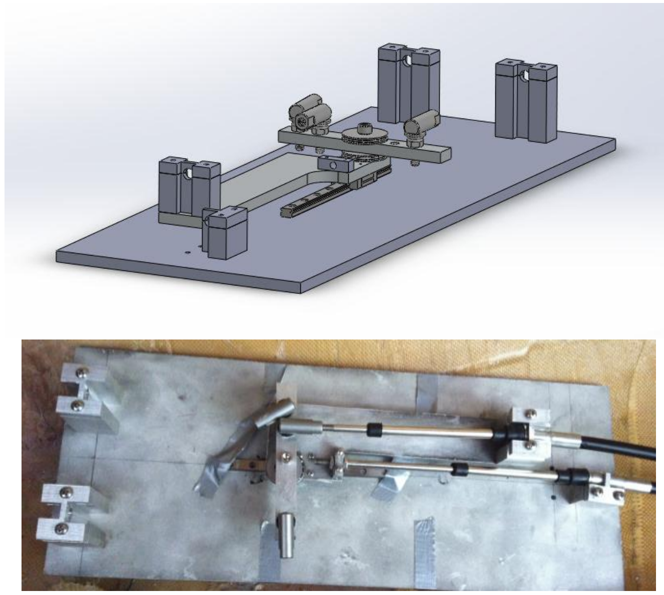

Figure 24: Controls Combination Device

Figure 25: Throttle Cables

Roll Motion

Two of four control cables are connected in such a way that both receive the same input (Figure 26), but are connected to opposite control combination devices. This feature allows for roll on all four planes. By applying torque to the steering wheel handles, as shown in Figure 27, both control cables are deflected equally allowing for synchronized and smooth changes in roll.

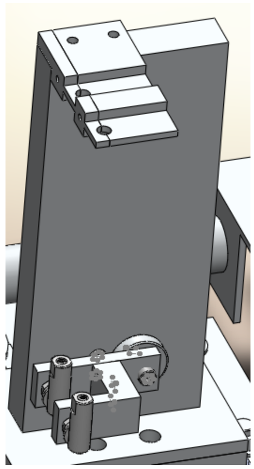

Figure 26: Roll Control Cable Connections on the Steering Wheel

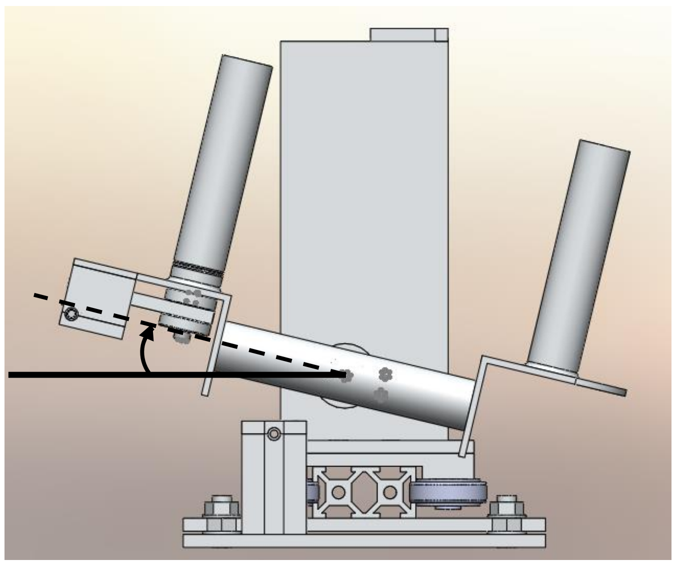

Figure 27: Motion to Induce Roll Correction

Yaw Motion

Changes in yaw are governed by one cable, which is connected to the left handle of the steering wheel, as shown in Figure 28, to one of the control combination devices.

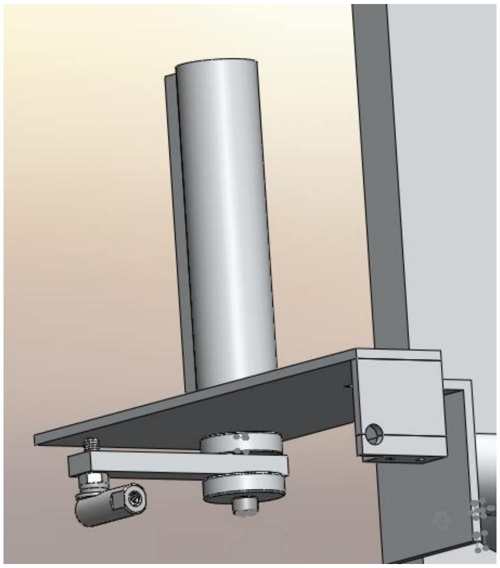

Figure 28: Yaw Control Cable Connection on the Left Handle

Then, by simply rotating the handle, as shown in Figure 29, the control cable is either subjected to tension or compression and results in corrections to yaw through the movement of the control combination device.

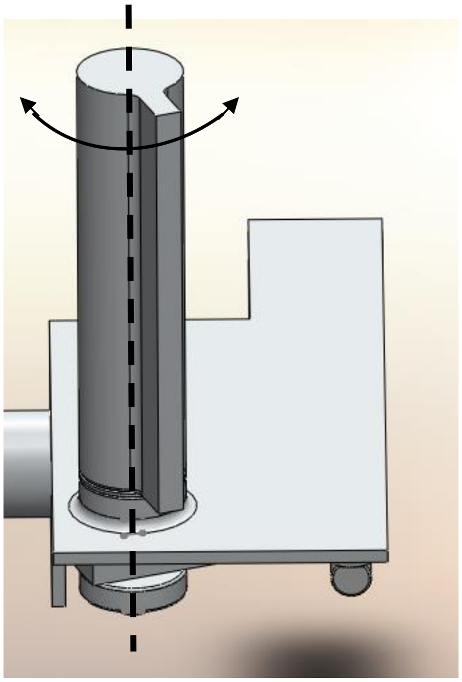

Figure 29: Motion to Induce Yaw Corrections

Pitch Motion

The fourth control cable is connected to the wheeled carriage, shown in Figure 30, which moves freely along the track attached to the base plate.

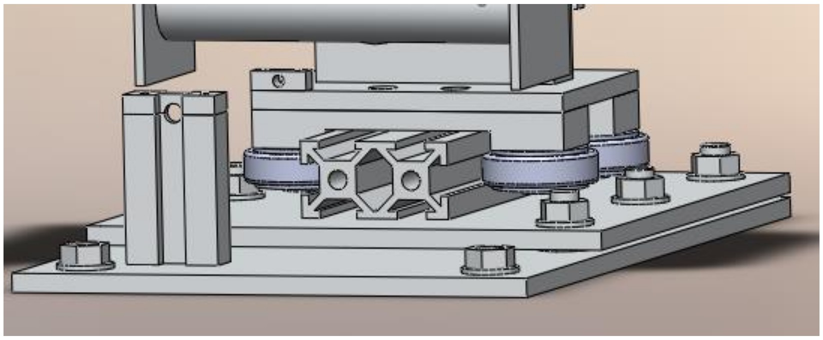

Figure 30: Pitch Control Cable Connection on the Steering Wheel

With such an arrangement, by pushing or pulling the steering wheel along the track as shown in Figure 31, the cable is subjected to either tension or compression, respectively. This induced force results in a corresponding change of the control combination device that the cable is connected to, which produces a correction in pitch.

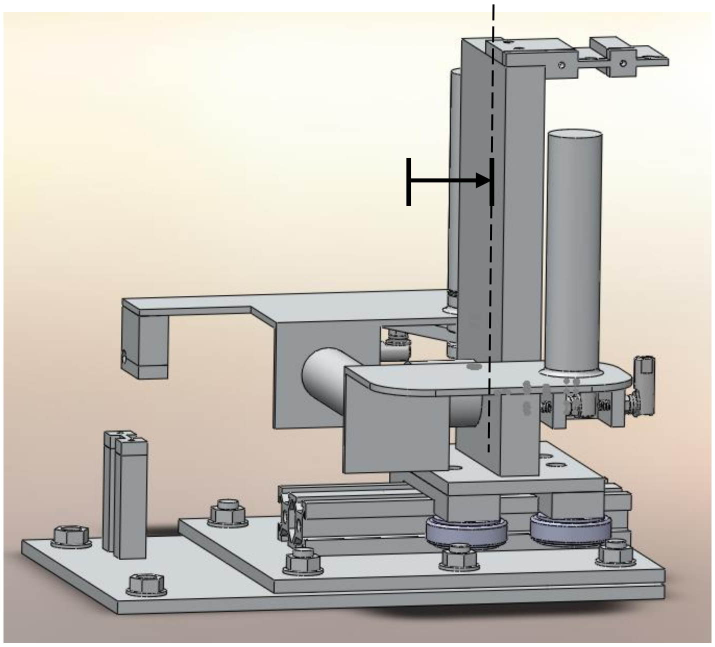

Figure 31: Motion to Cause Pitch Correction

This system allows for the correction of yaw, pitch, and roll, as well as the ability to control roll with all 4 control planes, which gives an advantage over previous control designs that only allowed for the control of roll with 2 control planes. The ability to control the roll of the submarine allows the pilot to counter the torque imparted by the propeller. The intermediate linkage modules for the respective horizontal and vertical control planes allows for better arrangement within the submarine. These include connections that provide for both concurrent and opposing movement of the control planes. The control planes are one-piece airfoils as seen in Figure 32. To help protect the bottom control plane a rudder guard is attached to the stern of the submarine seen in Figure 33.

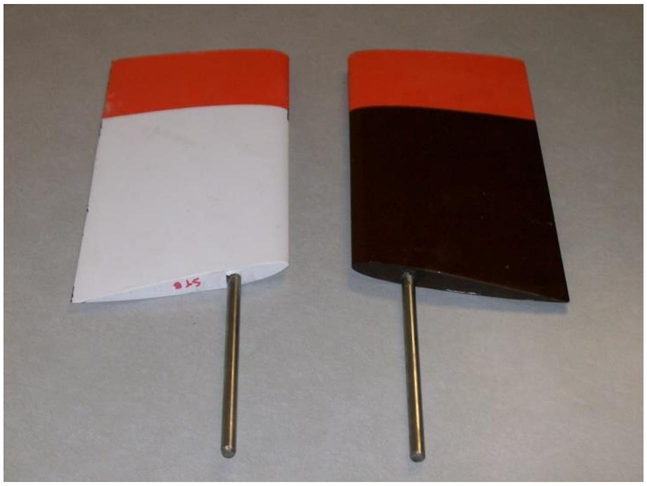

Figure 32: Control Planes

Figure 33: Rudder Guard

Braking

Braking is performed by reverse pedaling, which switches the direction of the propeller and causes the submarine to slow. Also, the pilot can bank into a turn to decrease momentum when space is available.

Life Support and Safety

Life Support

The air supply requirements satisfy the guidelines in the IRS Contest Rules and Regulations. The air supply, with a minimum of 150% reserve for each crewmember, is used primarily for life support while underwater. All breathing air is compressed, normal, atmospheric air. The primary air supply (60 ft^3 cylinder) is located under the pilot's torso. A secondary air supply is attached to the pilot, and each support diver is equipped with an octopus regulator. No air tank supply is allowed to fall below 500 PSI.

Air Supply Requirement

The duration rate of air supply is dependent on a pilot/diver's consumption rate, depth, and the capacity/ recommended minimum pressure of the cylinder(s). Temperature is not considered because it is only an important factor under extreme conditions. The duration of air supply for the proposed cylinder, may be calculated using equation 1.

$$C = \frac{D+33}{33} RMV \tag{1}$$

where C is the pilot/diver's consumption rate in standard ft^3/min (scfm), D is the depth, and RMV is the diver's respiratory minute volume (scfm).

Table 2: Driver RMV and Consumption Chart

Level of Exertion	RMV	C
Heavy	1.7	2.16
Moderate	1.3	1.65
Light	.065	0.83

In order to calculate the capacity of air that is available to the pilot/diver, as opposed to the total capacity of cylinders, the equation on the next page is utilized:

$$V_a = \frac{V_c N(P_c - P_{rm})}{P_r + 14.7} \tag{2}$$

where V_a is the is the capacity available (scf), V_c is the rated capacity of each cylinder (scf), N is the number of cylinders, P_c is the measured cylinder pressure (psig), P_{rm} is the recommended minimum pressure of the cylinder (500 psig), P_r is the rated pressure of the cylinder (psig), and 14.7 is the standard atmospheric pressure (psi). To calculate the duration in minutes, the capacity available is divided by the consumption rate using the following equation:

$$Duration = \frac{V_a}{C} \tag{3}$$

To solve for the air supply and the consumption needs of the pilot, Tables 3 through 5 were used in association with the equations provided.

Table 3: SCUBA Cylinder Information

Rated Capacity / Rated Pressure	60 ft^3 / 3000 psi
Absolute Minimum Air Pressure	500 psi
Capacity Available per Cylinder	49.76 ft^3

Table 4: Time Calculations (all values in seconds unless noted otherwise)

Time to secure hatches and setup for run (max)	827
Time to accelerate to 6 knots in 150 feet	31
Time to transit gate area (100 meters = 328 feet)	32
Time for deceleration	10
Total time from setup to completion of run (min)	15

Table 5: Air Consumption and Available Resources

Case	Crewmember	RMV (scfm)	Rate of Consumption (scfm)	Duration of Air Supply (min)	Available Reserves (%)
A	Operator	1.70	2.16	22.41	153.58
B	Operator	1.30	1.65	30.16	201.05
C	Operator	0.65	0.83	59.95	399.69

These calculations demonstrate that even when conditions are harshest (case A); a 153.58% reserve is still maintained. These calculations are estimated for a speed of 7.0 knots.

Emergency Buoy System

The emergency buoy is constructed from a square cutout (Figure 34) of the top of the hull toward the stern of the submarine. The buoy contains a spool of 30 feet of 1/16 inch highly visible line. The spool is located on the buoy to reduce failure rate due to the line getting caught inside the hull of the submarine. The spool system is also made to quickly install a new fully wound spool in seconds. This is possible through the use of the cabinet hinges used to contain the rod for the spool. The purpose of this buoy is to provide indication of possible pilot distress by automatically releasing if the submarine pilot should lose consciousness.

Figure 34: Emergency buoy

In the SS Rowdy Howdy, a quick release shackle is connected to the release mechanism which is wired to a bicycle brake handle on the steering column. During the race, the pilot depresses the handle and will release the handle when distressed. When the pilot releases the handle, the spring activated release lever pulls on the quick release shackle and frees the buoy to a positive ascent.

Submarine Markings

External markings follow the procedures outlined in ISR 2013. The submarine is painted with contrasting maroon and white colors, with silver accents. The submarine name, logo, and team sponsors are also located on the hull. The propeller tips, emergency buoy, hatch release, harness belt release, rudder guard, and control plane tips are marked with orange paint for visibility and safety.

Strobe Light

For additional safety, a flashing white strobe light that is visible for 360 degrees in the horizontal plane is energized whenever the submarine is submerged, Figure 35. The strobe is placed at the top of the hull to achieve such visibility. The light flashes once every second, and it is visible for thirty feet under normal visibility conditions.

Figure 35: Emergency Strobe Light

Pilot Restraint

The pilot is harnessed into the submarine in order to position the pilot in a manner that produces effective pedaling (or horsepower). The restraining strap has an orange airline seat buckle release that is easily visible to safety divers seen in Figure 36 and accessible by the pilot. In order to satisfy safety requirements, all harnesses and toe clips are visibly marked with orange paint. In addition, the pilots all practiced self-egress maneuvers during testing at Offshore Technology Research Center.

Figure 36: Pilot Restraining Straps

Pilot Visibility

The only window, or view port, on this submarine is the nose cone. However, the pilot is positioned to look straight out of the nose cone while pedaling and maneuvering the submarine.

Figure 37: Forward View

Rescue Egress

A four-inch orange patch displaying the word “Rescue” on the outside of the hatch marks the location of the latch release. On the inside of the hatch a painted orange handle (Figure 38) is used by the pilot to release the hatch from the inside, it can also be accessed from the front after the nose cone has been removed. A green string is attached to the orange handle in case the pilot cannot find the handle they can pull ant point along the string to release the hatch, shown in Figure 39. In an emergency situation, the safety divers are also able to remove the door from the outside of the submarine.

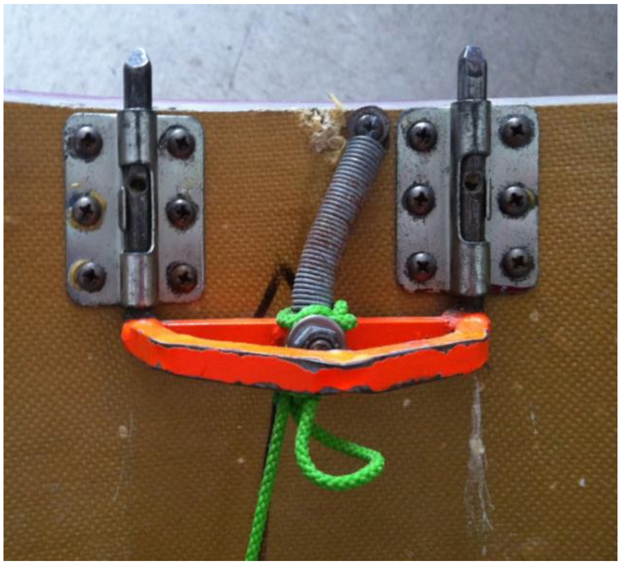

Figure 38: Pilot Egress Handle

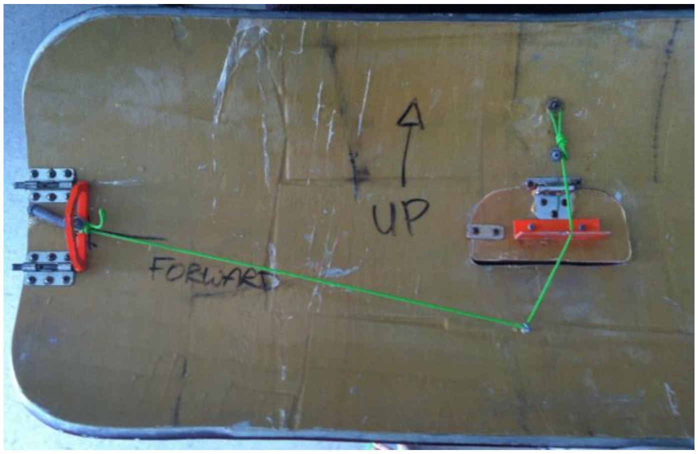

Figure 39: Inside of Hatch

Testing and Training

Testing is conducted in the Offshore Technology Research Center (OTRC) on the Texas A&M University campus in College Station, Texas. Testing is scheduled for May 8 and 9, 2013. The OTRC wave basin is 150 feet long by 100 feet wide by 20 feet deep. Full speed is not attainable within these dimensions. However, safety features, ballasting, and proper functioning of the submarine is checked to determine what adjustments need to be made prior to the races. Pilots are trained for egression to the surface with assistance from support divers, and also without assistance. The pilots are also trained on general piloting skills, through short test runs. In addition the support diving crew is trained for launch and recovery of the submarine.

Figure 40: Underwater Testing at OTRC

Summary

Texas A&M University Ocean Engineering students designed and built SS Rowdy Howdy to compete in the One Man, Propeller-Driven category at the 12th International Submarine Races, held at the David Taylor Model Basin in Bethesda, MD.

There have been many improvements made to SS Rowdy Howdy during the 2012-2013 academic year. The control system has been designed for yaw, pitch and roll using throttle cables. The emergency buoy system was redesigned to eliminate the risk of similar past failure. The new gearbox housing was built to be lighter and so the gearbox can be quickly removed from the submarine. The overall length of SS Rowdy Howdy is 10.3 feet, maximum diameter is 2.2 feet, with a hull thickness of 0.375 inches. With these recent improvements, the team is confident in the SS Rowdy Howdy's success in Bethesda.

Sponsors

The Texas A&M University human powered submarine team would like to give special thanks to the sponsors who contributed to the 2012-2013 race year. Without their help the team would not be able to attend these races.

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