

FLORIDA INSTITUTE OF TECHNOLOGY
Department of Ocean Engineering

PROPOSAL

The Surface Riding Submersible: “Seal Submarine”

Prepared by:

Charles Cousin

Aaron Gelfand (From: aaron.gelfand@ni.com <aaron.gelfand@ni.com>)

Chiquinquirá Gonzalez

Marta Ramos

Ocean Engineering Design Class

Teacher: Dr. Rae

TABLE OF CONTENTS

Table of Contents

List of Illustrations

Abstract

1. INTRODUCTION

- 1.1 Statement
- 1.2 Objectives
- 1.3 Background

2. DESIGN: the Seal Submersible

- 2.1 Hull
 - 2.1.1 General view of the hull
 - 2.1.2 Hydrostatics stability
 - 2.1.3 Materials
- 2.2 Control System
- 2.3 Propulsion
 - 2.3.1 Overview
 - 2.3.2 Gas engine
 - 2.3.3 Electric motor
 - 2.3.4 Shroud
- 2.4 Dry Compartment
- 2.5 Ballast Tanks
 - 2.5.1 Ballast tanks system
 - 2.5.2 Ballast tanks characteristics
- 2.6 Safety

3. CONCLUSION

Reference

LIST OF ILLUSTRATIONS

Tables

- Table1. Hydrostatics Stability
- Table2. Computation of the frontal area
- Table3. Computation of the different volumes of the Seal Submersible
- Table4. Design Schedule in Weeks
- Table5. Production Schedule in Weeks
- Table6. Budget
- Table7. Seal Submarine

Figures

- Figure1. 2-D right view of the hull
- Figure2. 2-D top view of the hull
- Figure3. 2-D front view of the hull
- Figure4. 3-D right view of the hull
- Figure5. 3-D top view of the hull
- Figure6. 3-D bottom view of the hull
- Figure8. View of the intake air system
- Figure9. View of the shroud
- Figure 12. View of the pressurization of the dry compartment
- Figure13. Distribution of ballast tank
- Figure14. View of the ballast system
- Figure15. Distribution of main components in the dry compartment

ABSTRACT

The goal of this project is to design and build a submersible able to ride on the surface. This vehicle will perform two main functions: act as a boat to provide fast access to diving sites and to conserve air for longer immersions; act as an underwater vehicle - maneuverable, efficient, and safe.

The study of the design is divided into six major categories:

1. Hull. The hull has been designed as a wet submersible with a jet-ski shape. The hull is divided into two parts: a planing hull (V-shape) to provide stability to the boat and a upper round design to reduce the submersible drag. The hull will be made of fiberglass and core.
2. Control system. A handlebar is the main part of the control system (primary control). The handlebar will control speed and direction of movement. Additional controls will allow for the purging and venting of the hull.
3. Propulsion system. Gas and an electrical engines will be used to propel the vehicle at the surface and underwater respectively.
4. The dry compartment. The primary goal of the dry compartment is to keep all the component dry. The main problem encountered was to design a compartment able to resist to pressure change. As the fiberglass is not enough resistant to pressure, a pressurization system was designed to keep the dry compartment at ambient pressure.
5. Ballast system. The ballast system is enclosed in the hull. It represents the volume of water displaced by the boat minus the volume under the seats that is used for the engines. All the volumes of the vehicle and its weights were calculated to achieve a slightly positive buoyancy.

6. Safety. In order to enjoy the Seal Submersible in a safe and responsible manner, safety rules were developed to avoid any injuries or accidents.

1. INTRODUCTION

1.1 Statement:

Dry and wet submarines have been highly developed and produced. High technologies are used to increase their efficiency. But today's market place does not offer many low-cost and multi-use submarines. A surface riding submersible could be an interesting design which would have a broad range of functions and safety requirements that would satisfy the demand of both scientific and recreational customers.

1.2 Objectives:

The goal is to design a low cost, easy to use and to maintain surface riding submersible which will perform two main functions:

- A submersible that can be used as a boat to access different locations and save air allowing longer immersion.
- An environmentally friendly, maneuverable, efficient and safe underwater vehicle.

1.3 Background

To begin the project, the Seal Submarine team first contacted a company named Submersible Systems Technology, INC, who provided some information about their three- person wet submarine - The Reef Ranger - and a comparison between eight wet submersibles. The Seal Submarine team counts upon the help of Antonio Javier Munoz who specializes in fiberglass and boat design. The Seal Submarine team had the opportunity to present the project to companies in IBEX who were interested in it and who are actually helping with materials and ideas.

2. DESIGN: The Seal Submersible

2.1 Hull

2.1.1 General view of the hull

The main problem in designing the hull was to provide both stability to the boat and to the submarine. The center of buoyancy for a boat has to be lower than the center of gravity, and inversely for a submarine, the center of gravity should be lower for the sub.

All the components of the Seal Sub are close to the bottom of the hull. A layer of lead will be added at the bottom to lower the center of gravity. Thus, to counteract this low center of gravity, the boat stability has been increased by other means. The stability of the boat at rest will be provided by its width of 1.12 meters and its length of 2.3 meters. In motion, the stability of the boat will be provided by a planing hull and a great speed. Moreover, the diver should be able to balance any roll motion by moving himself and by changing the overall longitudinal and transverse stability.

A planing hull requires an angle with the horizontal from 0 degrees to 30 degrees. The sharper the angle, the less the hull has planing capability and the better are its reactions in waves. The angle chosen is almost 20 degrees (19.82°) which is a good compromise between planing capability and wave penetration. Moreover, in order for this hull to be efficient, the minimum speed has to be 9.4 knots:

$$V_{\text{planing hull}} \geq 3.3 * L_{\text{hull}}^{0.5}$$

$$V_{\text{planing hull}} \geq 3.3 * (2.3 * 0.3048 \text{ ft})^{0.5}$$

$$V_{\text{planing hull}} \geq 2.76 \text{ ft/sec}$$

$$V_{\text{planing hull}} \geq 9.4 \text{ knots}$$

To reduce the drag of the submarine, the design is achieved with smooth angles to allow good penetration in water. A shield is also added to guide water, reduce drag, and protect the diver from pressure variation due to speed.

(See Figures 1 - 6)

Volume of the compartments:

Entire Hull	0.746m ³ / 16.81 ft ²
Dry compartment	0.428m ³ / 15.12 ft ³
Ballast tank	0.182m ³ / 6.43 ft ³

Weights:

Weight of the dry compartment (engines, batteries, air tanks ...)	190 kg / 418 lb.
Ballast filled with sea water	187 kg / 410 lb.
Overall weight of the vehicle with empty ballast	247 kg / 719 lb.
Overall weight of the vehicle with flood ballast	434 kg / 954 lb.

2.1.2 Hydrostatics stability

The hydrostatics stability was performed by the program Multisurf. Results are shown in table 1.

2.1.3 Materials

The hull will be built mainly in fiberglass for three main reasons:

- To avoid any problem of corrosion
- To make the hull easy to repair and maintain
- To provide light weight, and thus reduce the power required by engines

Moreover, fiberglass is relatively inexpensive and has good material properties. The strength of the hull will be reinforced at critical points by core. This study of materials will be done by Diab company that provides us with Divinycel core. The rest of the hull is made of layers of $\frac{3}{4}$ oz/ft² Chopped Stand Mat. and 18 oz/yd² Woven Roven mixed with STYPOL 040-44822 resin which is provided by CCP. The mold for the hull will be completed by Mollicam, a molding company. The shield will be Plexiglas. As it is difficult and very expensive to mold Plexiglas, the canopy will be made of three flat plates linked together with aluminium screws.

2.2 Control system

The primary control system will be a handlebar from a Sea-Doo HX. The left grip will be replaced with a plastic rotating gear shift grip available at most bike shops. The left grip is a seven position grip. The left grip will rotate to provide up-down control. The seven positions correspond to the rudder being in the three different degrees of up turn ability, three degrees of down turn ability, and a neutral position. The grip, when rotated, either pushes or pulls on a marine control cable which is linked to the elevator fin on the shroud. The marine control line will be attached to the gear shift in the same manner as the cable that is normally used on bicycles (IE. a twist and lock mechanism). The marine control cable will attach to the elevator fin through the use of a 8 cm screw that protrudes through the fin. There will be two nuts attached at the end of the screw that will be tightened together to cinch the control cable between the nuts. This methods allows for the fine tuning of the fin response by moving the control cable closer to or father from the fin to make it more or less responsive, respectively.

Additionally, there is a lever on the right handlebar which controls the throttle of the engine. The marine control cable inserts into the end of the lever. The lever will have a marine control cable linked to the speed control of both the motor and the engine.

Secondary controls include a start button for the engine, a choke for the gas engine, a start button for the electric motor, a valve to allow flooding of the ballast system, a

safety kill switch, a gas tank select switch (fuel, no fuel, reserve) and a button to allow the purging of the ballast system. The safety switch, engine starting switch, choke and gas tank select are all being removed from a Sea-Doo HX.

2.3 Propulsion

2.3.1 Overview

The propulsion system will include a gas engine and an electric motor. They will both be housed in a watertight, pressure adjusted fiberglass housing (see Dry Compartment). The gas engine will be used for surface propulsion while the electric motor will be used for underwater propulsion.

The engine is used to drive an impeller similar in design to those found on personal watercraft. The motor will drive a propeller that is mounted inline with the center of drag on the submarine. The propeller will be housed in a shrouded prop that has an elevator for direction control.

A dead-man switch will be installed with a short rope that attaches to the person's wrist, so that if the person falls off or gets off the Seal Sub, both the electric motor and gas engine will be prevented from functioning. A normally-open double-pole-single-throw switch will be depressed whenever the "key unit" is in place, allowing current to flow to the electric motor on the first pole and the gas engine (charge capacitor) on the second pole. Thus, if the "key unit" is removed, the engine and motor will die. The switch and "key unit" are from a Sea-Doo HX. The "key unit" has a coiled plastic rope attached to it that clips on to the divers harness.

The engine will be mounted to the submarine by laminating screws, upside down, into the hull. The screws will serve as the mounting platform for the engine and motor and

will be tightened down by nuts threaded on top of the screws after the engine and motor are mounted in place. Prior to placing the engine on the mount, a layer of neoprene will be placed along the length and width of the engine mount and glued in place using neoprene cement. The layer of neoprene will dampen the effect of engine vibrations on the hull of the vessel. The engine will then be placed into position and tightened down. The motor will be attached with a bracket to the rear of the submarine.

2.3.2 Gas Engine

The submersible's speed at the surface has to be greater than 9.4 knots, according to the planing hull specifications. In order to generate sufficient power, a Sea-Doo engine is used. The engine provided by Sea-Doo is a Rotax Engine Type 717 manufactured for Bombardier. The engine has a 2x 32mm bore, 68 mm stroke, and has a capacity of 718.2cc.

The fuel tank and reserve are those normally found in a Sea-Doo HX. The fuel tank will be located in the middle of the sub, inside the dry compartment. A screw-in cap located at the top of the stern will allow the fuel tank to be filled.

A water trap system will be attached to the intake and exhaust pipes of the gas engine. The exhaust will have a one way valve, allowing air to exit while preventing water from entering. The intake is 2 inch PVC pipe with a 90 degree bend at the top and a female screw adapter. Two-thirds from the top is a T-adapter with the bottom of the T going in to the engine compartment. There is a 5 inch section of pipe located at the other end of the T connecting to a check valve which will allow water to drain out but prevents backflow into the intake. This intake functions similar to the purge and trap on "dry" snorkels.

2.3.3 Electric Motor

The motor power was determined by calculating the necessary force, using the following equation:

$$F = \frac{1}{2}\rho V^2 A C_d$$

where $V = 2 \text{ m/s}$ (4 knots)

$$\rho = 1025 \text{ Kg/m}^3$$

$$A \text{ (frontal area)} = 0.92 \text{ m}^2 \text{ (See Table 2)}$$

$$C_d = 0.2$$

This gives a value of 377 N. In order to determine the needed power, the force was multiplied by the velocity, 4 knots (speed of submersible underwater), to give a value of 754 W. This would require a 24 V motor with a current draw of 31.4 A. The motor selected is a Minnkota EM48. The motor has a 28 A draw at 24 V and produces 48 lb (213.5 N) of thrust. Therefore, the top speed will be slightly less than 4 knots.

Power for the electric engine will be provided by two GPL-24 Lifeline AGM (Absorbed Glass Mat) batteries. AGM is a new technology that outperforms gel-cell batteries offering more power and having a longer life span (number of recharge cycles). Hooked in series to provide 24 volts, they will provide 149 minutes at a 25amp draw with an ending voltage of 21 volts. Recharging can be accomplished through an alternator voltage-regulated at 14.2 V with up to 100 A. They are 10.87 inches long by 6.58 inches wide by 9.97 inches high. Each battery weighs 53 lb. They are designed to provide approximately 1,000 cycles, and they have a 5-year guarantee.

2.3.4 Shroud

There will be a cylindrical shroud around the propeller. Attached to the shroud will be 6 control fins (Figure 9). Five will be mounted vertically to provide port-starboard movement, and one will be mounted horizontally to provide up-down movement. The 5 rudders will be linked to each other with 2 small rods attached on the rear surfaces at the elevator cut-out. There will be a control horn attached to the bottom of the center rudder. The marine control line will attach to the control horn, run along the submarine, then

down the right side of the seat into the handlebar mount. The elevator fin will have a control horn on the top of the left side. The marine control line will attach to the horn, run along the hull, down the left side of the seat and into the handlebar mount (Figure 10).

2.4 Dry compartment

In order to use the vehicle as a submarine and to avoid any damage to the engines and electric parts, a watertight compartment was designed and located under the central part of the submarine, from the stern to the handlebar.

The submarine is designed to reach a depth of 100 feet. The dry compartment, mainly made of fiberglass, has to overcome a pressure of 58.8 psi. Two solutions were studied to achieve this purpose.

First, a rough study of the resistance of fiberglass to 58.8 psi was made. The conclusion was that fiberglass has not enough resistance in shear stress, not enough elasticity and tensile strength to overcome such a high pressure. Even a strong combination of many layers of fiberglass Knytex CDM 1808 and the use of a strong resin would result in a thickness of fiberglass of 2.5 inches. Considering the volume of the dry compartment this solution is not acceptable. The only means would be to use a sandwich structure of core and fiberglass combined with stiffeners to provide enough strength. The main drawbacks are the cost of this structure and its thickness which reduces the storage volume.

Second, a system of pressurization of the hull was designed to always equalize the internal pressure of the dry compartment with the water pressure. Therefore, fiberglass strength does not need to be further improved. (Figure 12).

The second system is basically made of:

- an overpressure relief valve set to open when the pressure inside the dry compartment exceeds the ambient pressure by 2psi (0.14 bar).
- a second stage of a regulator with the diaphragm (purge button) in contact with the water pressure. The second stage exhaust air is linked with the inner part of compartment, so Nitrogen is added whenever ambient pressure is 2psi (0.14 bar) greater than the compartment pressure.

(Figure 12).

Before submerging, the air intake of the engine is tightly closed. While submerging, the pressure of the water acting on the hull exceeds the ambient pressure of the dry compartment. This water pressure then acts on the diaphragm which pushes the demand lever and opens the second stage valve. The suction of the flowing nitrogen creates a venturi effect that helps the diaphragm to remain depressed until the pressure in the compartment equalizes the outside pressure. If the submersible goes up, the inner pressure exceeds the outer pressure. The overpressure relief valve opens when this pressure is greater than 2psi/0.14 bar, allowing the nitrogen to escape, and then the valve closes when pressures are equalized.

When the sub is under water, the pressure in the dry compartment pressurizes slightly higher than ambient. If air were used, this would result in a higher ppO₂ which leads to the increased possibility of combustion from any sparks generated by the engine or motor system. In order to minimize this possibility, the cylinder providing gas for the ballast and dry compartment is filled with nitrogen rather than air.

The main drawback of this system is its consumption of nitrogen. However, the volume of nitrogen in a tank is sufficient to fill the dry compartment 6.6 times. Moreover, attention has to be paid to be certain that pressure inside the engine is always the same as the pressure inside the dry compartment. All parts (pistons, oil injection

pipe...) have to be opened to let gas enter and to equalize pressures in order to avoid any damage to the gas engine.

2.5 Ballast tanks

2.5.1 Ballast tank system

The surfacing and diving of the submersible will be accomplished through a ballast system. The ballast tank, enclosed in the hull, will be located under the waterline. It forms a U-shape, as shown in Figure 13.

The ballast system will be composed of:

- a) three vents, one located in the upper bow part of the ballast and the others at each side of the seat at the stern part of the ballast (Figure 14). The distribution of these vents are designed to permit a homogeneous escape of air. Moreover, to avoid any trapped air, the shape of the ballast system will be divided into two parts. The top of each part will slope 10 degrees upwards from the center to the outermost point where the vents are located. This will guide air pockets out the vents. (Figure 14)
- b) three opened flood holes at the bottom of the submersible, two at each side of the stern and one at the front.
- c) two hoses, allowing air to enter the ballast tanks and push the water out for surfacing. These hoses will be linked respectively to the stern and bow parts of the ballast for a smooth distribution of air.

The two main operations of the ballast system are:

- Diving operation. The vents are opened so the air will escape and the tanks will be flooded with water entering the flood holes at the bottom of the hull. Once the ballast tank is complete flooded, the pressure release valves are closed.
- Surfacing operation. High pressure air is supplied to the ballast tank through the hoses from the air tank. This forces the water out of the ballast tank through the flood holes. As the submersible reaches the surface, the air supply is cut off.

The vents are opened and closed manually with a cable acting on the springs of the valves. If the pressure of the air reaches a critical pressure, the air will no longer push out the water; rather, it will pass through. If this occurs, it will be necessary to open the valves and relieve some pressure. The air will be provided by one air tank connected to two hoses. The purge buttons of the hoses will be located near the handlebar. The air escaping from the hosing will be guided to the ballast by two PVC pipes. The 15 l. air tank will provide 3 times the volume in air of the entire ballast system, calculated to be 0.182 m^3). (The rest of the tank is used for the dry compartment system.)

Each hose provides 5 lbs. of lift/sec. Thus the surfacing operation should take approximately 2 minutes and 45 seconds to reach the surface.

The slope of the upper part of the ballast tank is 10 degrees what allows trapped air to escape through the vents when the vehicle is at zero degrees. If the submersible is inclined ten degrees, the air located at the front will be guided out through the frontal valve but there will be some air trapped at the stern which will raise the back of the submarine and therefore, air will escape. The air will exit continuously until the vehicle reaches an inclination of 90 degrees. Practically, the air should have escaped before the vehicle reaches this angle.

A layer of lead will be placed in the ballast tank to balance the submerged weight with the submerged displacement. It helps to lower the center of gravity which is favorable for stability control, and it also reinforces the hull.

Over pressurization and possible explosion of the hull will be avoided through the use of over-pressure relief valves, similar to those found in BCD's, and by having a small portion of the hull less resistant that will crack in case of valve deficiency.

2.5.2 Ballast system characteristics

The ballast tank was made for the submarine to be neutrally buoyant or slightly positive. Due to the difficulty of knowing exactly the value and distribution of each weight that composed the submarine, its buoyancy will be adjusted during testing.

Theoretically, all the displacements were calculated (See Table 3). The submarine is expected to carry a weight of 255kg (the diver is assumed to be neutrally buoyant). This mass added to the weight of the diver represents the displacement of the boat. Submerged, the volume of the dry compartment represents a positive displacement of 439 kg; the ballast represents a negative displacement of 187 kg.

Therefore, the submarine encounters, theoretically, a positive buoyancy of 3 kg. The thrust of the propeller will correct easily such small differences. Moreover, if the stability of the submarine is not good, this would permit the addition of weights in order to correct the transverse or longitudinal position of the vehicle.

2.6 Safety

The surface-riding submersible was designed to avoid any kind of injuries or accidents. Many aspects were developed to provide a safe vehicle:

1. Over-pressurization and possible explosion of the hull will be avoided through the use of over-pressure relief valves similar to those found in BCD's. In case of malfunction of the over-pressure relief valves, the hull around the valves will be thinner, and therefore, less resistant to pressure, so it will crack first.

2. In case of fire in the gas engine, exhaust and intake pipes have to be immediately closed. As the dry compartment is water tight, the fire should extinguish itself by the absence of oxygen.

3. The air tank and the fins of the diver will be located at each side of the handlebar. Therefore, if the diver has to leave the vehicle, he/she would have direct access to the air supply.

4. Before reaching the surface, the diver will inflate a diving buoy or flag to alert other vehicles of his/her presence.

5. It is important for the safety of the rider and for the environment to have good knowledge of the vehicle.

5.1 Check if everything is working properly (functioning of the engines and control panel).

5.2 Close intake and exhaust valves before submerging to avoid water entering the engine, and open them when surfacing.

5.3 Switch off the gas engine before submerging.

6. In order to follow the safety rules of diving, the diver should wear his/her own dive equipment including computer, and he/she should be aware of the Recreational Dive Tables.

Hangers would be fixed on the side of the submersible in order to provide transport to others divers and avoid to dive alone.

8. Riders have the responsibility to learn and to practice safe boating.

3. CONCLUSION

The goal of the project is to design an efficient submersible and surface riding vehicle at a low price. At the same time it will be safe, and easy to use and to maintain.

The submersible will be 2.3 meters long with a planing hull made of fiberglass and core. A handlebar will be used to control up-down movement and the speed of the vehicle. There will be a control for switching positions of the Z-drive, among others.

The submersible will have a gas engine (surface propulsion) and an electric motor (underwater propulsion) connected together to a single shrouded propeller. A system of pressurization of the dry compartment will allow the submersible to attain a depth of 100 feet (58.8 psi).

The ballast tank, enclosed in the hull, will be flooded with water and filled with air for diving and surfacing operations, respectively. Over-pressurization of the ballast is controlled with pressure relief valves, and a small part of the hull will be designed to be less resistant; therefore, it will crack in case of pressure problems to avoid an explosion of the hull.

Due to its high cost, the realization of this project will be possible with the support of companies who will supply us with the necessary materials.

The original design of the surface riding submarine could be subjected to possible changes at the time of building and testing it.

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Internet sites

Kraken-90 Subskimmer: <http://www.cru.uea.ac.uk/ukdiving/equip/subskim/index.htm>

Mantaray submersible: <http://www.direct.ca/marketing/techdesc.htm>