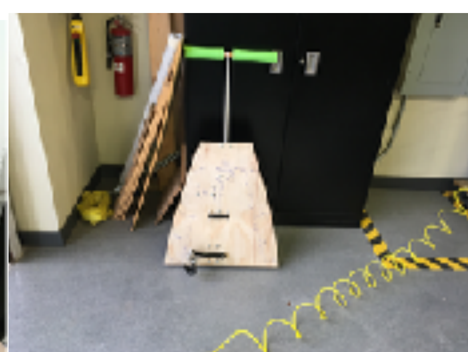
# Final Design Report

## 15th international Submarine Races

## Commodore

## Gulf Coast State College Team

## PREFACE

This report documents the design of the first human powered submarine created by E.M.P club. The E.M.P club is comprised of students from GCSC. E.M.P. has developed a wet human powered submarine where a single pilot breath Scuba called The Commodore. The purpose of this submarine is to compete in the 15th International Submarine Race. The aim of this report is to describe the design of the Commodore and is an educational resource for future teams. First a word of thanks must be pronounced to all parties involved who helped during the design, production and testing of the Commodore. A special thanks goes to all of our sponsors, because without them our existence wouldn't be possible.

May 18, 2018

The Commodore Team,

-Robert Copsey

-Landon McCoy

## Executive Summary

This report concerns the design of the first submarine designed by the E.M.P club. The goal of this submarine is to complete the course outlined the ISR manual in the one person propeller driven class at the 15th International Submarine Race. To achieve this goal there where two major focuses: a proper design and a designated testing period. This is our first attempt at building and testing a sub-

mersible and requires a way to easily fix problems. Our Decision to make our mechanics modular will help us test and fix errors efficiently.

Commodore is a human powered submersible that consists of a carbon fiber shell with modular propulsion and control components. The hull is designed with  with profiles based on NACA shapes.

# 1. Introduction

## 1.1 Design Philosophy

Our design philosophy is focused on developing a simple and reliable design to encourage others without extensive engineering and machining experience to compete in the ISR. We focused on designs that were capable of being produced with readily available materials and construction techniques. We selected the NACA 67597 airfoil shape as our basic template and scaled it to the a size that would provide us both space and speed. This shape will allow us to go faster than a common cylindrical hull.

Commodore is a human powered submersible that consists of a hull with detachable pedal-powered transmission. This design enables the use of a multiple transmission designs including propeller or non-propeller driven.

The resulting design is entirely modular. Individual components can be easily altered or replaced. This allows for rapid prototyping of individual components.

### 1.1.1 Design requirements

Requirements for the design are that it be relatively simple with a minimal amount of specialized parts that could be fabricated with consumer-grade 3D printing hardware and material commonly found at hardware stores or readily available through online retailers or be easily machined. The threshold performance goals of the system are that it can complete the course outlined in the ISR manual. Once this performance threshold is met, the modular nature of the system will be exploited to tune the design in order to achieve the fastest time possible on the course. However, we understand that given the constraints on the design regarding simplicity and materials choice will limit performance relative to some of the more high-tech contestants.

### 1.1.2  Materials and construction methodology

The hull is constructed using carbon fiber molding where Carbon fiber cloths are laid upon a plug of the desired shape. Using the NACA airfoil design, cross-sectional pieces are mounted on an eight foot long piece of plywood. Materials including tape, bondo, fiberglass, and epoxy are then used to mold a plug with a similar contour to the airfoil template. The final Hull is comprised of two positive molds using this plug. In this instance we used carbon fiber for the final material.

A variety of construction techniques have been used for the remaining individual components (elements of the transmission, latches, axles, etc.). The primary means of fabrication has been the use of a 3D printer (prusa 13 clone built from a kit). Welding and construction from simple hand tools were also used for components. No machine-shop tools were used. All construction was completed with consumer-grade tools.

### 1.2 Acronyms and Symbols:

| | |
|---|---|
| BCD | Buoyancy Control Device |
| Cf | Cubic Feet |
| ISR | International Submarine Races |
| PLA | Polylactic Acid |
| PVC | Polyvinyl Choloride |
| SCUB | Self Contained Underwater Breathing Apparatus |
| GCSC | Gulf Coast State College |
| E.M.P. | Engineering Minded People |

## 2.0 Final Design and Fabrication

### 2.1 Modular Frame and Components

### 2.1.1 Propulsion Module

our design was simple. One of our goals was to have a modifiable design and therefore propulsion system. We decided to have the ability to adjust gear ratios as well as propeller ratios for the the specific driver. The propulsion system consists of bicycle pedals connected to two helical gears in a 3:1 ratio. This forms a right angle, changing the axis of rotation so that the propellers would spin perpendicular to the pedals. The rod attached to this gearbox would then be fastened onto another gearbox giving us another opportunity to change the gearing as we so pleased. The first components to be produced were 3d printed. These included spacers, plates, and bushings, and two gears. Although not known for its durability, the plastic would provide a fast and cheap alternative. As long as the components lasted long enough for the race we wouldn’t need to worry about durability. Our remaining components included two rods, 2 helical gears, a bicycle axle with crank arms and pedals. The end of the rod facing out of the sub was tapped so that it could be mated to the propeller using a bolt. The axle was keyed for the larger gear and press fit into the gear. These gears will take most of the input force so we did not risk them being made of plastic and purchased gears. *For the output shaft and there is a second set of gears to provide an additional 3:1 step-up to the gear ratio for a final gear ration of 1:9. The intermediate set of gears can be replaced with a 1.5:1 set to reduce the final gear ratio to 1:4.5 if needed for pilot performance. The output shaft is threaded on the end and can accept a variety of propellers.

The propulsion module consists of several principle components: the transmission housing, the shafts, bearing mounts, and the bottom bracket housing. The transmission is built from flat sheets of PVC connected by brackets that hold bushings for the different axles and bolted together. The plastic sheets are tapered to fit into the contour of the submarine. Brackets not only connect the plastic housing but they are also used to hold the shafts in place. The brackets contain holes larger than the diameter of just the shafts to provide space for delrin bushings around the transmission axles. There are only two shafts in the transmission, one that connects to the helical gears to mate with the bottom bracket and one that connects to the step-up gears to the propeller. The shafts are all solid stainless hex rods so that the gears do not need to be keyed.

We have three possible propellers we can use. The first has a 14” pitch and a 24” length, the second has a 14” pitch and 18” length, and the third has a 28” pitch and a 24” length. Considering that a human pedals at approximately 60 rpm without slipping the resulting speed will be around 6 knots depending on the selected prop. Additional propellers will be tested at the event in order to optimize the resulting maximum speed for a particular pilot. Diameter and pitch will be varied to determine which combination provides the best performance. Expected speeds for the propeller combinations is shown in Table 1.

### 2.2.3 Control Modules

Control is provided by a set of dive planes (horizontal) and a pair of rudders (vertical). The pilot controls levers connected by fiberglass rods to the control module in the back of the submarine. The rear control module is bolted on the back of the transmission and connects the fin shafts to the control rods. The fins are mounted on shafts made from acrylic hex rods. Fins are 3D printed, slide on the acrylic hex rods, and are glued in place. They are locked in place on the control assembly with a pin or tape. This simplistic arrangement was designed to minimize the number of moving parts and the failure rate at the event.

### 2.1.4 Life Support modules

Life support in the Commodore consists of standard recreational SCUBA regulator and 80cf aluminum cylinder (first stage regulator, 2 second stage regulators -1 as backup, pressure and depth gauges, low-pressure inflator-not used). This cylinder is mounted just below the pilot and the gauges are clipped to the frame so that they are easily visible by the pilot. The pilot will also wear a deflated BCD with a 19cf aluminum cylinder, first and second regulator stages and a pressure gauge as an emergency backup. The 80cf primary tank is more than required for normal use and was selected to ensure that the pilot had sufficient air in the case of an emergency. The 19cf bailout bottle is also a conservative choice compared to most other secondary systems at the ISR, but was selected to ensure sufficient resources in any emergencies.

### 2.1.5 Center of gravity/buoyancy adjustment

A small amount of foam is added to the upper portion of the submarine and the transmission in the back while trim weights are attached to the lower portion of the hull to achieve near neutral buoyancy. Material selection during manufacture helped reduce the need for floatation and keeping components each near neutral made system trim relatively easy. This system can be easily adjusted to accommodate for changes to internal design, a new pilot, or environmental changes by moving relatively small amounts of weight (~2lbs) from the front weight storage area to the rear area.

## 2.2 Hull

### 2.2.1 Design

The Commodore is made out of carbon fiber and has a polycarbonate bubble at its front for the pilot to see out of. Holes were cut out of the entire hull for different reasons. One is cut out at the very bottom of the hull to drain water out. A second hole was cut on the side of Commodore to make the hatch for the pilot to enter and exit the sub. A third hole was cut in the rear of the submarine to make room for the emergency release buoy.

### 2.2.2. Materials and construction

The material used for the hull is carbon fiber. The hull was constructed from Composite material formed over a positive mold. By building the shell out of carbon fiber, it was possible to have a smooth exterior while maintaining a large and wide interior. However, our first building material was fiberglass, but various obstacles showed that new material was needed. The hull is made of 3 layers of carbon fiber (2 12k and 1 3k), which makes it flexible yet sturdy. Additional 12k strips were used to reinforce areas around hatches or other mounted structures.

### 2.2.3. Hatch

Presently the hatch is a sheet of carbon fiber, cut out of the sub to make a large hole. To create this hatch, we had to epoxy in 2 layers of carbon fiber to the interior of the sub to make sure that the hatch would not fall into the sub. After that, we cut out the hatch from the sub and cleaned the carbon fiber so that the hatch would fit nicely. The hatch is a simple door that provides an effective way of entering and exiting the submarine.

### 2.2.4 Emergency pop-up buoy

A pop-up buoy was added to the hull. This is constructed from a strobe light and flotation that is locked in position with a cantilever pincer modeled after a bicycle brake. This is connected via bicycle brake cable to a bicycle brake lever mounted on the control levers in front of the pilot. The buoy will be released if the pilot releases the control lever. However, the buoy will remain attached to the hull via an indexing spool of Dacron line designed for SCUBA cave and wreck exploration. The loss of a relative small amount of buoyancy in the buoy will cause the submarine to become slightly negatively buoyant.

## 2.3 Life Support Equipment

### 2.3.1 SCUBA equipment

As previously mentioned, life support in Commodore consists of standard recreational SCUBA regulator and 80cf aluminum cylinder (first stage regulator, 2 second stage regulators -1 as backup, pressure and depth gauges, low-pressure inflator-not used). This cylinder is mounted on the bottom of the sub just below the pilot and the gauges are clipped to the frame so that they are easily visible by the pilot. The pilot will also have a spare pony bottle in case of emergency. The SCUBA gear is not specific to the submarine, but will be the pilots personal gear. All SCUBA gear for the team will be properly serviced recreational SCUBA gear from reputable manufacturers.

### 2.3.2 Hull system quick-release mechanisms

There will be no latched connection between the pilot and the hull. The pilot will have shoulder posts to push against, but will not be confined by the structure. We understand that not having a full pilot harness will not allow the pilot to exert maximum power. However, we feel that since our design objectives are focused on novel design and course completion, we have opted for the increased safety of pilot maneuverability.

### 2.3.2 Navigation Strobes

Coast Guard Compliant strobe lights are connected to the hull in order to provide 360 degree visibility. The strobe will be mounted on the upper rudder to provide full visibility from all angles. Extra lights will be available on site and batteries will be changed regularly to ensure appropriate operation.

### 2.4 Support equipment

A simple shop cart was bought and modified in order to transport, store, and work on Commodore. The cart matches the shape of the hull and is made up of plastic.
A crate of spares will be onsite for testing. This will include a complete spare transmission and control assembly, and tools necessary for repair. Since our design does not rely on a machine shop for fabrication, we should be able to completely rebuild Commodore onsite if necessary.

## 3.0 Experimental Procedures

### 3.1 Personnel training

All team members were able to participate with the design and fabrication of the Commodore. These activities included gaining experience in the use of basic power tools, fiberglass and carbon fiber techniques, and 3D printing and design. Several members gained SCUBA certification for the event. The team is comprised of GCSC students and Has been helped by the Mosley high school students of team Son of Trigonus that through this experience have learned invaluable skills.

### 3.2 Static in-water testing

Initial in water testing was conducted in a pool at Gulf Coast State College and were aimed at testing the propulsion system. These tests were conducted on the surface with the propulsion system mounted in an open and positively buoyant hull to give the pilot ease of entry and revealed issues with the propulsion system that have been solved. The Commodore team has planned for more in-water testing prior to the event to give the multiple pilots experience and allow for additional problem mitigation.

### 3.3 Event test matrix

Testing at the ISR will be primarily focused on getting a clean run in to complete the course. This will involve meeting the dry and wet tech inspections followed by completing a successful run. If this is achieved, the focus will shift to completing the fastest run possible. This will involve completing runs until a near constant result is achieved, and then modifying variables to determine how the different variables affect the results. The following variables will be tested:

1) Pilot: This one is likely to have the most impact as the strength, stamina, and reflexes will vary between pilots.
2) Propeller diameter/pitch: An 18” 14 pitch, 24” 14 pitch, and 24” 28 pitch propeller will be tested.

## 4.0 Summary

Commodore is a human powered submersible that consists of a composite hull and a modular component system. The hull is constructed using a stitch-and-glue technique to produce a sleek hydrodynamic NACA profile. The design described here is focused on simplicity of design, ease of manufacture, and providing pilot safety with the hopes that it could be used as an example and encourage others without extensive engineering and machining experience to compete in the ISR. This design can be produced with consumer grade material and tools that would be available to most GCSC Students. Furthermore, this design and the models used for 3D printing modules can be shared with future participants so they can get started with a functional prototype and modify the design to fit their vision.